Scientific and Policy Developments in Radiofrequency Radiation

December 2019 through November 29, 2021

Selected Research Publications Showing Adverse Effects Since the FCC Issued its Determination December 2019 Not to Update its 1996 Standards for Evaluating Wireless Radiation from Cell Phones, Electronic Devices and Networks

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New Scientific and Policy Developments in Radiofrequency Radiation

A Sampling of Research Publications Showing Adverse Effects Since the FCC Issued its Determination Not to Update its 1996 Standards for Evaluating Wireless Radiation from Cell Phones, Electronic Devices and Networks

More than 75 new important scientific developments, expert reports and recommendations have been published since the FCC issued its determination to not initiate a rulemaking proceeding to update its regulatory limits for human exposure to wireless radiofrequency radiation (RFR) in December 2019.

This report showcases a small sampling of the last two years of scientific publications that have documented adverse effects of RFR exposure. Studies include impacts to wildlife and the environment, the unique vulnerability of children and the fetus, DNA damage, oxidative stress, nervous system impacts and brain development. New experimental and epidemiological evidence for cancer tied to RFR has been published as well as papers detailing how cancers can arise from non-ionizing radiation.

Further, recent publications have documented significant health and environmental implications arising from 5G network related millimeter wave frequencies and all current and new wireless air interfaces' use of modulation, pulsation and other waveform manipulation. Wireless telecommunications signals are complex and FCC regulations do not address the biological impact of different modulations nor consider the numerous unique characteristics of real world telecommunication signals. We highlight how new landmark papers document the science indicating the urgent need to consider modulation and pulsation, rather than simply power density.

The evidence is now clear that RF emissions within the Commission's guidelines have significant adverse biological effects.

WILDLIFE/ENVIRONMENT

The FCC's current FCC radiofrequency radiation (RFR) emissions limits apply to human exposures.They do not address wildlife, plants or trees. Birds perch and nest on cell towers. Bats and bees and other airborne species occupy air space in close proximity to transmitting cell antennas. Wireless network densification increases RFR levels (El-Hajj & Naous, 2020) and with over 800,000 new cell sites projected[1] for the 5G buildout, environmental effects need to be properly examined because ambient RFR is increasing in wildlife habitat.

A landmark three-part research review on effects to wildlife was published in R*eviews on Environmental Health in 2021* by U.S experts, including former U.S. Fish and Wildlife senior biologist Albert Manville. The authors reviewed and cited more than 1,200 scientific references. These experts concluded that the evidence was adequate to trigger urgent regulatory action. The review found adverse biological effects to wildlife from even very low intensity non-ionizing

[1] Remarks of FCC Chairman Ajit Pai White House 5G Summit Washington DC, September 28, 2018

radiation emissions at multiple orders of magnitude below current FCC-allowed levels (Levitt et al., 2021a, Levitt et al., 2021b, Levitt et al., 2021c).

Comprehensive documentation of the biological effects of non-ionizing electromagnetic radiation to flora and fauna has never before been undertaken to this degree in any previous publication. These three experts divide their science and findings with urgent warnings into three parts: **Part 1** identifies ambient EMF adverse effects on wildlife, and notes a particular urgency regarding millimeter wave emissions and the pulsation/modulation used in 5G technologies. **Part 2** explores natural and man-made fields, animal magnetoreception mechanisms, and pertinent studies to all wildlife kingdoms. **Part 3** examines current exposure standards, applicable laws, and future directions. Their conclusions after this expansive review of the science are neither equivocal nor speculative. This environmental research review is a clarion call to develop regulations that ensure wildlife and its habitat are protected. The abstract summarizes the findings:

> "Numerous studies across all frequencies and *taxa* indicate that low-level EMF exposures have numerous adverse effects, including on orientation, migration, food finding, reproduction, mating, nest and den building, territorial maintenance, defense, vitality, longevity, and survivorship. Cyto-toxic and geno-toxic effects have long been observed. It is time to recognize ambient EMF as a novel form of pollution and develop rules at regulatory agencies that designate air as 'habitat' so EMF can be regulated like other pollutants. Wildlife loss is often unseen and undocumented until tipping points are reached. A robust dialog regarding technology's high-impact role in the nascent field of electroecology needs to commence. Long-term chronic low-level EMF exposure standards should be set accordingly for wildlife, including, but not limited to, the redesign of wireless devices, as well as infrastructure, in order to reduce the rising ambient levels."

Numerous individual studies on impacts to flora and fauna have been published over the last two years, notably several on pollinators and insects.

Two studies used scientific simulations to quantify the amount of power absorbed into the bodies of various insects for different RFR frequencies. In January 2020 researchers published "Radio-frequency electromagnetic field exposure of Western Honey Bees" in *Scientific Reports* on the absorption of RFR into honey bees at different developmental stages with phantoms simulating worker bees, a drone, a larva, and a queen (Thielens et al., 2020). The simulations were combined with measurements of environmental RF-EMF exposure near beehives in Belgium in order to estimate realistic exposures. They found absorbed RF-EMF power increases by factors of up to 16 to 121 when the frequency is increased from 0.6 GHz to 6 GHz for a fixed incident electric field strength. The implications of the impacts to such an ecologically and economically important insect species bees would be widespread and consequential.

In October 2021 a second simulation study with far-reaching implications "Radio-frequency exposure of the yellow fever mosquito (*A. aegypti*) from 2 to 240 GHz" published in *PLOS Computational Biology* simulated the far field exposure of a mosquito between 2 and 240 GHz and found the power absorption into the mosquito is 16 times higher at 60 GHz than at 6 GHz at the same incident field strength. This increase is even larger (by a factor of 21.8) for 120 GHz when compared to 6 GHz. The authors conclude “higher absorption of EMF by yellow fever mosquitoes, which can cause dielectric heating and have an impact on behaviour, development and possibly spread of the insect.”

In 2020, a report by Alain Hill of the biological effects of non-ionizing radiation on insects found that mobile communications was a critical factor in weakening the insect world along with pesticides and habitat loss. (Khan et al., 2021) found the Apis Cerana bee becomes very passive at a certain level of frequencies and power.

In May 2021, Spanish biologist Alfonso Balmori published “Electromagnetic radiation as an emerging driver factor for the decline of insects” in *Science of The Total Environment.* Balmori found that electromagnetic radiation threatens insect biodiversity worldwide. He documents the sufficient evidence of effects of non-thermal, non-ionizing radiation on insects, at well below the limits allowed by FCC guidelines, and warns that action must be taken now before significant new deployment of new technologies (like with 5G) is undertaken. He cautions that the loss of insect diversity and abundance will likely provoke cascading effects on food webs and ecosystem services.

A November 2021 review of the effects of millimeter waves, ultraviolet, and gamma rays on plants found many non-thermal effects specifically from millimeter waves (Zhong et al. 2021). (The paper examined the millimeter range 30 to 300 GHz which overlaps with FCC’s limits 300 kHz to 100 GHz.) Millimeter-wave irradiation stimulated cell division, enzyme synthesis, growth rate, and biomass. The review highlights how different doses and durations provoked dynamic morphophysiological effects in plants. Seed pretreatment with weak microwaves or millimeter wave irradiation altered root physiology. Different effects were observed in different plants and the authors state that, “the discordance of proteomic changes in different plants is reasonable, since different plants have a distinct tolerance to stress. Moreover, the cell tissues from soybeans and chickpeas used for proteomic analysis were different, which implies that tissue-specific or organ-specific responses of plants under millimeter-wave irradiation might exist and require further investigation.” This review adds to the published analysis confirming non thermal effects from RFR. While these frequencies may have beneficial uses in agriculture, the adverse impact to trees and plants in close vicinity to transmitting antennas must be addressed.

CHILDREN

Children are proportionally more exposed to RF-EMF than adults because their brain tissue is more conductive, their skulls are thinner, and their bodies are smaller. Children are known to be at greater risk than adults when exposed to any carcinogen because of their rapidly dividing cells. Because the average latency time between first exposure and diagnosis of a tumor can be decades, tumors induced in children from RFR may not be diagnosed until adulthood. Even more importantly, children and the developing fetus are more vulnerable to RFR because their brains and organs are still developing and more sensitive. Research over the last two years has added critical new science on children's vulnerability to health impacts from RFR and supports the acute need to reduce exposure to children.

To start, the Environmental Working Group published a landmark study in *Environmental Health* analyzing the findings of increased tumors and heart damage from the National Toxicology Program study and concluded that FCC limits should be strengthened by 200 to 400 times to protect children according to current risk assessment guidelines (Uche, 2021). "The analysis presented here supports a whole-body SAR limit of 2 to 4 mW/kg for adults, an exposure level that is 20- to 40-fold lower than the legally permissible limit of 0.08 W/kg for whole-body SAR under the current U.S. regulations. A ten-fold lower level of 0.2–0.4 mW/kg whole-body SAR may be appropriate for young children. Both technology changes and behavior changes may be necessary to achieve these lower exposure levels. Simple actions, such as keeping the wireless devices farther away from the body, offer an immediate way to decrease RFR exposure for the user."

(Cabré-Riera et al., 2020) investigated RFR doses in preadolescents at 9 – 12 years old. In "Estimated whole-brain and lobe-specific radiofrequency electromagnetic fields doses and brain volumes in preadolescents" published in *Environment International* the authors reveal their findings that although whole-brain and lobe-specific RF-EMF doses from all RF-EMF sources together, from mobile and DECT phone calls and far-field sources were not associated with global, cortical, or subcortical brain volumes, a higher whole-brain RF-EMF dose from mobile phone use for internet browsing, e-mailing, text messaging, tablet use, and laptop use while wirelessly connected to the internet was indeed associated with a smaller caudate volume. The caudate nucleus plays an important role in procedural learning, associative learning and inhibitory control of action and it is also one of the brain structures comprising the reward system. Analysis of cognitive impacts in another analysis (Cabré-Riera et al., 2020) found higher overall whole-brain RF-EMF doses from all RF-EMF sources together and from phone calls were associated with lower non-verbal intelligence score in Dutch and Spanish preadolescents.

Yet another publication by the same group (Cabré-Riera et al., 2021) investigated the association of estimated all-day and evening whole-brain radiofrequency electromagnetic field (RF-EMF) doses with sleep disturbances and objective sleep measures in preadolescents. The researchers, publishing their findings in *Environmental Research*, found preadolescents with high evening whole-brain RF-EMF dose from phone calls had a shorter total sleep time compared to preadolescents with zero evening whole-brain RF-EMF dose from phone calls.

A 2020 research review from the Department of Pediatrics, Hanyang University School of Medicine, Seoul, Korea (Moon, 2020) recommends precaution and minimizing EMF exposure to children, cautioning that the nervous systems of children are more vulnerable to the effects of electromagnetic waves than those of adults.

PREGNANCY

Using a mobile phone for calls for more than 30 minutes per day during pregnancy was associated with a negative impact on fetal growth (Boileau et al., 2020). Mobile phone use during pregnancy was associated with night-wake of infants (Weng et al., 2020). (Bektas et al., 2020) concluded that mobile phone exposure during pregnancy could cause oxidative stress and DNA damage in cord blood and placenta. Finally, the combined effects of Wi-Fi plus mobile phone exposure could have a higher potential to cause synergistic effects.

Recent animal research includes a study that found Wi-Fi signals increase lipid peroxidation, SOD activity (oxidative stress), apoptosis and CDKN1A and GADD45a overexpression in mice placenta tissue (Vafaei et al., 2020). A study on pregnant rats found damage to cells in the cerebellum. The authors conclude that prenatal mobile phone radiation might lead to the damage of axon, the nerve fiber, and myelin, the sheath that forms around nerves, with activity of astrocytes in cerebellum of male rat offspring (Yang et al., 2020).

CHARACTERIZING RFR EXPOSURES DURING CHILDHOOD AND PREGNANCY

Current FCC exposure levels were set in 1996 without a complete understanding of how RFR is absorbed into the fetus, pregnant women or children. Research published in 2020 and 2021 adds critical new data regarding these exposures. For example, (Foroutan et al., 2020) studied the absorption of WiFi and LTE frequencies into a 43-year-old pregnant woman model carrying a 24-week baby to allow scientists to better understand health impacts due to the interaction between electromagnetic fields and human tissue. (Psenakova et al., 2020) states “numerical results have shown that the obtained maximal SAR values in AustiWoman model is higher than are maximum values determined according to maximum SAR in European standards limit.”

In “Electromagnetic Field in Vicinity of Electronic Baby Monitor” published by IEEE, (Gombarska et al., 2020) found exposures from a baby monitor to be regulation-compliant but the authors warn, “Some caution should be exercised when using such devices, in particular regarding keeping a safe distance from the little children.” These and other new studies confirm the urgent need to reduce exposures, especially for children and pregnant women.

FERTILITY

Environmental Research published “A meta-analysis of in vitro exposures to weak radiofrequency radiation exposure from mobile phones (1990–2015)” describing 1127 experimental observations in cell-based in vitro models on RFR. It found less differentiated cells such as epithelium and spermatozoa are more sensitive to RF (Halgamuge et al., 2020). This study also confirms observations from the REFLEX project, Belyaev and others that cellular response varies with signal properties.

Several reviews on RFR impacts to sperm and reproduction were published over the last two years analyzing the body of evidence. A systematic review and meta-analysis (Sungjoon et al., 2021) evaluated 18 studies and found exposure to mobile phones is associated with reduced sperm motility, viability and concentration. (Yu et al., 2021) found mobile phone RFR exposure could decrease the motility and viability of mature human sperm *in vitro* and the pooled results of animal studies showed that mobile phone RF-EMR exposure could suppress sperm motility and viability. A systematic review on the effects of RFR to male reproductive hormones (Maluin et al., 2021) found that wireless can impact testosterone. The authors detail how testes are one of the most vulnerable organs to RF-EMR. Testicular tissues are more susceptible to oxidative stress due to a high rate of cell division and mitochondrial oxygen consumption.

(Okechukwu, 2020) reviewed human and animal studies published from 2003 to 2020 investigating RFR from cell phones and male fertility, publishing their findings "Does the Use of Mobile Phone Affect Male Fertility? A Mini-Review" in *Journal of Human Reproductive Sciences*. They found evidence in both animal and human spermatozoa of reduced motility, structural anomalies, and increased oxidative stress due to overproduction of reactive oxygen species after RFR exposure. The authors assert that scrotal hyperthermia and increased oxidative stress might be the key mechanisms through which EMR affects male fertility.

As an example of the experimental studies published over the last two years, an animal study on 4G found kidney inflammation and damage to the testes in mice (Hasan et al., 2021). The researchers concluded that fourth-generation cell phone radiation exposure may affect blood hemostasis and inflammation of mice's kidney and testis tissue and they warn that "based on these studies, it is important to increase public consciousness of potential adverse effects of mobile phone radiofrequency electromagnetic radiation exposure."

(Hassanzadeh-Taheri et al., 2021) assessed the effects of cell phone RFR on sperm parameters, DNA fragmentation, and apoptosis in normozoospermic and found higher apoptotic sperms and DNA fragmentation in the RFR exposed. The authors conclude: "it is recommended to keep the cell phone away from the pelvis as much as possible."

ELECTROSENSITIVITY

The International Journal of Molecular Sciences published "Electrohypersensitivity (EHS) as a Newly Identified and Characterized Neurologic Pathological Disorder: How to Diagnose, Treat, and Prevent It" (Belpomme & Irigaray, 2020). This paper documents the data and shows EHS is a neurologic pathological disorder which can be diagnosed, treated, and prevented. Utilizing a database of over 2000 electrohypersensitivity (EHS) and/or multiple chemical sensitivity (MCS) self-reported cases, they found EHS can be clinically characterized by a similar symptomatic picture to multiple chemical sensitivity by low-grade inflammation and an autoimmune response involving autoantibodies against O-myelin. According to the authors: "80% of the patients with EHS present with one, two, or three detectable oxidative stress biomarkers in their peripheral blood, meaning that overall these patients present with a true objective somatic disorder."

“The Critical Importance of Molecular Biomarkers and Imaging in the Study of Electrohypersensitivity. A Scientific Consensus International Report” in the *International Journal of Molecular Sciences* is a scientific consensus international report authored by 32 scientists. They call for the acknowledgement of electrohypersensitivity as a distinct neuropathological disorder and for inclusion in the WHO International Classification of Diseases (*e.g.*, distinct from the current grouping within other ICD codes addressing exposure to non-ionizing radiation) (Belpomme et al., 2021). The paper presents the French teams’ EHS/MCS physiopathological model based on low-grade neuroinflammation and oxidative/nitrosative stress-induced blood–brain barrier disruption, which attempts to account for the mechanisms through which pathophysiological effects could take place in the brain of EHS and/or MCS patients and how EHS and/or MCS pathogenesis may consequently occur. The paper also documents the methodological defects that make provocation tests unsuitable for sham versus EMF exposure analysis in EHS-bearing patients. The paper documents how EHS patients’ RFR exposure has been found to increase plasma glucose levels, affect heart rate variability and in multiple sclerosis-bearing patients RFR exposure can worsen symptoms, meaning that RFR can induce objective, bioclinical alterations in humans.

BRAIN/NEUROLOGY

(Hasan et al., 2021) found long-term exposure to 2400 MHz 4G impacted the structural integrity of the hippocampus and increased anxiety-like behavior in mice. (Hu et al., 2021) published “Effects of Radiofrequency Electromagnetic Radiation on Neurotransmitters in the Brain” in *Frontiers in Public Health,* offering a review that summarizes the effects of EMR on the neurotransmitters in the brain. The nervous system is an important target organ system and is sensitive to EMF. They document research that suggests that long-term exposure to EMR may lead to abnormal norepinephrine and epinephrine contents in the brain, metabolic disorders of monoamine neurotransmitters in the brain and excitatory amino acid neurotransmitters in the hippocampus, “which may affect the excitatory-inhibitory balance of neurons, thus causing a decline in learning and memory ability.” The authors also considered the underlying mechanism as “EMR exposure does increase the intracellular calcium and the formation of ROS, which would alter the cellular function eventually and lead to numerous biological effects including neurotransmitter imbalance.” The authors call for more research to clarify effects.

A systematic review by (Bertagna et al., 2021) published in *Annals of the New York Academy of Sciences* found that neuronal ion channels are particularly affected by EMF exposure. Changes in calcium homeostasis, attributable to the voltage-gated calcium channels, were the most commonly reported result of EMF exposure. EMF effects on the neuronal landscape appear to be diverse and greatly dependent on parameters like the field's frequency, exposure time, and intrinsic properties of the irradiated tissue, such as the expression of VGCs. The researchers systematically clarify how neuronal ion channels are particularly affected and differentially modulated by EMFs at multiple levels, such as gating dynamics, ion conductance, concentration in the membrane, and gene and protein expression. Ion channels represent a major transducer for EMF-related effects on the CNS.

(Tan et al., 2021) evaluated the acute effects of 2.856 GHz and 1.5 GHz microwaves to male rats and found exposures induced a decline in spatial memory.

“Exposure of Radiofrequency Electromagnetic Radiation on Biochemical and Pathological Alterations” in *Neurology India* (Sharma et al., 2020) found 800 MHz frequency at a SAR of 0.433 W/kg in male Wistar rats led to neurochemical and pathophysiological damage by initiating the inflammatory process in various brain regions, especially in hippocampus and cerebral cortex. The authors conclude that since the hippocampus involves storing and retaining information during the learning process, RFR exposure negatively affects the memory and learning process and “could be a huge risk of induction of brain damage.”

(Hinrikus et al., 2021) review “Threshold of radiofrequency electromagnetic field effect on human brain” in the *International Journal of Radiation Biology* found the threshold for EEG effects is far lower than the level deemed safe by the U.S. FCC. The lowest level of RF EMF at which the effect in EEG was detected is 2.45 V/m (SAR = 0.003 W/kg). The authors state the changes in EEG caused by RF EMF appeared similar in the majority of analyzed studies and similar to those found in depression. They conclude that the “possible causal relationship between RF EMF effect and depression among young people is [a] highly important problem.”

(Luo et al., 2021) in their paper “Electromagnetic field exposure-induced depression features could be alleviated by heat acclimation based on remodeling the gut microbiota” published in *Ecotoxicology and Environmental Safety* share their findings that pulsed electromagnetic fields (2450 MHz) caused gut microbiota and metabolites disturbance similar to depression model. “In our study, EMF induced disturbance in the metabolite profiles of serum samples. Significantly different metabolites included cholesterol, D-fructose and fumaric acid and these were associated with depression (Xiong et al., 2020). Based on KEGG classification, the metabolites involved in neurotransmitters and steroids were altered significantly.”

They concluded that “our study demonstrated that EMF exposure could not only lead to neurobehavioral disorders such as depression, but also cause gut microbiota imbalance.” The researchers also referenced how “growing evidence indicates that the gut microbiota affects not only gastrointestinal function but also central nervous system (CNS) physiology and behavior by regulating the microbiota-gut-brain axis.”

OXIDATIVE STRESS

More recently published studies demonstrate consistency for the induction of oxidative stress. Oxidative DNA damage can lead to mutations, chromosomal translocations, and genomic instability, which are cellular events that can result in cancer development. Induction of oxidative stress, which is a key characteristic of many human carcinogens including ionizing radiation and asbestos, may also lead to the genotoxicity and carcinogenicity of non-ionizing RFR. Oxidative stress caused by EMFs is thought to be due to the altering of recombination rates of short-lived radical pairs leading to increases in free radical concentrations. Thus, even without causing direct DNA damage, RFR may induce oxidative DNA damage and thereby initiate or promote tumor development.

(Schuermann & Mevissen, 2021) published a major review on oxidative stress, “Manmade Electromagnetic Fields and Oxidative Stress – Biological Effects and Consequences for Health” in *International Journal of Molecular Sciences*. The authors found increased oxidative stress in the majority of animal studies and cell studies, many with exposures compliant with FCC and ICNIRP regulatory limits. Increased oxidative stress caused by RF-EMF and ELF-EMF were reported in the majority of the animal studies and in more than half of the cell studies. Investigations in Wistar and Sprague-Dawley rats provided consistent evidence for oxidative stress occurring after RF-EMF exposure in the brain and testes and some indication of oxidative stress in the heart. Observations in Sprague-Dawley rats also seem to provide consistent evidence for oxidative stress in the liver and kidneys. “A trend is emerging, which becomes clear even when taking these methodological weaknesses into account, i.e., that EMF exposure, even in the low dose range, may well lead to changes in cellular oxidative balance.” The authors explain that pre-existing conditions like diabetes and neurodegenerative diseases compromise the body’s defense mechanisms, including antioxidant protection processes, and individuals with pre-existing conditions are more likely to experience health effects. Further, very young or old individuals can react less efficiently to oxidative stress. This puts them at greater risk of health impacts.

“Effects of different mobile phone UMTS signals on DNA, apoptosis and oxidative stress in human lymphocytes” (Gulati et al., 2020) published in *Environmental Pollution* comparatively analyzed genotoxic effects of UMTS signals at different frequency channels used by 3G mobile phones (1923, 1947.47, and 1977 MHz) and found a relatively small but statistically significant induction of DNA damage in dependence on UMTS frequency channel with maximal effect at 1977.0 MHz, supporting the notion that each specific signal used in mobile communication should be tested.

“Effects of pulse-modulated radiofrequency magnetic field (RF-EMF) exposure on apoptosis, autophagy, oxidative stress and electron chain transport function in human neuroblastoma and murine microglial cells” published by (Zielinski et al., 2020) in *Toxicology in Vitro* investigated the effects of ELF-modulated 935 MHz RF-EMF on apoptosis, autophagy, oxidative stress and electron exchange in human neuroblastoma and murine microglial cells. The authors found effects indicating that “short-time RF-EMF at SAR levels accepted by today's safety guidelines might cause autophagy and oxidative stress with the effect being dependent on cell type and exposure duration. Further studies are needed to evaluate possible underlying mechanisms involved in pulse-modulated RF-EMF exposure.”

(Singh et al., 2020) exposed male Wistar rats to RFR for 16 weeks (2 h/day) and observed oxidative stress, an inflammatory response, and HPA axis deregulation. “Effect of mobile phone radiation on oxidative stress, inflammatory response, and contextual fear memory in Wistar rat” was published in *Environmental Science and Pollution Research International.* The study shows that chronic exposure to MP-RF-EMF radiation emitted from mobile phones may induce oxidative stress, inflammatory response, and HPA axis deregulation.

(Hussien et al., 2020) found a significant decrease in plasma nesfatin-1 level and thyroid functions with an increase in oxidative stress and apoptosis. Further, there was a correlation between nesfatin-1 level and markers of thyroid function, oxidative stress and apoptosis. The researchers conclude that Nesfatin-1 plays a role in thyroid dysfunctions of rats exposed to mobile phone radiation. The authors' "Decreased level of plasma nesfatin-1 in rats exposed to cell phone radiation is correlated with thyroid dysfunction, oxidative stress, and apoptosis" published in *Archives of Physiology and Biochemistry* details these findings.

GENOTOXICITY/ DNA DAMAGE

Major studies using validated experimental protocols published in 2020 and 2021 associate non-ionizing RFR exposure with DNA damage.

In February 2020, U.S. government scientists published landmark findings of "significant increases in DNA damage" in groups of male mice, female mice and male rats after just 14 to 19 weeks of non-thermal cell phone RFR exposure as part of the large scale National Toxicology Program cell phone animal studies (Smith-Roe et al., 2020). "Evaluation of the genotoxicity of cell phone radiofrequency radiation in male and female rats and mice following subchronic exposure" published in *Environmental and Molecular Mutagenesis* details the much-anticipated results of the comet assay showing significant increases in DNA damage in the frontal cortex of male mice (both modulations), leukocytes of female mice (CDMA only), and hippocampus of male rats (CDMA only). Increases in DNA damage judged to be equivocal were observed in several other tissues of rats and mice. "In conclusion, these results suggest that exposure to RFR is associated with an increase in DNA damage." In short, DNA damage was found at non-thermal RFR levels, levels the FCC regulatory limits presume are harmless.

The authors explain that the NTP studies were designed to evaluate non-thermal effects of cell phone RFR exposure, which meant that body temperature could not change more than 1° C and therefore the NTP scientists considered it unlikely that thermal effects were a confounding factor for these genetic toxicity tests. Thus, this data again adds to the large body of evidence confirming that the assumption that non-ionizing radiation does not cause any adverse health effects other than by heating is wrong. The study is a game changer because the NTP exposures were carefully controlled and NTP studies are considered the gold standard in animal testing.

In "Genetic effects of non-ionizing electromagnetic fields" published in *Electromagnetic Biology and Medicine,* (Lai, 2021) reviewed the research on the genetic effects of non-ionizing electromagnetic fields and found many studies reported effects in cells and animals after exposure to EMF at intensities similar to those in the public and occupational environments. Approximately 70% of reviewed studies showed effects including DNA strand breaks, micronucleus formation, and chromosomal structural changes. Lai highlights how the effects are waveform and cell-type specific.

Dr. Lai's findings underscore the complexity of interactions between EMF and biological tissues, and may partially explain why effects were observed in some studies but not others. Lai states it is essential to understand why and how certain wave-characteristics of an EMF are more effective than other characteristics in causing biological effects, and why certain types of cells are more susceptible to EMF effects. Very significantly, Dr. Lai asserts that "there are different biological effects elicited by different EMF wave-characteristics" and this is a critical proof for the existence of non-thermal effects.

The review explains how genetic effects depend on various factors, including field parameters and characteristics (frequency, intensity, wave-shape), cell type, and exposure duration. Lai also found non-ionizing EMFs interact synergistically with different entities on genetic functions. These interactions, particularly with chemotherapeutic compounds, raise the possibility of using EMF as an adjuvant for cancer treatment to increase the efficacy and decrease side effects of traditional chemotherapeutic drugs.

Lai explains that since the energy level is not sufficient to cause direct breakage of chemical bonds within molecules, the effects are probably indirect and secondary to other induced chemical changes in the cell. He suspects that biological effects are caused by multiple inter-dependent biological mechanisms. He states that the mechanism remains to be uncovered, "but, knowing the mechanism is not necessary to accept that the data are valid. It is also a general criticism that most EMF studies cannot be replicated. I think it is a conceptual and factual misstatement. Replication is also not a necessary and sufficient condition to believe that certain data are true." Lai then states that, "to prove an effect, one should look for consistency in data. Genetic damage studies have shown similar effects with different set-up and in various biological systems. And, the gene expression results (Supplement 3) also support the studies on genetic damages. Expression of genes related to cell differentiation and growth, apoptosis, free radical activity, DNA repair, and heat-shock proteins have been reported. These changes could be consequences of EMF-induced genetic damages."

An October 2021 review "Human-made electromagnetic fields: Ion forced-oscillation and voltage-gated ion channel dysfunction, oxidative stress and DNA damage (Review)" in the *International Journal of Oncology* describes the cascade of effects from non-ionizing EMFs that lead to DNA damage. (Panagopoulos et al., 2021) documents the scientific research base indicating EMF exposures lead to ion channel dysfunction. According to the ion forced-oscillation mechanism for dysfunction of VGICs, human-made (polarized and coherent) ELF/ULF EMFs or the ELF/ULF modulation/pulsing/variability components of modern RF/WC EMFs can alter intracellular ionic concentrations by irregular gating of VGICs on cell membranes. This leads to immediate oxidative stress by ROS [oxidative stress that cause damage to lipids, proteins and DNA] (over)production in the cytosol and/or the mitochondria, which can damage DNA when cells are unable to reinstate electrochemical balance (normal intracellular ionic concentrations). Consequently, DNA damage can lead to reproductive disabilities, neurodegenerative diseases, aging, genetic alterations and cancer.

Moreover, the review addresses how, in addition to polarization and coherence, ELFs are a common feature of almost all human-made EMFs. The authors suggest that the non-thermal biological effects attributed to RF EMFs are actually due to their ELF components. The researchers conclude that, “The long-existing experimental and epidemiological findings connecting exposure to human-made EMFs and DNA damage, infertility and cancer, are now explained by the presented complete mechanism. The present study should provide a basis for further research and encourage health authorities to take measures for the protection of life on Earth against unrestricted use of human-made EMFs.”

NEW GOVERNMENT REPORTS AND RECOMMENDATIONS

The European Union

In July 2021, the European Parliament Panel for the Future of Science and Technology European Parliamentary Research Service Report “Health Impact of 5G” offered a review of the epidemiological and experimental evidence which has significantly increased since 2011 when the International Agency for Research on Cancer (IARC) classified radiofrequency (RF) EMF as “possibly carcinogenic to humans” (Group 2B). Due to the post-2011 published research, the IARC advisory group has now recommended RF exposure for re-evaluation “with high priority” (IARC, 2019). The report concludes that the body of evidence now indicates that the frequencies of 450 to 6,000 MHz are “probably carcinogenic for humans, in particular related to gliomas and acoustic neuromas.”

For non-cancer effects the EU Report concludes that there was sufficient evidence of reproductive/developmental adverse effects in experimental animals and “these frequencies clearly affect male fertility and possibly female fertility too. They may have possible adverse effects on the development of embryos, foetuses and newborns.” In regards to 5G’s higher frequencies (24.25-27.5 GHz), and frequencies 24 to 100 GHz the systematic review found there was an inadequate base of studies either in humans or in experimental animals with which to even substantiate a conclusion one way or the other regarding a carcinogenic effect or any other non-thermal effect.

The report makes several policy recommendations, including:

- Adopting stricter RFR limits for mobile phone devices and reducing RFR exposure with devices that emit lower energy and “if possible only working when at a certain distance from the body”.
- Revisiting RFR exposure limits for the public and the environment in order to reduce RF-EMF exposure from cell towers through more stringent limits such as those used in Italy, Switzerland, China, and Russia - all of which are significantly lower than those recommended by ICNIRP and the FCC.

- Adopting measures to incentivise the reduction of RF-EMF exposure which include using optic-fibre cables to connect schools, libraries, workplaces, houses, public buildings, and all new buildings etc. “Public gathering places could be 'no RF-EMF' areas (along the lines of no-smoking areas) so as to avoid the passive exposure of people not using a mobile phone or long-range transmission technology, thus protecting many vulnerable elderly or immune-compromised people, children, and those who are electro-sensitive.”
- Promoting a multidisciplinary scientific research effort to assess the long-term health effects of 5G millimeter waves (MMW) in order to rule out the risk that tumours and adverse effects on reproduction and development may occur upon exposure to 5G MMW, and to exclude the possibility of synergistic interactions between 5G MMW networks and other frequencies and networks that are already being used. Research is needed on the biological effects of 5G MMW at frequencies between 6 and 300 GHz not only for humans but also for the flora and fauna of the environment, e.g. non-human vertebrates, plants, fungi, and invertebrates.
- Promoting research to identify an adequate method of monitoring exposure to 5G because there is currently inadequate monitoring of the actual exposure of the population.
- Promoting a public educational awareness campaign on the potential harms of RFR at all levels, beginning with schools. This campaign should include the potential health risks, opportunities for digital development, safer infrastructure alternatives, and strategies to reduce exposure to wireless phones.

The report concludes that the gaps in knowledge in regards to 5G’s higher frequencies justify the call for a moratorium on 5G millimeter wave networks, pending completion of adequate research, “before exposing the whole world population and environment.” The report’s conclusion carries a very clear warning: “Implementing MMW 5G technology without further preventive studies would mean conducting an 'experiment' on the human population in complete uncertainty as to the consequences.”

In 2020, the European Parliament briefing Effects of 5G wireless communication on human health reviewed the various policies and reports in Europe including: 1) the 2011 Council of Europe Parliamentary Assembly Resolution 1815 that recommended reducing RFR exposure; the fact that the European Environment Agency (EEA) has long advocated precaution concerning EMF exposure; 2) the European Commission Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) 2015 opinion and the organizations that suggest many members of SCENIHR could have conflict of interests, as they had professional relationships with or received funding from various telecom companies; 3) the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER), replacing the former Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) evaluated the scale, urgency and interactions (with ecosystems and species) of possible hazard from 5G *as high as “*there could be biological consequences from a 5G environment.”

The briefing also highlighted the biological impacts from pulsations and modulations stating, “Studies show that pulsed EMF are in most cases more biologically active and therefore more dangerous than non-pulsed EMF. Every single wireless communication device communicates at least partially via pulsations, and the smarter the device, the more pulsations. Consequently, even though 5G can be weak in terms of power, its constant abnormal pulse radiation can have an effect. Along with the mode and duration of exposures, characteristics of the 5G signal such as pulsing seem to increase the biologic and health impacts of exposure, including DNA damage, which is considered to be a cause of cancer. DNA damage is also linked to reproductive decline and neurodegenerative diseases."

A review of occupational EMF exposures (Stam, 2021) of the National Institute for Public Health and the Environment of the Netherlands pointed to the need for exposure guidelines and regulation to incorporate new technology developments, especially in regards to 5G applications. Although ICNIRP's thermally-based RFR limits were used as the action level in this article (and adverse biological effects have been found at non-thermal levels as documented in this report), this paper highlights the critical need to characterize occupational exposures and better assess health effects because of the new wireless networks found in the modern workplace.

In April 2020, the Swiss Parliament refused to weaken their RFR radiation limits. In September 2020, the Netherlands issued a 5G and Health Advisory Report that recommended measuring environmental levels of RFR (an action the FCC does not take) and importantly, the Report also recommended *against* using the 26 GHz frequency band for 5G "for as long as the potential health risks have not been investigated."

Starting in July 2020, new French government policy ensures that wireless companies label tablets, laptops, Wi-Fi routers, DECT phones and other wireless connected electronics with RFR SAR exposure levels at point of sale and in all advertising. Legislation in the country has long ensured labeling cell phones for SAR levels, but this did not apply to other wireless devices. Now all wireless devices used close to the head and body are potentially covered.The ANFR (The National Frequency Agency) SAR Regulation Guide lists the equipment qualified as radio equipment that required SAR testing. One category includes mobile phones, tablets equipped with a 3G or 4G/5G SIM card, connected watches that contain a mobile phone SIM card, 3G or 4G/5G pocket format routers, Maritime Portable VHF, laptops (3G or 4G/5G); and the second category includes DECT cordless phones, walkie-talkies or equivalent devices (PMR), tablets operating using Wi-Fi or bluetooth, wireless microphones, radio controls used for drones or model making, connected motorcycle helmets and Wi-Fi laptops. ANFR states that technological evolutions in connected objects may lead to the extension of this labeling to include radio frequency belts, connected glasses ("smart glasses"), wireless headphones or headsets, portable safety sensors (distance sensors) and virtual reality headsets.

Expert Recommendations to Minimize Exposure to Children

Since the COVID pandemic, there have been several new expert recommendations to reduce RFR exposure for children in virtual education on computers for 7 hours or more a day. For example, in April 2020 the Cyprus National Committee on Environment and Children's Health released recommendations for parents on how to set up wired internet. In March 2020, the Scientific Research Institute of Hygiene and Children's Health of the Russian Ministry of Health and the Russian National Committee on Non-Ionizing Radiation Protection also released recommendations for distance learning including restricting cell phones, using wired connections rather than Wi-Fi, reading real books and writing in real notebooks to support learning objectives. In November 2020, the Switzerland Doctors for Environmental Protection (AefU) released "Consistently apply the precautionary principle in mobile communications" demanding a reduction in exposure for children and youth.

Expert Appeals

Expert recommendations to reduce public and environmental exposures have escalated over the last two years. The 2020 Consensus Statement of UK and International Medical and Scientific Experts and Practitioners on Health Effects of Non-Ionising Radiation (NIR) was signed by over 3500 medical doctors cautioning: "Hundreds of peer-reviewed scientific studies have demonstrated adverse biological effects occurring in response to a range of NIR [non-ionizing radiation] exposures below current safety guidelines; however emissions continue to escalate. Medical evidence of harm has now reached the critical mass necessary to inspire the medical community to step out of their usual roles, stand up and speak out regarding their concern."

Expert groups have continued to organize and call for urgent action in various countries. For example, in October 2020 a letter signed by 135 health professionals in Chile requested a moratorium on the deployment of 5G technology, and a 5G Appeal was launched in support of a new 5G petition: "Apoya con tu firma la carta de solicitud de moratoria al 5G en Chile enviada al Ministro Paris"; English Translation: "With your signature, support the letter requesting a moratorium on 5G in Chile sent to Minister Paris".

In France, a September 2020 petition addressed to the Prime Minister was signed by over 60 elected officials urging the government to assess environmental effects before deploying 5G. In Canada, the Urgent Appeal to the Government of Canada to Suspend the 5G Rollout and to Choose Safe and Reliable Fiber Connections was launched by Canadians for Safe Technology (C4ST) in May 2020. The Appeal calls for a systematic review of the scientific evidence of health effects of RFR as well as binding guidelines to protect wildlife and the environment from RFR. The CEO of C4ST calling for this review is Frank Clegg, the former Chairman of Microsoft Canada.

Medical Conference on EMF

In 2021, the EMF Medical Conference 2021 presented evidence based information on the prevention, diagnosis and treatment of EMF associated illness featuring leading EMF experts in science, medicine, health and assessment. These proceedings are available as online courses for continuing medical education credits for medical doctors and health professionals. See www.emfconference2021.com

Expert Recommendations in the USA

The New Hampshire State Commission released its 2020 Report on 5G Health and Environment with 15 recommendations that included reducing public exposure to RFR via wired (not Wi-FI) internet connections in schools and libraries; software changes to phones and wireless devices to minimize exposure; informing the public about RFR exposures via educational campaigns and public posting of RFR levels; government measuring of RFR exposures; developing updated safety standards to protect the public and environment; and ensuring independent scientific review of the research.

On June 17th, 2020, over U.S. 400 medical professionals wrote the FCC a letter calling for consideration of non-thermal biological impacts. The Alliance of Nurses for Healthy Environments (ANHE), a national organization of nurses, also sent a 2020 letter calling for the FCC to address the science on children's vulnerability.

Over the last two years, several U.S. cities have passed resolutions and policies to halt increased RFR exposure and to ensure adequate scientific review of the health effects of RFR radiation. For example, Hawai'i County (July 2020), Easton Connecticut (May 2020), Keene New Hampshire (March 2020) and Farragut Tennessee (May 2020) have passed resolutions to halt 5G. The Coconut Creek Florida Commission adopted a Resolution on 5G and radiofrequency radiation (November 2020) "imploring the US Congress to allocate funding and direct a cross discipline federal agency study of the effects caused by exposure to current and proposed electromagnetic spectrum and radiofrequency commissions on human health and the environment in light of the recent implementation of fifth generation technology and to use those findings to create science based laws or rules regarding limiting human and environmental exposure."

On April 2, 2021 Montgomery County Maryland Council President Hucker and County Executive Elrich sent a letter to U.S. Senator Chris Van Hollen that included two specific requests regarding RFR:

> *"Request responsibility for setting RF standards be transferred from the Federal Communications Commission (FCC) - a regulatory agency - to the National Institute of Standards and Technology (NIST) - a standards setting body. Direct NIST to complete a review of credible published papers on the health effects of RF emissions on humans, including women and children, and tests to measure biological impact on humans, and thermal and biological tests of RF at different frequencies within 6 months. Further direct NIST to create and update thermal and biological standards for smart phones, small cells, and household Internet-of-Things (IoT) devices, Wi-Fi, and Bluetooth devices within 2 years and review and update standards every 5 years thereafter.*

Environmental Groups

Internationally and in the USA, environmental groups have issued statements and positions calling for protections for the environment before allowing wireless network proliferation. For example, in 2021, a major environmental group in Spain, Ecologistas en Accion or Ecologists in Action issued a position on 5G calling for precaution. They propose information campaigns, reducing exposure, monitoring compliance and requiring transparency, impartiality and plurality in health risk assessments. They also recommend wireless networks are replaced with wired connections and the recognition of electrohypersensitivity syndrome as an environmental disease with protections that include the creation of EMF-free zones.

In February 2021, the Green Party of California issued a Statement on 5G Wireless Technology advocating for "robust and independent scientific environmental review of 4G/5G wireless exposure" and to reduce exposures per the As Low As Reasonably Achievable (ALARA) principle. It is notable that environmental organizations are also issuing statements regarding the increased energy consumption of 5G. For example, Greenpeace France's "What is Digital Pollution" addresses how 5G will increase "digital pollution." Several investigative articles have been published on the environmental impacts including "How Green is 5G?" published November 2021 in Envirotech Magazine; "What Will 5G Mean for the Environment?" published January 2020 by Clair Curran of the Henry M. Jackson School of International Studies; and "Is Wireless Technology an Environmental Health Risk?" published January 2021 by Katie Alvord in the journal of the Society of Environmental Journalists.

5G NETWORKS AND MILLIMETER WAVE FREQUENCIES

The review paper "Adverse health effects of 5G mobile networking technology under real-life conditions" (Kostoff et al., 2020) published in *Toxicology Letters* identified a wide range of adverse systemic effects from 5G network deployment when real life conditions are considered such as the information content of signals along with the carrier frequencies and other toxic stimuli that can act in combination with the exposure. Many experiments do not include the real-life pulsing and modulation of the carrier signal. The vast majority of experiments do not account for synergistic adverse effects of other toxic stimuli with wireless radiation. 5G mobile networking technology will affect the skin and eyes and has adverse systemic effects. "In aggregate, for the high frequency (radiofrequency-RF) part of the spectrum, these reviews show that RF radiation below the FCC guidelines can result in: carcinogenicity (brain tumors/glioma, breast cancer, acoustic neuromas, leukemia, parotid gland tumors), genotoxicity (DNA damage, DNA repair inhibition, chromatin structure), mutagenicity, teratogenicity, neurodegenerative diseases (Alzheimer's Disease, Amyotrophic Lateral Sclerosis), neurobehavioral problems, autism, reproductive problems, pregnancy outcomes, excessive reactive oxygen species/oxidative stress, in ammation, apoptosis, blood-brain barrier disruption, pineal gland/melatonin production, sleep disturbance, headache, irritability, fatigue, concentration difficulties, depression, dizziness, tinnitus, burning and flushed skin, digestive disturbance, tremor, cardiac irregularities, adverse impacts on the neural, circulatory, immune, endocrine, and skeletal systems." The authors conclude that "Superimposing 5G radiation on an already imbedded toxic wireless radiation environment will exacerbate the adverse health effects shown to exist. Far more research and testing of potential 5G health effects under real-life conditions is required before further rollout can be justified."

In "Absorption of 5G Radiation in Brain Tissue as a Function of Frequency, Power and Time" published in *IEEE Access* (Gultekin & Siegal, 2020) examines the beam penetration, absorption and thermal diffusion at representative 4G and 5G frequencies and shows that RF heating increases rapidly with frequency due to decreasing RF source wavelength and increasing power density with the same incident power and exposure time.

(Trillo et al., 2021) in their paper "Effects of the signal modulation on the response of human fibroblasts to in vitro stimulation with subthermal RF currents" published in *Electromagnetic Biology and Medicine* found the modulated signal was more efficient in inducing Hsp27 and decorin overexpression and promoting cell proliferation. "These data indicate that the cellular response is dependent on the RF signal modulation…"

5G human exposure studies include (Kim & Nasim, 2020). In their paper "Human Electromagnetic Field Exposure in 5G at 28 GHz" published in *IEEE Consumer Electronics Magazine* the authors compared the human EMF exposure in a 5G system to previous-generations of cellular systems. They suggest a minimum separation distance between a transmitter and a human user in order to keep exposure compliant with regulatory limits.

In their paper "Human RF-EMF Exposure Assessment Due to Access Point in Incoming 5G Indoor Scenario" published in *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology* (Bonato et al., 2021) simulated the exposure to an adult and child from an indoor 5G access points (3.7 GHz and at 14 GHz) to evaluate how beamforming and the higher frequency use could impact exposure levels and found the reciprocal position between the antenna and the model head and the frequency range and the distance are factors that could greatly influence the exposure levels.

"Physiological effects of millimeter-waves on skin and skin cells: an overview of the to-date published studies" published in *Reviews on Environmental Health* is an overview of the physiological effects of millimeter waves on skin and skin cells (Leszczynski, 2020) by Dr. Leszczynski, one of the IARC working group members who voted 29 to 1 in May 2011 to classify RF-EMF as a 2B or "possible human" carcinogen. The author explains how the skin and eyes are directly exposed to the millimeter-waves from 5G and yet the current body of research on millimeter-waves is insufficient to devise science-based exposure limits and policies. He recommends precautionary measures such as postponing or limiting 5G deployment in residential areas until adequate research studies scientifically establish safety thresholds.

In "Limiting liability with positioning to minimize negative health effects of cellular phone towers" published in *Environmental Research* (Pearce, 2020) summarizes the peer-reviewed literature on the effects of RFR from cellular phone base stations and concludes that, "to protect cell phone tower firms, companies should seek to minimize human RFR exposure" because there is "already enough medical-scientific evidence to warrant long-term liability concerns."

In "Millimeter (MM) wave and microwave frequency radiation produce deeply penetrating effects: the biology and the physics" published in *Reviews on Environmental Health*, (Pall, 2021) highlights three very important findings “rarely recognized in the EMF scientific literature: coherence of electronically generated EMFs; the key role of time-varying magnetic fields in generating highly penetrating effects; the key role of both modulating and pure EMF pulses in greatly increasing very short term high level time-variation of magnetic and electric fields. It is probable that genuine safety guidelines must keep nanosecond timescale-variation of coherent electric and magnetic fields below some maximum level in order to produce genuine safety. These findings have important implications with regard to 5G radiation.”

STANDARDS

The Environmental Working Group modeled the health effects incidence data from the National Toxicology Program (NTP) cell phone radiation studies to estimate departure points for exposure guidelines in a landmark analysis published in *Environmental Health*. The NTP study reported an increased incidence of cardiomyopathy in female and male rats and increased incidences of various neoplasms in male rats. They concluded that FCC limits should be strengthened by 200 to 400 times to protect children according to current risk assessment guidelines concluding that ”the analysis presented here supports a whole-body SAR limit of 2 to 4 mW/kg for adults, an exposure level that is 20- to 40-fold lower than the legally permissible limit of 0.08 W/kg for whole-body SAR under the current U.S. regulations. A ten-fold lower level of 0.2–0.4 mW/kg whole-body SAR may be appropriate for young children.

Both technology changes and behavior changes may be necessary to achieve these lower exposure levels. In “Development of health-based exposure limits for radiofrequency radiation from wireless devices using a benchmark dose approach” published in *Environmental Health*, the authors suggest: “Simple actions such as keeping the wireless devices farther away from the body offer an immediate way to decrease RFR exposure for the user.” (Uche, 2021)

In April 2020, Barnes and Greenebaum published “Setting Guidelines Electromagnetic Exposures Research Needs”, in *Bio Electro Magnetics* about the fact that current limits for exposures to non-ionizing electromagnetic fields do not address long-term exposures but are instead based on relatively short-term exposures. “What is missing in the current guidelines or regulations are guidelines for long-term exposure to weak EMF.” The authors document the science substantiating their recommendations for next steps regarding research and approaches for more protective exposure guidelines. They conclude that the science is sufficient indicating biological impacts at low levels:

> *“However, over the last 20 years the evidence has become extremely strong that weaker EMF over the whole range for frequencies from static through millimeter waves can modify biological processes. There is now solid experimental evidence and supporting theory showing that weak fields, especially but not exclusively at low frequencies, can modify reactive free radical concentrations and that changes in radical concentration and that of other signaling molecules, such as hydrogen peroxide and calcium, can modify biological processes…”*

The authors posit with copious scientific documentation how non-ionizing EMFs can impact cancer cell growth rates, membrane potentials, concentrations of calcium, reactive oxygen species (ROS), superoxide ($O2^{-}$), nitric oxide (NO), hydrogen peroxide ($H2O2$), and intercellular pH, specifically highlighting the issue of oxidative stress as long-term elevations "are associated with cancer, aging, and Alzheimer's." They highlight how funding for research into the effects of EMF in the United States "is close to nonexistent" and make numerous recommendations for research studies. They also recommend, for example, that guidelines be set at three levels: the individual user, local company, and national or international level and posit that recommended limits could well be a function of frequency, amplitude, and modulation systems as well as be dependent on the condition of the person being exposed. Barnes and Greenebaum acknowledge, "There seem to be a smaller number of 'hypersensitive people' who have very real and serious problems" from exposure to weak RF fields.

The co-authors conclude: "We believe a carefully targeted program of federal research funds is called for, supplemented by communications system operators and corporations that manufacture equipment, under independent scientific management. Both governmental and private entities that emit RF signals would be well advised to fund research to elucidate and define threshold signal levels for the generation of long-term biological effects."

CANCER

The evidence that RFR is a human carcinogen has continued to increase with the publication of several new research studies and papers. Furthermore, cancer incidence is rising among children and young adults. The latest U.S. Annual Report to the Nation on the Status of Cancer (a collaborative effort among the American Cancer Society, the Centers for Disease Control and Prevention, the National Cancer Institute, part of the National Institutes of Health; and the North American Association of Central Cancer Registries) published in *Journal of the National Cancer Institute* found higher overall cancer incidence rates in children and young adults in almost all racial/ethnic groups, with increasing trends for the most common cancer types among children including leukemia, brain and other nervous system cancers, and lymphoma.

In November 2020 a systematic review and meta-analysis of case-control studies by (Choi et al., 2020), "Cellular Phone Use and Risk of Tumors: Systematic Review and Meta-Analysis", was published in *Environmental Research and Public Health.* The authors found evidence that linked cellular phone use to increased tumor risk. The meta-analysis established that 1,000 or more hours of cell phone use, or about 17 minutes per day over 10 years, was associated with a statistically significant 60% increase in brain tumor risk.

In their paper "Genetic susceptibility may modify the association between cell phone use and thyroid cancer: A population-based case-control study in Connecticut" published in *Environmental Research* (Luo et al., 2020), the Yale researchers with support from the American Cancer Society found cell phone use was significantly associated with thyroid cancer in people with a type of common genetic variation. The association increased as cell phone use duration and frequency increased. The authors conclude that their findings “provide more evidence for RFR carcinogenic group classification.”

Regarding the impact of EMFs to the thyroid, a 2021 review by California Institute of Behavioral Neurosciences & Psychology researchers (Alkayyali et al., 2021) focused on thyroid hormones and thyroid gland histopathology documented studies indicating that RFR could be associated with alterations in hormone levels and impacts such as the hyperstimulation of thyroid gland follicles, causing oxidative stress and apoptosis of follicular cells. In “An Exploration of the Effects of Radiofrequency Radiation Emitted by Mobile Phones and Extremely Low Frequency Radiation on Thyroid Hormones and Thyroid Gland Histopathology” published in *Cureus*, the researchers found studies correlated thyroid impacts to the exposure duration, intensity, and SAR value of the RFR exposure. The authors state that “non-ionizing EMF radiation might be responsible for the recent increase in the incidence of thyroid insufficiency and cancer in the general population.”

In “The Effect of Continuous Low-Intensity Exposure to Electromagnetic Fields from Radio Base Stations to Cancer Mortality in Brazil” (Rodrigues et al. 2020) published their findings in the *International Journal of Environmental Research and Public Health* linking higher exposure to radio frequency radiation from cell antenna installations in Brazil to increased deaths from cancers. For all cancers and for the specific types investigated (breast, cervix, lung, and esophagus cancers), the higher the exposure, the higher the median of mortality rate.

The last two years of research has significantly increased the scientific evidence that RFR can increase oxidative stress, a hallmark of cancer, addressed earlier in this document. However, in addition, there are other endpoints associated with cancer that have been published in the last two years increasing the evidence related to the carcinogenicity of RFR. For example, (Ghandehari et al. 2021) found increased cell phone usage significantly correlated with a higher frequency of the micronucleus containing buccal mucosa cells and a higher frequency of micronucleus in each cell in the buccal mucosa. In “Micronucleus Assay in Cell Phone Users: Importance of Oral Mucosa Screening” published in *International Journal of Preventive Medicine*, the authors surmise, “Based on these results, it can be concluded that human buccal cells are likely to show increased micronucleus cells as a result of the genotoxic effects of cell phone waves which have been chronically exposed.”

Micronuclei are biomarkers of disease and they play an active role in tumor biology (Kwon et al. 2020). (Yao et al. 2021), in “The biological effects of electromagnetic exposure on immune cells and potential mechanisms” published in *Electromagnetic Biology and Medicine*, undertake a review of the biological effects of electromagnetic exposure on immune cells. The researchers found: “Accumulated data suggested that electromagnetic exposure could affect the number and function of immune cells to some extent, including cell proportion, cell cycle, apoptosis, killing activity, cytokines contents…”; and the authors conclude that, “knowledge of the biological effects on immune cells associated with electromagnetic fields is critical for proper health hazard evaluation, development of safety standards, and safe exploitation of new electromagnetic devices and applications.”

(Hardell & Carlberg, 2021) published “Lost opportunities for cancer prevention: historical evidence on early warnings with emphasis on radiofrequency radiation” in *Reviews in Environmental Health*. This eloquent review gives insight into missed opportunities for cancer prevention exemplified by asbestos, tobacco, certain pesticides and now RF radiation. The authors highlight how economic considerations were favored instead of cancer prevention. “A strategy to sow doubt on cancer risks was established decades ago and is now adopted and implemented in more sophisticated way by the telecom industry regarding RF-EMF risks to human beings and the environment. Industry has the economic power, access to politicians and media whereas concerned people are unheard.” The examples clearly show that if the scientific evidence on cancer risks had been taken seriously, many lives could have been saved.

The 2020 study “Increased Generational Risk of Colon and Rectal Cancer in Recent Birth Cohorts under Age 40 - the Hypothetical Role of Radiofrequency Radiation from Cell Phones” published in *Annals of Gastroenterology and Digestive Disorders* by Davis et al. presented data from the U.S. Centers for Disease Control and Prevention, the U.S. Surveillance Epidemiology and End-Results Program and Iranian cancer registries on the staggering increases in colon and rectal cancer in those under age 50. Those born in the U.S. in the 1990s have a doubled risk of colon cancer and a fourfold increase in rectal cancer by the time they reach age 24 compared to those born six decades ago. The researchers document experimental studies indicating that cells from the colon and rectum of Sprague-Dawley rats are exquisitely sensitive to RFR and assert that these cancer increases could be due to the way people carry cell phones close to their bodies in front and back pockets. They reference how the French government frequency testing agency (ANFR) found that 9 out of 10 phones exceeded the safety guidelines when held against the body by factors of 1.6-3.7 times for the European standard or by factors as high as 11 if 1-g SAR values were to be measured as required by the U.S. FCC. “It appears prudent to promote policies to reduce exposures to radiofrequency radiation and encourage ALARA during pediatric CT procedures, while continuing to promote advances in software and hardware of phones and scanners that can lower exposures to non-ionizing radiation during normal operations. In addition, major public educational programs should be developed to promote awareness of the need to practice safer technology, especially for the young, who may well be at greater risk of developing cancer due to their immunological immaturity.”

In March 2021, Christopher Portier, Ph.D., formerly the Director of the United States National Center for Environmental Health at the Centers for Disease Control and Prevention (CDC) in Atlanta and the Director of the Agency for Toxic Substances and Disease Registry submitted a comprehensive review of the scientific research in a major cell phone/brain cancer lawsuit where he concludes: “The evidence on an association between cellular phone use and the risk of glioma in adults is quite strong.” Portier further states in his Expert Report: “In my opinion, RF exposure probably causes gliomas and neuromas and, given the human, animal and experimental evidence, I assert that, to a reasonable degree of scientific certainty, the probability that RF exposure causes gliomas and neuromas is high.”

A important paper was published in *Health Physics* in 2020 by longtime NIH scientist Dr. Ronald Melnick entitled "ICNIRP'S Evaluation of the National Toxicology Program's Carcinogenicity Studies on Radiofrequency Electromagnetic Fields" addressing numerous criticisms of the NTP findings. Melnick documents one by one how these criticisms include false claims and "several incorrect statements that appear to be written to justify retaining exposure standards that were established more than 20 years ago." He presents the scientific documentation that each of these criticisms are unfounded stating "ICNIRP's misrepresentation of the methodology and interpretation of the NTP studies on cell phone RF radiation does not support their conclusion that "limitations preclude drawing conclusions about carcinogenicity in relation to RF EMFs."

Melnick explains that the utility of the NTP studies for assessing human health risks is undermined by the incorrect statements and misinformation in the ICNIRP critique. Melnick describes how the ICNIRP note failed to recognize that focal hyperplasias (proliferative lesions) of glial cells in the brain and of Schwann cells in the heart are putative preneoplastic lesions that may progress to malignant glioma or to cardiac schwannoma tumors, respectively.

Further, Melnick documents how the ICNIRP note focused on the carcinogenicity but ignored other adverse biological effects observed in the NTP studies, including reduced birth weights, DNA strand breaks in brain cells (which is supportive of the cancer findings), increased incidences of proliferative lesions (tumors and hyperplasia) in the prostate gland, and exposure-related increases in the incidence of cardiomyopathy (a type of tissue damage) of the right ventricle of the heart in male and female rats.

"After all, it was the US Food and Drug Administration that requested the NTP studies of cell phone radiation in experimental animals to provide the basis to assess the risk to human health. The NTP studies show that the assumption that RF radiation is incapable of causing cancer or other adverse health effects other than by tissue heating is wrong. If ICNIRP's goal is truly aimed at protecting the public from potential harm, then it would be appropriate for this group to quantify the health risks associated with exposure to RF-EMFs and then develop health-protective guidelines for chronic exposures, especially for children, who are likely to be more susceptible than adults to adverse effects of RF radiation."

These studies are a small sampling of the numerous studies that have documented adverse effects from RFR.

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Review Article

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Effects of non-ionizing electromagnetic fields on flora and fauna, part 1. Rising ambient EMF levels in the environment

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Abstract: Ambient levels of electromagnetic fields (EMF) have risen sharply in the last 80 years, creating a novel energetic exposure that previously did not exist. Most recent decades have seen exponential increases in nearly all environments, including rural/remote areas and lower atmospheric regions. Because of unique physiologies, some species of flora and fauna are sensitive to exogenous EMF in ways that may surpass human reactivity. There is limited, but comprehensive, baseline data in the U.S. from the 1980s against which to compare significant new surveys from different countries. This now provides broader and more precise data on potential transient and chronic exposures to wildlife and habitats. Biological effects have been seen broadly across all taxa and frequencies at vanishingly low intensities comparable to today's ambient exposures. Broad wildlife effects have been seen on orientation and migration, food finding, reproduction, mating, nest and den building, territorial maintenance and defense, and longevity and survivorship. Cyto- and geno-toxic effects have been observed. The above issues are explored in three consecutive parts: Part 1 questions today's ambient EMF capabilities to adversely affect wildlife, with more urgency regarding 5G technologies. Part 2 explores natural and man-made fields, animal magnetoreception mechanisms, and pertinent studies to all wildlife kingdoms. Part 3 examines current exposure standards, applicable laws, and future directions. It is time to recognize ambient EMF as a novel form of pollution and develop rules at regulatory agencies that designate air as 'habitat' so EMF can be regulated like other pollutants. Wildlife loss is often unseen and undocumented until tipping points are reached. Long-term chronic low-level EMF exposure standards, which do not now exist, should be set accordingly for wildlife, and environmental laws should be strictly enforced.

Keywords: 2G – 4GLTE; 5G; cell phone towers/masts/base stations/small cells; "Internet of Things" (IoT); magnetoreception; millimeter waves (MMW); nonionizing electromagnetic fields (EMF); radiofrequency radiation (RFR); satellites; wildlife.

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PART 1: DEFINING THE PROBLEM: TECHNOLOGY AND RISING EMF LEVELS

Introduction: environmental disconnect

Since the advent of electrification in the late 1800s and wireless communications in the 1930s, ambient levels of radiation from devices, broadcast facilities, land-based telecom infrastructure, satellites, and military applications have gradually risen across a range of frequencies in the nonionizing bands of the electromagnetic spectrum. There has been broad discussion in the media and elsewhere about nonionizing electromagnetic fields (EMF) effects to humans, especially since the International Agency for Research on Cancer (IARC) at the World Health Organization (WHO) classified extremely-low frequency (ELF) magnetic fields and radiofrequency radiation (RFR) ([1, 2] respectively) as 2B possible human carcinogens — similar to lead, exhaust fumes, DDT and formaldehyde. But is there a larger environmental downside to rising ambient EMF exposures — particularly RFR — from popular mobile communication devices, WiFi antennas, and all accompanying infrastructure that is being overlooked by environmentalists, researchers, and government regulators alike. We may be missing critical physiological effects across species based on obsolete assumptions about low-level far-field exposures being too weak to adversely affect living tissue. We have yet to take into consideration the unique physiologies of other species, or how they use the environment in ways that humans do not, when we assume that the unfettered use of EMF/RFR can continue unabated and be allowed to grow indefinitely. Ambient electromagnetic fields, such as ELF from powerlines, wiring and electrical appliances, and RFR used in all broadcast, wireless communications, and transmitting devices, are biologically active and may cause adverse effects to different species of living organisms.

Because of the extensive research that applies to this subject, this work is divided into three consecutive parts:

Part 1 explores the research on rising ambient levels of EMFs, how fields are measured, the use of tracking devices in animals, and what new technologies like 5G will add.

Part 2 explores the Earth's natural geomagnetic fields and non-human species mechanisms of magnetoreception, as well as cyto- and genotoxin effects from manmade EMFs. It focuses on the unique physiologies of non-human species, their specific habitats, and how energy travels through different environments. The section then ties what has been seen in the laboratory, as well as field studies, in all frequencies and representative biological taxa at exposures now seen in ambient environments.

Part 3 discusses government exposure standards and explores existing laws already in place in Western countries, then points to how a new vision of aeroecology and electroecology can use those laws to inform policy regarding nonionizing radiation's impacts.

Supplementary materials include extensive Tables of applicable studies per section at extremely low intensity exposures and accompanying references.

There is abundant research on how low-level EMFs affect non-human species, including extensive reviews of nonionizing radiation across all frequencies and environments about which many environmentalists and regulators are unaware [3–14]. In research into the biological effects of EMF, it has been known since the 1960s that many species are sensitive to low-level energy exposures. Numerous laboratory and field studies have noted heightened sensitivity and adverse effects in birds [15–32]; mammals (cows and bats [33–38]); insects [39–54] bacteria/protozoa [55–61]; amphibians [62–67]; fish and turtles [68–82]; and in trees and plants [83–85], among many others.

Living organisms evolved in a matrix of environmental nonionizing electromagnetic fields, particularly the Earth's geomagnetic field. These natural fields are required to keep organisms well and living in harmony. For example, it has long been known that the geomagnetic field is needed to coordinate embryonic development and provide information for directional migration of insects and birds. These fields are relatively weak and also vary with location. For millions of years, living organisms lived and thrived in these fields. It is therefore logical to assume that man-made fields, which are unfamiliar to living organisms, could disturb their normal physiological functions. And this could happen at very low intensities of the unfamiliar fields. The proliferation of wireless communication systems in particular may pose a dangerous challenge to living organisms on Earth. In addition, there is the more difficult challenge that these novel EMF exposures do not allow living organisms to adapt or adjust since technology's signaling characteristics change rapidly as new technologies emerge and are constantly being developed.

Despite accumulating evidence, there has been a broad disconnect in environmental circles regarding the possibility that there may be serious consequences to this increasing cumulative EMF background from devices like cell phones, smart phones/tablets (iPods, iPads, Kindles), wireless Internet (WiFi, 2G, 3G, 4G, 4G LTE, and now the 5G "Internet of Things"), tower/antenna infrastructure needed to support vast wireless services, and the recent 'smart' grid/metering systems being built across industrialized countries by numerous utility companies, as well as the auto industry with anti-collision/remote-sensing devices now embedded in vehicles, among others. In fact, major national organizations like the Natural Resources Defense Council [86] and the Sierra Club [87] are active proponents of smart grid/meters and other wireless technologies in the name of energy conservation without considering EMF's biological effects. When organizations fail to address the growing database of EMF impacts, however, the result is the tacit and/or explicit approval to introduce whole new layers of EMF into every home and neighborhood, without a full examination of what potential consequences may arise. Federal and state regulatory environmental protection agencies in the U.S. are also proponents of smart grid technology [88] with no mention of possible effects to wildlife from EMF.

Reasons for this disconnect include the fact that many biologists are unfamiliar with the research that exists and/or lack the specialized knowledge of bioelectromagnetics needed to assess the published research. There is also an absence of familiarity — and often low comfort levels — with the cross-discipline of bioelectromagnetics, as well as a professional bias against or feelings of intimidation in biologists regarding the 'hard' sciences of physics and engineering which are the natural homes of technology. In fact, other than the embrace of technology to facilitate various research objectives, such as imbedding RFID microchips and/or attaching radio-transmitters to wildlife in order to track migration, behavior, and breeding patterns, biologists can seem incurious about the effects of environmental EMF on living systems. They appear more focused on technology's end point of what it can accomplish rather than how it actually functions as a biologically active entity.

At one time, electromagnetism was understood as integral to the natural world, and still is in many indigenous cultures and throughout Asia. But that knowledge was largely lost in Western cultures during the 20th Century during an era of over-specialization among the sciences, especially between the physics/engineering disciplines, which provide the underpinnings of EMF and energy propagation, and the biological sciences. This has created a chasm in which background levels of EMF continue to rise with each new added technology, yet little research is called for by environmentalists to determine what effects, if any, may be occurring in technology's path in myriad species as well as their habitats.

We are on the cusp of introducing a massive new level of exposures in the extremely high frequency range (EHF 30–300 GHz) never previously used in civilian telecommunications, although it has been used in military radar and some medical applications. This is the new 5G and Internet of Things [89], which uses complex phased millimeter waves that are smaller in wavelength, and therefore capable of reaching resonant match with some insect species [90], as well as disrupting crucial biological functions of numerous other organisms. In theory, this one technology has the ability to disrupt important ecosystems with broad-based effects to food webs. In addition, the top end of these ranges reach infrared frequencies, some of which are actually visible to other species — especially birds — and can impede their ability to sense natural magnetic fields necessary for migration and orientation [91]. Yet no environmental review in the U.S. has been recommended before buildout [89]. Other countries, especially in Europe, are being more cautious.

Historically, the U.S. was the leader in EMF health and environmental research, but now most of that work — and any accompanying public policy recommendations — are coming from Europe and elsewhere [92, 93]. There is virtually no public or private funding in the U.S. for ambient EMF research into the effects on wildlife, despite appeals from federal agencies such as the U.S. Fish & Wildlife Service [94–96] to study the effects of EMF on nonhuman species, and requests to the U.S. EPA and FCC to address exposures to wildlife [94, 96–100]. Industry funded research cannot be considered unbiased. There are no regulations specifically designed to protect wildlife from EMF. All regulations are intended for human health, even as most research has historically been conducted on animal models [94, 95]. The unintended consequences of this, in fact, may be that we know more about EMF effects to nonhuman species than we realize, making a large amount of information available for ecological integration and environmental utilization.

Review studies chosen: defining how low level spatial energy may translate to non-human tissue absorption

Studies on the biological effects of anthropogenic electromagnetic fields number in the thousands (101) and span more than eight decades. However, the majority of the early research studied EMF at intensities much higher than those of man-made EMF in the environment. We raise a fundamental question in this paper: Is low-intensity anthropogenic EMF in the environment capable of affecting physiological functions in living organisms? There is an abundance of studies in very low-level ranges to draw from (see Part 2: Supplements 1, 2, 3 and 4).

The primary focus of this review is on low-intensity far-field EMF exposures, i.e., at some distance for the radiating source, comparable to ambient fields that various species might repeatedly encounter. The studies we reference were chosen according to general significance and specific relevance to the species being discussed in both the text and Supplemental Charts.

There are literally thousands of studies going back to the 1930s (e.g., [90, 102–107]) that used test animals in controlled laboratory conditions to determine EMF effects on humans. To conduct such work directly on humans is ironically considered unethical at the same time we allow technology to flourish. Although most research has been conducted on rodent models such as mice and rats, one unintentional byproduct is that we actually know a considerable amount about how both high and low intensity EMF can affect species such as rabbits, dogs, cats, chickens, pigs, primates, amphibians, fruit flies, bees, Earth worms, various microbes, and yeast cells which have all been used as research models. Typically this work has not been understood as broadly germane to wildlife but in many instances it can be seen as important as illustrated throughout this paper.

The vast majority of the early research prior to the 1960s using animal models was done with high-intensity RFR [108–112] unlike most low-level ambient exposures today. The early work was specifically designed to determine gross thermal effects in humans at a time when electrophysiology and thermoregulatory mechanisms were not well understood. The more subtle non-thermal effects were of little interest then, although certainly known to exist [104–106, 113–115]. Additionally, signaling characteristics were unlike today's complex pulsed digital exposures. Thus the large body of early work is not included in this review except where appropriate for the general understanding of trans-species physiological patterns and for an overall understanding of how energy couples with living tissue which the early work helped delineate.

How government exposure standards relate to wildlife

To develop a sense of the potential relevance of ambient exposures to wildlife, it is necessary to briefly compare standards for human exposure. In the U.S., the Federal Communications Commission (FCC) is the agency authorized by law to regulate the communications industry and grant licenses for radiation transmission/reception/exposure from communications devices. FCC adopted exposure standards [116–118] that include both power density for ambient exposures from transmitting sources (generally defined as the rate of energy transmitted in space) and specific absorption rates (SARs) reflecting the dose rate of energy absorbed in tissue – both potentially relevant metrics to species in the wild.

For power density, the U.S. standards are between 0.2 and 1.0 mW/cm^2 and for SAR between 0.08 and 0.40 W/kg of human tissue. For cell phones, SAR levels require hand-held devices to be at or below 1.6 W/kg averaged over 1.0 g of tissue. For whole body exposures, the limit is 0.08 W/kg. In Canada and throughout most European countries that use the exposure standards created by the International Commission on Non-ionizing Radiation Protection [119, 120], the SAR limit for hand-held devices is 2.0 W/kg averaged over 10 g of tissue. Whole body exposure limits are 0.08 W/kg. At 100–200 ft (30.5–61 m) distances from a cell phone base station (i.e., an antenna or antenna array), a person or animal moving through the area can be exposed to a power density of 0.001 mW/cm^2 (i.e., 1.0 μW/cm^2). The SAR at such a distance can be 0.001 W/kg (i.e., 1.0 mW/kg) for a standing man.

For the purposes of this paper we will therefore define low-intensity exposure to RFR for power density of 1 μW/cm^2 or a SAR of 0.001 W/kg.

Many biological effects have been documented at low intensities comparable to what the population — and therefore wildlife — experience within 200–500 ft (61–152 m) of a cell tower [100]. These can include effects seen in *in vitro* studies of cell cultures and *in vivo* studies of animals after exposures to low-intensity RFR. Reported effects include: genetic, growth, and reproductive alterations; increases in permeability of the blood brain barrier; stress protein increases; behavioral changes; molecular, cellular, and metabolic alterations; and increases in cancer risk (see Ref. [100], Table 1).

Sensitivity to RFR and the setting of exposure standards for humans are mostly based on research data from rats (another mammalian species). In general, however, it is not valid to apply the same data to species more distant on the evolutionary scale, e.g., birds, insects, and trees. Realistically one should only use the available dosimetric data on each particular species to understand its RFR sensitivity, which is why this paper goes into such detail in Part 2 on EMF studies covering all taxa. However, exposure standards set by the FCC and others do not set limits with nonhuman species in mind.

Unlike field research, *in vivo* and *in vitro* laboratory studies are conducted under highly controlled circumstances often with immobilized test animals, typically at near-field, for set durations, at specific frequencies and intensities. Extrapolations from laboratory research to species in the wild are difficult to make regarding uncontrolled far-field exposures, other than for example to seek possible correlations with laboratory-observed DNA, behavioral, or reproductive damage. In the wild, there is more genetic variation and mobility, as well as variables that confound precise data assessment. In addition, there are complex variables like orientation toward the generating source, exposure duration, animal size, species-specific physical characteristics, and genetic variation that also come into play. Assessments for wildlife may vary considerably depending on numerous factors.

It is highly likely that the majority of wildlife species are constantly moving in and out of varying artificial fields. Precise exposure data, however, are difficult to estimate. Nevertheless, there is a growing body of evidence that finds damage to various wildlife species near communication structures, especially where extrapolations to radiation exposure have been made [15, 17, 32, 36, 37, 121–123].

The major question of whether man-made environmental EMF creates biological effects in wildlife species has now become urgent with 5G technologies and potentially more lenient allowances being considered by the major standards-setting committees at FCC and ICNIRP (see Part 3 on government exposure standards and new proposed changes).

Are we using the right physics model in standards setting?

From the beginning, there has been discussion regarding basic physics models used to determine manmade EMF effects to living systems [124–131]. The discussion has focused on classic models of photonic energy vs. wave energy in relationship to thermodynamic equilibrium. These are highly complex biophysics discussions beyond the scope of this paper in anything other than the broadest description. They are included here because of ramifications to the standards-setting models noted above and in Part 3, and particularly regarding effects to DNA discussed in Part 2. These factors are linked and apply to all species.

The electromagnetic spectrum is divided into ionizing and nonionizing bands. Classic quantum theory EMF photon models used to assess ionizing radiation [132] established long ago that ionizing radiation has enough inherent energy to knock electrons off orbits within atoms thereby causing structural cellular changes that are potentially carcinogenic and mutagenic due to DNA damage.

Those same models were then extrapolated to conclude that since nonionizing EMF does not have enough inherent power to displace electrons from atoms, it therefore cannot damage molecules such as DNA directly and certainly not indirectly. Historically, held against that one definition regarding inherent photonic energy, man-made nonionizing EMF has been presumed to be relatively innocuous beyond its ability to heat tissue and cause electrical shock. Most modern technology, including all current exposure standards and categorical exclusions, are based on that rationale, along with observed behavioral effects in animal models. Exposure standards have been strictly based on the easily quantifiable thermal hazards of tissue heating with safety margins built in [116–120]. While those safety margins vary between countries, the fundamental exposure mechanism assumption is not challenged.

What is left out of that narrow model, however, is the fact that all living things are fundamentally coherent electrical systems that interact in highly sensitive ways to minute levels of nonionizing EMF — sometimes at vanishingly low intensities far below current standards [3, 4, 100, 133–135]. This is particularly true of other species that have evolved to sense and use low level EMF fields in surprising ways (see Part 2).

In addition, much of biology is nonlinear. For example, a small amount of bee venom can create an outsized effect (anaphylaxis) in people allergic to bee stings. The weather is also nonlinear [136], e.g., a small perturbation in one part of the world can theoretically result in a major weather event like a tornado in a far distant area [137–139] (This is not to be confused with the so-called Butterfly Effect — or chaos theory of butterfly wing flapping affecting weather events in other parts of the globe, which has never been documented). Evidence has been mounting for decades that biology is more related to quantum states and resonant responses, not to the traditional linear equilibrium thermodynamic models currently used to define what biological effects *should* occur but often do not [127].

Also left out of that narrow linear model, which is based on a single photon acting on a single cell at a singular moment in time, is the fact that today's uses of EMF/RFR involve many photons acting in unison [140] in extremely complex ways such as in phased array technology. In other words, the entire thermodynamic model traditionally used to promote RFR safety regulation may not apply. It also excludes most recent research pointing to both cumulative and synergistic effects [141], and is unable to embody the complexity and totality of today's exposures, much less biological sensitivity in general.

Radiation is not a classical closed system in a thermodynamic equilibrium [142]. Yet it has been repeatedly put forth that devices and infrastructure must be safe because a single microwave photon, for instance, does not have enough energy to break a chemical bond. While that might be accurate for some sources of ionizing radiation, it may not hold true for lower frequency bands that operate within the classical wave limit of high photon densities where the energy of each photon is often irrelevant ([132], updated 2017).

Panagopoulous et al. [143–146] have written extensively on this issue, noting that man-made electromagnetic emissions are very different than what is found naturally in light spectra and the ionizing bands; that man-made EMF is not "quantized." They posit instead that nonionizing EMFs do not consist of photons but rather of continuous waves in high-density photon "packets" described in classical electromagnetism that interact very differently with biological systems than traditional models assume. It remains to be seen if this hypothesis gains wide acceptance.

If we are to truly shift to safer exposure standards, we need an accurate model based on biology, observation, and experimentation, not just physics theory. Typically when contradictory information that goes against popular assumptions reaches a sufficient critical mass, those assumptions eventually give way to more current knowledge. At present, there are no true biologically based standards in existence other than for a narrow range of heating effects. What we appear to have are dosimetry models that easily allow technology to function.

What may be the most accurate model has yet to be determined but may evolve into a new hybrid. It is already well known that distribution of absorbed RF energy in living tissue is not uniform, varying widely within cells and different body areas and organs, which is why SARs are generally averaged [142]. If nonuniformity can be more accurately factored in, subthermal interactions may make sense with or without new mechanistic models being delineated. What has become increasingly clear is that current models no longer withstand close scrutiny in the face of so much contradictory science begging for a more accurate assessment.

Increasing ambient background levels

Exposure to anthropogenic environmental RFR began little more than 100 years ago – an extremely short window from an evolutionary perspective. Amplitude modulation (AM) radio broadcasting was first introduced in the 1920s in the medium-frequency band (500–1,600 kHz), with both frequency modulation (FM) radio and television broadcast in the very-high frequency band (VHF 30–300 MHz) introduced in the 1930s. The end of World War II and advances in technology saw the rapid expansion throughout the 1950s with television stations operating in the ultra-high frequency ranges (UHF 300 MHz–3 GHz; [147]). Throughout the 1970s and 1980s, FM came to dominate commercial radio but AM never stopped broadcasting. From the 1980s through the present, large swaths of high-powered commercial radio infrastructure (50,000,000 W and more) has moved from terrestrial-based towers to satellite platforms, while low-powered FM stations (1,000 W) have increased their terrestrial footprint. There was another exponential increase from the mid-1990s through the present with the introduction of cell phone technology, also in the UHF bands, which has become by far the dominant RFR exposure today [148, 149]. Ambient RFR has since grown into a constant ubiquitous exposure in all industrialized nations from both terrestrial and satellite-based infrastructure.

Today's wireless applications are legion. The latest include smart grid/metering, 3G/4G LTE and now 5G telecommunications networks offering endless click-on "apps," TV/music/video downloads, e-books, photos in the "Cloud", voice, 'smart' homes and personal assistants like Amazon's Alexa, Apple's Siri, and Google Homes, WiFi/WiMax Internet connectivity and texting — all available from a cell phone. Then there are universal GPS systems that work off of satellites and a host of vehicle-mounted radar RFR collision avoidance devices built into vehicles to automatically stop, detect people or animals on the road, or park the vehicle without engaging the driver. Already out of prototype are driverless cars and trucks, as well as a new broadband wireless service that will introduce a new form of ubiquitous WiFi with antennas capable of transmitting in a 12,000 mi^2 (31,080 km^2) radius with a 62 mi (100 km) reach from one antenna. Also rapidly being built in many areas are augmented cell services via distributed antenna systems (DAS) and small cells mounted on utility poles targeted for urban as well as rural mostly RFR-free areas. DAS/small cells will host the 5G Internet of Things (IoT). Then there are new Homeland Security networks like GWEN and FirstNet, and emergency first responder systems like Terrestrial Trunked Radio (TETRA). All of these technologies use extremely complex signaling characteristics carrying a lot of information with potentially complex biological effects. Each new technology introduces a new level of environmental exposure. Just 70 years ago, very little of this existed and its consequences had been little studied or understood until now — a focus of this paper.

With the exception of some developing countries, 2G has largely faded from use in most industrialized nations where third generation (3G) is still operational for global system mobile communications (GSM), while fourth generation (4G) long-term evolution (LTE) has become increasingly popular for smart phones/technology using the universal mobile telecommunications system (UMTS). Gonzalez-Rubio et al. [150] found the highest environmental mean radiation values measured today are for GSM/UMTS/DCS, accounting for approximately 70 percent of outdoor environmental mobile communication exposures, although in some countries, like Turkey, the highest exposure still comes from radio and television broadcasts. First and second generation systems were very frequency specific (850–1,200 MHz) but today there are multi-frequency bands used within systems for up-and download frequencies from devices and base stations — e.g., GSM + UMTS 900 MHz, UMTS 2,100 MHz, LTE 800 MHz, LTE 2,600 MHz and GSM 1,800 MHz bands.

Prior to the telecom buildout in the early 1990s, a detailed sample of ambient baseline data existed based on a 1980 study by the U.S. Environmental Protection Agency

(EPA) which we can compare to today's rising exposures. In the first study of its kind, EPA researchers Tell and Mantiply [151] assessed background levels of broadcast signal field intensity of RFR for three years and obtained data at 486 locations distributed throughout 15 large U.S. cities. The data collectively represented 14,000 measurements of very high frequency (VHF) and ultra high frequency (UHF) radiation (used in television broadcast) in ambient environments with estimated exposure at 47,000 census districts within the metropolitan boundaries of those cities. At the time, ground-based broadcast signals from TV, AM radio and the then-increasing FM radio transmissions were the primary exposures. There were no cellular services, very few wireless devices, and very little satellite transmission compared to today.

The Tell and Mantiply [151] study found that 20 percent of the total U.S. population was exposed to time-averaged VHF and UHF broadcast radiation at a median level (i.e., the middle value of the highest and lowest measured values) of 0.0005 µW per centimeter squared (µW/cm^2). This represents a measurement of power density in a set space commonly used to delineate RFR field intensity. In Los Angeles, for instance, Tell and Mantiply [151] found the median level was 0.005 µW/cm^2 [152]. Their data also suggested that only 1% of the population, or about 441,000 people, were potentially exposed to levels greater than 1 µW/cm^2 — the safety limit recommended by the USSR which was 1,000 times more stringent than the U.S. safety guidelines in 1980. At the time, the researchers clearly found the data reassuring for the general population.

Tell and Kavet [147] revisited the subject in 2014 but specifically did not replicate or try to update the large 1980 study. Their goal was to determine if, and how, environmental levels could now be assessed, given the number and variety of RF transmitters used today. They tested in four small-to-medium size municipalities and found that the FM bands were still a major contributor to overall RFR exposure, but noted that over time, intensities in the VHF bands decreased while the UHF bands increased, reflecting the shift in the UHF bands for cellular use since 1980. European researchers, however, did not find FM to be a significant factor in today's exposures [153–155].

The original 1980 U.S. study cannot be replicated since the profile and nature of RFR has completely changed since that time. But an international team of researchers [149] measured EMF/RFR in 94 matched microenvironments in six countries, including Switzerland, Ethiopia, Nepal, South Africa, Australia and the Los Angeles area of the U.S. — one of the 1980 EPA sites — where they found a 70-fold increase in RF levels compared to the late 1970s measurements [152]. See below for more information on this study with cell phone infrastructure as the dominant contributor. Other than the one Sagar et al. [149] study, there are no current data on background radiation levels in the U.S. However, findings from U.S. and Canadian cities are thought to be comparable to studies coming from Europe which takes more interest in the subject in general as well as quantifying the continuously rising indoor and outdoor levels in particular.

Although cell service did not exist when the original 1980 EPA study was performed, cell technology now functions in similar UHF bands measured by Tell and Mantiply in 1980 [151]. Thus today's rising exposures can be assessed against the baselines noted back then. When the U.S. switched to digital television in 2008, it freed up spectrum "white space" previously used for analog TV transmission. That spectrum space is now allocated for 4G wireless Internet, and both the VHF and UHF bands will be used in expanding ubiquitous broadband/Internet service in rural areas. But the advent of digital technology, which simulates pulsed waves, significantly changed communications signaling characteristics, essentially allowing for a second universal transmission system to be built on top of the old analog signals [100]. This not only doubled overall environmental RFR exposures, it introduced a completely new kind. It was the global introduction of digital technology that facilitated the reshuffling of various RFR bands in the finite "real estate" of the electromagnetic spectrum. The introduction of 5G is now doing the same thing.

There is never enough spectrum to satisfy society's desire for it, a consequence of which is that we have now completely filled in most of the lower nonionizing bands with commercial and military use, and are branching into much higher frequencies using millimeter waves between 30 and 300 GHz for communications and other applications. The U.S. was the first country to approve the buildout of the fifth Generation (5G) communications, to date in the 28, 37, and 39 GHz ranges for 5G. The new 5G systems, using small cells and Distributed Antenna Systems (DAS) networks, are being built with antennas attached to buildings and powerline utility poles in very close proximity to the population, using extremely complex phased array signaling heretofore mostly used by the military. Neither these frequencies nor signaling characteristics existed for civilian use in 1980 and therefore constitute a whole new and novel environmental exposure since that early EPA review, along with all of the other wireless technologies since introduced. One thing is certain — exposure patterns are rapidly changing with each new technology development, far in advance of our biological understanding of the consequences.

With the advent of cell technologies in the mid-to-late 1990s, background ambient RFR exposures began to steadily increase, particularly — though not exclusively — in urban areas [18–149, 156–165]. Cellular infrastructure, though orders of magnitude lower in power density than that from broadcast facilities, has become vastly more ubiquitous and is placed much closer to the human population in both urban and rural areas [155].

Difficulties in assessing ambient exposures

Assessing ambient exposures, both indoors and outdoors, has frustrated researchers and regulators alike regarding how best to capture field exposure data. Should it be through computer simulation or actual field measurements? Variables in environmental assessments can be blindingly complex. Power density and distance from a generating source have traditionally been used as the surrogate for ambient exposures but those metrics can be imperfect given how RFR couples with the environment once transmitted, as well as the necessary factoring in of multiple overlapping sources today. Aside from distance and multiple sources, environmental assessments involve variables such as orientation toward the transmitting source, species, size, physical composition, the presence of metal objects, and topography, to name but a few [100, 155].

RF field strength falls off rapidly with distance from the transmitting source (Maxwell's inverse square law) but predicting actual exposures based on simple distance from antennas using standardized computer formulas is inadequate. Actual exposures are far more complex in both urban and rural environments to both humans and wildlife.

Contributing to the complexity is the fact that the narrow vertical spread of the beam creates a low RF field at ground level directly and at some distance below the antenna. As a person or wildlife species moves away from or within a particular field, exposures create peaks and valleys in field strength. In addition, scattering and attenuation alter field strength in relation to building placement, architectural composition, the presence of trees, soil type, and topographical features such as mountains and rock formations [166]. Power density levels can be 1–100 times lower inside a building, for instance, depending on construction materials used and antenna gain [155]. Exposures can differ greatly depending on the presence of conductive mediums like water or soil containing mineral salts with sodium, iron, copper, and zinc, among others. Exposures can be twice as high in upper floors of buildings as in lower floors [167, 168]. This would also apply to birds/bats/bees and other insects receiving higher exposures when flying at a lateral plane with transmitting antennas mounted on a tower or atop other structures.

Although distance from a transmitting source has been shown to be an unreliable determinant for accurate exposure measurements due to potential creation of RFR hotspots [155], the metric is nevertheless useful in some general ways. For instance, Rinebold [169] has shown that radiation levels from a tower with 15 non-broadcast radio systems will fall off to natural background levels at a distance of approximately 1,500 ft (457 m). This would be in general agreement with the lessening of symptoms in human populations living near cell towers at a distance greater than 1,000 ft (300 m; [170]). There is, of course, no adequate or reasonable way to restrict wildlife from approaching, defending territories, and/or living near towers, including birds nesting directly on or immediately near them.

Animal radiotracking devices: RFID and radio collars

In human populations, wearing or carrying personal dosimetry devices appears to be a promising area for capturing cumulative exposure data. But attaching such devices for the same purposes to wildlife is ill-advised given the amount of tracking equipment — RFID chips, radio collars, and radio/satellite implants — already globally deployed by biologists on/in numerous species of avian, terrestrial, aquatic and marine wildlife for study and media entertainment.

Arguably, important behavior and migratory findings have been discovered for myriad species from such use — including the deep dives of great white sharks (*Carcharodon carcharias)* and the 50,000+ mi (80,470 km) annual "figure eight" migrations of Arctic Terns (*Sterna paradisaea)*, among many others. One of the authors [171] radio-tagged black bears (*Ursus americanus*) in Michigan's Lower Peninsula for three years using receivers on the ground and in aircraft, investigating impacts from humans on bears, but at the time he was unaware of possible impacts from EMF. Aside from the newest telemetry technologies with safety features such as immediate break-away telemeter/collar options, lost collar signaling, and data-card download capabilities, there can still be difficulty removing such devices after attachment/insertion, if at all, or collecting such devices once an animal has died, or devices have slipped off and/or self-released in remote areas.

Most important, however, are data available that confound the additional exposures [172] from the devices themselves, which has not been broadly addressed by the wildlife community. Balmori [8] noted that radio transmitters attached to animals can induce negative effects leading to biased results. Documented effects from use of the devices include decreased productivity, behavioral and movement changes/patterns, increased energy expenditure, biased sex ratios, and reduced survival. Biologists often attribute such factors to the weight of the radio transmitter and/or associated devices. Also the type of attachment (harness, collar, leg clamp, glue, or implant) and where mounted (subcutaneous anchoring, tail, head, wing, etc.) are also considered factors in adverse outcomes. So far, however, EMF/RFR has largely been left out as a confounder, even as adverse effects were found to be significantly associated with the duration of RFR transmitter attachment [8, 173]. This parallels similar effects seen in all wildlife taxa from RFR as demonstrated throughout this paper. Balmori [8] posited that ironically scientists investigating animal orientation understand they must shield their labs to prevent anthropogenic EMF from distorting or skewing research results, yet they directly attach transmitters to species in field studies without considering the confounding exposure of the radio tracking devices themselves on behavior, movement, orientation, and even survival.

Barron et al. [173] published a meta analysis of effects to avian species from use of radio tracking devices. Up until this large analysis, studies were limited to investigations of either the type of device or to a single species. The researchers reviewed 84 studies to determine if devices had an overall effect on avian species, which aspects of behavior and ecology were affected, and importantly, if mere capture and restraint were factors. They found significant overall device-induced negative effects as well as negative effects from eight of 12 specific aspects — most markedly from increased energy expenditure and reduced likelihood to nest. In fact, devices negatively affected every aspect considered except flying ability. Effects were independent of sex, age, primary method of locomotion and body mass. They also found no evidence of greater effects from heavier devices, but breast-mounted and harness attached equipment increased device-induced behaviors such as preening. Device-induced mortality differed between attachment methods with anchored and implanted transmitters (which generally require anesthesia) showing the highest reported device-induced mortality rates. Harnesses and collars also had relatively high mortality rates, possibly due to entanglement with vegetation. They further noted that cumulative impacts from some aspects of attachment were substantial. For example, reductions in nesting propensity, success, productivity, and foraging can all decrease reproductive potential, while reduced foraging, body condition and flying ability, along with increased device-induced behaviors and energetic expenditure, are likely to increase bird mortality with use of transmitters. Also, transmitters on some birds indirectly reduced the fitness of untagged mates if they had to compensate for decreased parental activities by the bird with the transmitter. Capture and restraint however, as independent variables, were not found to be of consequence. The authors deduced negative effects were primarily due to transmitters. They concluded that transmitters and other devices could negatively affect birds and may bias resulting data. Unlike Balmori's 2016 review [8], this study did not specifically include EMF/RFR but it can generally be implied.

Deadly sarcomas have also been observed in tissue around RFID chips imbedded in research animals and domestic pets [174–182] which some attributed to the casing material. Also noted were severe metabolic changes in animals exposed to 915-MHz RFID [183].

Not all animals studied with RFID chips however showed adverse effects [184–187] although most of those tests were of short duration [174]. Very little follow-up data have been collected on possible effects to wildlife after radio collars or other tracking devices have been attached, or what contribution, if any, such devices may be contributing to ambient exposures. Much still remains unknown about the impacts of telemeters in and/or on wildlife.

One field study by Raybuck et al. [188] of Cerulean Warblers (*Setophaga cerulea*), a small long-distance migratory songbird, found a 35% lower return rate when geolocators (also known as dataloggers or geologgers) were attached than in control populations without geolocators. Geolocators are miniature devices with tiny computers that produce a small magnetic field and record light at regular intervals, usually two times per day, enabling general position to be calculated. Birds must be re-captured to gather the range of location information over time. Devices are externally attached to birds with thin straps under their legs or harnesses on their backs and are widely used by biologists to track avian migration over their full annual cycle of spring return, mating, nesting, fledging, fall migration and overwintering. While Raybuck et al. [188] found no negative effects from geolocators during the breeding season, the return rate of geolocator-tagged birds was lower than that of control birds (16 ± 5% vs. 35 ± 7%). They attributed the loss to increased weight from the devices, adverse weather patterns especially to species flying over large bodies of water, return to areas other than expected, and death. The researchers did not explore potential effects from EMF but noted that caution was warranted.

Most wildlife biologists do not factor in the effects of exposures from microcurrents in batteries/computers, RFID chips that do or do not transmit RFR, or GPS radio collars that transmit to satellites which can create independent exposures to wildlife and surrounding environments. Because there is so little information regarding effects of EMF exposure in tagged wildlife, the use of dosimeters carried by humans may provide better information about ambient exposures that may then be extrapolated to wildlife as they move in and out of different habitats. Wildlife should not be equipped with devices to assess ambient EMF, even in remote wilderness areas. Biologists should reconsider the abundant use of such devices as if there are no consequences or confounding of data gathered from them.

Human personal dosimetry devices: capturing ambient field measurements

A novel approach for capturing and quantifying ambient exposures for larger built areas was created by Estenberg and Augustsson [153] for the Swedish Radiation Safety Authority. It involved a car-based measuring system for estimating general public outdoor exposures. The complicated but carefully designed system enabled fast, large-area, isotropic spectral bandwidth measurements covering the frequency range between 30 MHz and 3 GHz. The method allowed the complete mapping of a town with 15,000 inhabitants and a 115 km (71+ mi) reach performed in one day. Areas chosen in Sweden represented typical rural, urban and city areas. The data sets consisted of more than 70,000 measurements performed between 8:00 AM and 6:30 PM local time. Results found median power density was 0.0016 μW/cm2 in rural areas, 0.027 $\mu W/cm^2$ in urban areas, and 0.24 $\mu W/cm^2$ in city areas. In urban and city areas, mobile phone base stations were the clear dominating sources with GSM and UMTS downlinks. The many factors that affected measurement results were discussed, most crucial being the variation of the actual field strength over time caused by sporadic, pulsed or moving transmitters or by multipath fading due to reflections from moving objects. The authors said "…a single measurement of the field strength from transmitters like the global system for mobile communication (GSM) base stations can be both under- and overestimated depending on whether the burst is caught by the measurement," but added that "the extensive amount of measurements in each data set still ensures that the median or mean power density within a measured district is robust." They also noted that due to the antenna mount on top of the vehicle, both over- and underestimates may also occur between transmitters closer to the ground vs. those placed at a higher level, but added that the repeatability of the measurement method and its ability to locate local hotspots is a positive outcome acquired from using this method. While there are many complexities involved with such mobile measurements, on top of the fact that no standard or existing solution for how such mobile measurements should be carried out yet exists, the approach summarized above nevertheless seems a good start.

Gonzalez-Rubio et al. [150] tried another creative mobile method by placing an EME Spy 140 inside the plastic basket of a bicycle, performing measurements in all 110 administrative (electoral) regions with homogenous population counts in the city of Albecete, Spain. The use of the bicycle allowed better access to all areas of those districts — especially those areas inaccessible with motorized vehicles. The authors specifically sought to correlate exposure levels to known fixed mobile base station sites but surprisingly found they did not correlate. Possible reasons given for the absence of correlation were: orientation of the base station antennas, building construction features, land topography, RFR deflection off of buildings and signal attenuation. Gonzalez-Rubio et al. [150] did not characterize what, if any, contribution to outdoor ambient levels were made by possible leakage from indoor RF transmitters or handheld devices but they did use domestic DECT phones as their control since DECT operates without involving links with outside base stations. Their results averaged three bands of mobile telephone antennas (GSM, Digital Combat Simulator [DCS], and UMTS) in the different regions and found variations of average intensity from 0.04 V/m (0.00042 $\mu W/cm^2$) to 0.89 V/m (0.21 $\mu W/cm^2$). The study points to the complexities of how RFR dissipates in the environment and that distance from a generating source is an unreliable metric. Calvente et al. [189] earlier found similar wide spatial variability outside of 123 residences in Southern Spain using the same variables, plus seasonal differences. Lahham and Ayyad [190] measured environmental RFR in Palestine using a personal exposure meter EME SPY 140. The total daily exposure from all radiofrequency electromagnetic field sources varied widely among participants depending on their location, the mobile network they use, their activities, and their mode of transportation, ranging from about 0.2 to 0.9 V/m, mainly from WiFi 2G, GSM900 uplink, GSM900 downlink, and FM broadcasting.

Using such mobile measurement approaches in expansive rural areas with road access, as well as fixed measurement sites in very remote locations, would better capture real-time exposures (including intermittent peaks from space-based networks capable of affecting wildlife) than computer simulations or personal dosimeter methods, although dosimeters carried or properly attached to trekking gear could gather pertinent information as well.

Measured levels: (for a table of studies, see Part 1, Supplement 1, "Environmental EMF measurements from around the world")

Prior to the widespread use of the UMTS network in one of the earliest ambient environmental studies after Tell and Mantiply [151], Hamnerius and Uddmar [191] investigated EMF/RF at 16 different sites in Sweden, both indoors and outdoors in city areas like bus stops. The maximum value observed was 0.3 μW/cm^2 and was dominated by GSM 900 MHz. An indoor measurement in an office revealed a value of 0.15 μW/cm^2, 96% of the power density coming from a GSM-900 MHz antenna 328 ft (100 m) away. Measurements in the vicinity of radio and TV transmitters resulted in values up to 0.23 μW/cm^2.

Frei et al. [157] used dosimeters to examine the total exposure levels of RFR in the Swiss urban population. What they found was startling — nearly a third of the test subjects' cumulative exposures were from cell tower base stations. Prior to this study, exposure from base stations was thought to be insignificant due to their low emissions and to affect only those living or working in close proximity to such infrastructure. But this study showed that the general population moves in and out of these particular fields with more regularity than previously expected. That assessment would apply to wildlife, too.

In Frei et al.'s [157] sample of 166 volunteers from Basel, Switzerland, study participants wore a dosimeter for one week and also completed an activity diary. Results found a mean weekly exposure to all RFR and/or EMF sources was 0.013 μW/cm^2. Exposure was mainly from mobile phone base stations (32.0%), mobile phone handsets (29.1%), and domestic digital enhanced cordless telecommunications (DECT) phones (22.7%). Mean values were highest in trains (0.116 μW/cm^2), airports (0.074 μW/cm^2), and tramways or buses (0.036 μW/cm^2) and were higher during the daytime (0.016 μW/cm^2) than the nighttime (0.008 μW/cm^2).

Another surprising finding of the Frei et al. (157) study implied that at the belt, backpack, or in close vicinity to the body in test subjects, the mean base station contribution corresponded to about 7 min of mobile phone use. In other words, ambient exposure from infrastructure alone was a significant contributor beyond one's personal choice to use individual devices. Frei et al. estimated that there had been a 10-fold increase in RFR outdoor radiation since mobile phone technology was introduced than when broadcast RFR had been quantified by Tell and Mantiply [151]. That trend has continued to be measured by numerous researchers today.

Joseph et al. [158] tried to make sense of the measured but differing results coming from various countries. Their objectives were to compare exposure levels and contributions from different sources in different European countries, including Belgium, Switzerland, Slovenia, Hungary, and the Netherlands, standardizing with the same personal dosimeter across countries. Results found that levels were of the same magnitude in all countries except the Netherlands, which was higher in all environments. There was no adequate explanation for these Netherland findings. Highest total exposures, like other studies, were in transport vehicles (trains, cars, buses) due to mobile phone handsets (up to 97%). Exposure in offices was higher than in urban homes. For outdoor urban environments, mobile phone base stations and handsets dominated the exposure.

Others have also looked at various ambient exposures relevant to this paper, including domestic pets and animals sheltering in indoor environments. Viel et al. [165] investigated varying exposures according to day of the week, concluding that the highest exposure to residents was on Sundays, primarily due to UMTS upload transmission and domestic DECT phone use. Markakis and Samaras [159] took indoor measurements with dosimeters in 40 different urban and suburban locations throughout Greece from 2010 to 2012 and found that RF from mobile base stations was dominant in workplaces and schools during the day, whereas in home environments dominant exposures at night were from DECT/wireless phones and computer networks. Bolte and Eikelboom [156] posited that body-worn dosimeters may both under- and -over estimate actual exposures depending on how they are worn and that a calibration determination should be made. They found in their study, using 98 subjects wearing dosimeters, that train stations had a high mean power density of 0.0304–0.0354 μW/cm^2, but that pubs or cafés where more people gathered using mobile phones and laptops in crowded quarters showed even higher exposures with mean exposures of 0.0526 μW/cm^2. That study was conducted in 2011 when GSM use was prevalent, before smart phones using UMTS proliferated. Similarly, Gryz and Karpowicz [192] measured indoor RFR in the Warsaw, Poland, metro. The major source of exposure was the 900 GSM system. Rowley and Joyner [160] found the mean exposure based on 173,323 measurements in 21 countries worldwide was 0.073 μW/cm^2 over a decade. Joyner et al. [193] did further assessments in Africa for seven years and found results consistent with the previous 2012 study. Rowley and Joyner [161] further analyzed a database of more than 50 million data points from the Italian fixed radiofrequency field monitoring network between June 2002 and November 2006 and found the mean value for mobile communications band was 0.047 μW/cm^2. They concluded that the findings of all three studies were consistent irrespective of continent, country, network operator or regulatory RFR exposure limit, leading to confidence that mean environmental levels from cellular mobile communications systems are less than 0.1 μW/cm^2. However, according to Estenberg and Augustsson [153], the methods of these last studies were not well described.

With the introduction of new communications systems and more mobile phone use, measured background levels, not surprisingly, increased. Urbinello et al. [162], who used dosimeters, found a combined 57.1% increase in total RFR levels in European outdoor areas studied within just one year from 2011 to 2012, representing a significantly altered environment over a very short period. They measured three European cities — Basel, Switzerland; Ghent, and Brussels, Belgium — in various microenvironments that included public transportation hubs (train and bus stations), indoor areas (airports, railways, shopping centers), and outdoor areas (residential, downtown and suburb). The highest RFR radiation occurred in public transportation areas which found combined measurement values from 0.32 (272 μW/m^2) to 0.59 V/m (862 μW/m^2). In all outdoor areas combined, values ranged from 0.0128 μW/cm^2 to 0.0446 μW/cm^2. The authors found that the strongest increase in outdoor areas was from communications infrastructure rather than from mobile handsets.

Ambient levels in urban areas can be quite site specific as demonstrated by Hardell et al. [154] when they investigated the Stockholm Central Railway Station, Sweden, using the dosimeter EME Spy 200, which scans 20 different radiofrequency bands from 88 to 5,850 MHz, in order to collect RF exposure data. A total of 1,669 data points were recorded with primary exposures found from downlinks. The median value for total exposure was 0.092 μW/cm^2. The mean total RF radiation level varied between 0.28 and 0.49 μW/cm^2 for each scanning survey (High mean measurements were obtained for GSM + UMTS 900 downlink varying between 0.17 and 0.21 μW/cm^2. High levels were also obtained for UMTS 2100 downlink; 0.044–0.16 μW/cm^2. Also LTE 800 downlink, GSM 1800 downlink, and LTE 2,600 downlink were in the higher range of measurements). Hot spots were also identified, such as close to a wall mounted antenna yielding over 9.55 μW/cm^2 and exceeding the dosimeter's detection limit. It should be noted that these are mostly transient exposures to humans moving through the station, although employees there are subjected to extended exposures as well as any urban wildlife in such environments. This work illustrates the high indoor levels experienced today, perhaps affecting pets, and contributing to rising background levels in general beyond a building's walls. It is also generally indicative of what wildlife would encounter moving near such installations in outdoor areas.

Hardell et al. [155] later investigated outdoor exposures in major areas of Stockholm, Sweden. RF levels were measured during five tours in Stockholm Old Town in April of 2016 using the EME Spy 200 dosimeter with the same 20 predefined frequencies noted above. The results were based on a total of 10,437 samples from which they found the mean total RFR level was 0.4293 μW/cm^2. Similar to their indoor study, the highest mean levels obtained were for GSM + UMTS 900 downlink and long-term evolution (LTE) 2,600 downlink at 0.16 and 0.13 μW/cm^2, respectively. The town squares displayed highest total mean levels, with one example at Järntorget Square measured at 2.4 μW/cm^2 (minimum 0.0257, maximum 17.33 μW/cm^2), compared with results in other areas near the Supreme Court that showed the lowest total exposure with a mean level of 0.0404 μW/cm^2 (minimum 0.002, maximum 0.4088 μW/cm^2). Street measurements surrounding the Royal Castle area were lower than the total for Old Town, with a mean of 0.0756 μW/cm^2 (min 0.00003, max 5.09 μW/cm^2).While their results were below the reference level of 1,000 μW/cm^2 established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), that high-exposure standard, Hardell et al. [155] said, is less credible since it does not take effects into consideration below thermal thresholds for tissue heating and are "…not based on sound scientific evaluation". Their highest measured mean level at Järntorget was 0.24% of the ICNIRP level. Numerous studies have found adverse health effects far below ICNIRP or other such guidelines [100].

The Hardell et al. [155] studies were not compatible with Tell and Kavet [147] that found FM bands were still a significant contributor to ambient RFR exposures. Indeed, Hardell et al. [154, 155] found FM orders of magnitude lower than the most current frequencies used for mobile telecommunications from all sources, the highest contributors were download frequencies from base stations at GSM + UMTS 900, UMTS 2, 100, LTE 800, LTE 2,600 and GSM 1,800 bands.

Similarly, in a study in Switzerland, Sagar et al. [194] reported RFR measurements in 51 different outdoor microenvironments in 20 different municipalities while walking with backpack-mounted exposimeters (ExpoM-RF) through five city centers, five central residential areas, five non-central residential areas, 15 rural residential areas, 15 rural centers, and six industrial areas. They too found infrastructure downlink exposures were most relevant in outdoor areas and that exposures increased with urbanity. They also found uplink exposures from cell handsets were only relevant within public transportation areas (trains, buses, trams), and that repeat measurements were highly reproducible within 2–4 months. Their reported mean RF-MF exposure (sum of 15 main frequency bands between 87.5 and 5875 MHz) was 0.53 V/m in industrial zones; 0.47 V/m in city centers; 0.32 V/m in central residential areas; 0.25 V/m non-central residential areas; 0.23 V/m in rural centers and rural residential areas; 0.69 V/m in trams; 0.46 V/m in trains; and 0.39 V/m in buses. The major exposure in all outdoor locations was from cell phone base stations (480% for all outdoor areas regarding power density).

In the most comprehensive review to date, Sagar et al. [148, 149] measured EMF/RFR in 94 matched microenvironments in six countries, including Switzerland, Ethiopia, Nepal, South Africa, Australia and the Los Angeles area of the U.S. They included both urban and rural areas and matched microenvironments in city centers, central residential, non-central residential, rural centers, rural residential, industrial, and tourist and university areas. This was the first study — ironically initiated by European researchers — to reassess one of the original EPA/Tell and Mantiply (1980) sites in the U.S. where they found a 70-fold (i.e., 7,000%) increase in mean ambient levels since that pioneering 1980 baseline data were recorded [152]. Cell infrastructure was the dominant contributor to the increase. Using portable RFR ExpoM-RF and EME Spy 201, walking with backpack-mounted devices at head height at a distance of 7.8–11.8 in (20–30 cm) from the body, or by driving a car with the devices roof mounted at 5.57–5.9 ft (170–180 cm) above the ground, they measured 94 outdoor microenvironments as well as within 18 public transport vehicles throughout the six countries. Measurements were taken for approximately 30 min while walking and about 15–20 min while driving in each microenvironment, with a sampling rate of once every 4 s (ExpoM-RF) and 5 s (EME Spy 201). They found great variability between countries, and regions within countries, with cell phone infrastructure being the major outdoor contributor to background levels today. Broadcast RFR was second. Total mean RFR exposure in various outdoor microenvironments varied between 0.23 V/m in Swiss non-central residential areas and 1.85 V/m in an Australian university area; and in buses in rural Switzerland between 0.32 and 0.86 V/m in an auto rickshaw in urban areas in Nepal respectively. Uplink RFR connections from mobile phone handsets was generally very small, except in Swiss trains and buses and other transport in sample countries.

Exposure in urban areas tended to be higher. Mean total RFR exposure for city centers was 0.48 V/m in Switzerland, 1.21 V/m in Ethiopia, 0.75 V/m in Nepal, 0.85 V/m in South Africa, 1.46 V/m in Australia and 1.24 V/m in the U. S. Corresponding downlink exposure was 0.47 V/m (Switzerland), 0.94 V/m (Ethiopia) 0.70 V/m (Nepal), 0.81 V/m (South Africa), 0.81 V/m (Australia) and 1.22 V/m (U.S.).

Compared to other countries, the U.S. had high exposure levels, ranging from 1.4 mW/m^2 in a non-central residential area of Los Angeles to 6.8 mW/m^2 in a less populated area within the center of the city near a freeway. The median total exposure to RFR across all eight outdoor microenvironments in Los Angeles was 3.4 mW/m^2. Switzerland, which has stricter exposure standards based on precautionary limits, had the lowest measured levels among all countries in the study.

What the above studies show are steady increasing environmental levels of RFR, primarily due to the introduction of mobile telecommunications. All of the above studies were conducted prior to the introduction of 5G which will greatly increase RFR background levels. The above RFR levels now ubiquitous in the environment are capable of affecting wildlife, as we report in Part 2.

Wilderness areas: cell towers in national parks; military training over the Olympic Peninsula

The studies cited in Part 1, Supplement 1 were conducted primarily in urban and suburban areas with limited attention paid to rural environments. No one has yet measured environmental RFR in heavily forested areas, likely because it is assumed exposures are negligible to nonexistant. Investigators are traditionally more curious about effects in human populations. However, cell towers now transmit into our deepest vast wilderness areas. In addition, sources of environmental RFR include space-based transmissions aimed back toward Earth for military and commercial use, universal satellite transmissions for GPS, airborne transient infrastructure exposures such as Google blimps [195] intended for rural areas, new satellite platforms for 5G Internet connectivity, drone technology, and military blimps used in both war zones and/or for security and surveillance in remote areas [196]. Such blimp "airships" create their own infrastructure by circling large areas or being positioned over a single point on the Earth's surface for both civil and defense applications. They are intended to provide mobile communications specifically in remote areas lacking land-based infrastructure, as well as during disasters when land-based infrastructure becomes dysfunctional. There may actually be more ambient RFR exposure in our remote regions than we have assumed.

In the U.S., the National Aeronautics and Space Administration [197] houses the Socioeconomic Data and Applications Center (SEDAC) and along with the Wildlife Conservation Society, and Center for International Earth Science Information Network (CIESIN 2018, [198]) at Columbia University, published "The Last of the Wild Project, Version 2, 2005 (LWP-2): Global Human Footprint Dataset (Geographic), v2 (1995–2004)." Under this program, which accumulated information between 1995 and 2004, NASA facilitated large global data sets to map the Human Influence Index (HII) regarding impacts on the environment intended for use in wildlife conservation planning, natural resource management, and research on human-environment interactions. In 1 km (0.6 mi) grid cells created from nine global data layers, the HII assessed human population pressure (population density), human land use/infrastructure (built-up areas, nighttime lights, land use/land cover), and human access (coastlines, roads, railroads, navigable rivers). CIESIN 2018 had not considered cell technology or transmission infrastructure as factors in wildlife conservation but it is an important new yardstick for future consideration.

A group of researchers [199] used cell phone coverage as a surrogate measurement for human influence on wildlife. In a case study of the vast Brazilian Atlantic forest, the researchers first demonstrated the correlation between cell phone coverage and the global human wireless footprint, using a database of over 23 million antennas. They then correlated the presence of 45 species of medium to large-size mammals and cell phone coverage for the forest. Researchers recorded 18,211 points of mammalian presence from in-person sightings, animal tracks, and remote camera images. They found wildlife probability of being present under cell phone coverage conditions was on average only 18%, with threatened species correlated far lower at 4%. In other words, species appeared to be avoiding such radiated areas. They further noted: "Most of the species showed a clear negative relationship with cell phone coverage, and threatened species presented an even lower probability, of at least 4% when compared with non-threatened ones. The strong positive relationship between cell phone coverage and the Human Footprint gradient at a global scale corroborated our *a priori* hypothesis that cell phone coverage can act as a surrogate for human presence, even in forested areas were no other footprint evidence is easily detectable." Large cat species, like the Jaguar (*Panthera onca*), and other threatened mammals appeared most affected due to their absence in areas studied. The authors did not take RFR into consideration or individual cell phones in use, only the ability to make a cell phone call.

There are many reasons for wildlife abandonment of such areas, including human presence itself as well as the increased cell infrastructure with accompanying lighting, noise, access roads, and powerline connections creating disturbed/broken habitat since the 2005 Human Footprint Index work noted above. Mining, logging, road building, dams, and other human perturbations can also result in wildlife abandonment. The Macedo et al. study [199] may be a useful new metric for detecting human interference along with what is currently being used in conservation planning and decision making. Factoring the introduction of increased EMF from transmissions, electrical conduit, and new ground currents in pristine areas may create important new exposures that wildlife may sense (see Part 2 for information on magnetoreception), also leading to wildlife abandonment. Areas without cell phone coverage may provide an important new indicator for areas needing enhanced protection before wildlife damage is done [200].

In 2016, Yellowstone National Park, Wyoming, had five towers that provided coverage into some of the remotest regions with additional coverage coming into the Park from towers on all of its vast perimeters [201]. There were proposals for Theodore Roosevelt National Monument, North Dakota, to put a 4G cell tower on the edge of one of the largest stretches of designated wilderness there. Mount Rainier National Park, Washington State, despite opposition, planned to install a 4G cell system at a visitor center that would send RFR deep into the surrounding wilderness [202]. Mount Rainier National Park also reviewed right-of-way permit applications from Verizon Wireless and T-Mobile to install wireless communications facilities within the Jackson Visitor Center in Paradise, an area completely surrounded by wilderness. There was already significant coverage to that federally designated wilderness from surrounding towers on its periphery.

Within a few short years, tower proposals increased exponentially as the U.S government, spurred by industry, made coverage into our remotest regions on federally owned public lands a priority. While many see this as necessary for public safety, others see it as an incursion into our last iconic wild sacred refuges. Grand Teton

National Park, Wyoming, is planning a sprawling network of cell towers within its boundaries to run along its 45 mi (72 km) length from which there may be significant signal penetration [203]. Yosemite National Park has seen six new towers permitted in recent years; Sequoia National Park has a new 138’ (42 m) tower; Mt. Rainier has new antennas on a visitor center; Grand Canyon has five new towers proposed along the canyon’s rim and Yellowstone is improving infrastructure that would increase capacity by 38 times [203]. The fact that the National Park Service is promoting a sweeping tech build-out of wireless sites — including small cells attached to existing buildings, towers, and enhanced WiFi hubs across many of the 62 national parks — is troubling. Grand Teton alone is slated for nine new tower sites in addition to two existing ones, as well as 60 mi (100 km) of new fiberoptic cable as backhaul. Glacier National Park, Montana, is planning at least four new towers; new towers are also planned at Olympic and Bryce Canyon, and Glen Canyon National Recreation Area. At Yellowstone, cell phone users can reportedly already get weak signals across significant portions of the 3,500-square-mile (9,065 km^2) Park’s backcountry [204].

While some of the early tower applications got minimal environmental review, the most recent build-outs have evaded regulatory oversight due to the National Park Service declaring specific proposals as categorically excluded, thus negating full National Environmental Policy Act (NEPA) review and implementation of an Environmental Impact Statement/EIS [204]. All of this was made easier by new FCC rules that limited local control, environmental review, and compliance with the National Historic Preservation Act. That FCC ruling has since been successfully challenged in Federal court by the Natural Resources Defense Council [205]. Potential effects to forest wildlife from RFR have not been included but should be part of all applications under NEPA review (see Part 3).

It is well known that signal propagation loss can be due to several factors, including antenna height, depolarization, humidity/rain, tree species, and other variables [206]. Any attempt to intentionally direct strong RFR signals into remote forested areas from ground-based transmitters is confounded by tree leaves that absorb, defract, and scatter signals in myriad directions due primarily to moisture content. Live trees with wet leaves absorb RFR most efficiently while dead trees without leaves absorb the least [207]. Some evergreen tree species also have resonant properties due to needle configurations.

5G is of particular concern regarding vegetation, especially if satellite-based. The technicalities of propagation loss in forest environments are therefore getting renewed attention since rural areas are targeted 5G-service regions for satellite use. The subject is also of interest in the development of wireless sensor networks using low-power transceivers in remote regions for scientific and surveillance purposes [206]. As far back as 1997, the U.S. Federal Communications Commission issued a report [208] on millimeter wave (MMW) propagation characteristics that included information on signal loss due to foliage. In the frequency range between 200 MHz–95 GHz, the foliage signal loss at 40 GHz at a penetration of 32.9 ft (10 m) — equivalent to one large tree or two in tandem — was determined to be about 19 dBm (a unit of measurement of EMF-RFR power levels expressed in decibels referenced to 1 mW). The report noted this is not a negligible signal loss value. The report also discussed signal attenuation effects due to rain, as well as water vapor absorption and oxygen, noting resonant frequencies below 100 GHz occur at 24 GHz for water vapor and at 60 GHz for oxygen. Hakusui [209] also investigated 60 GHz and O_2 absorption properties, as have others. There may be implications for climate change (see Part 3).

Clearer dosemitry standardization is being called for regarding 5G buildout in general, including in urban areas as trees can also affect 5G network designs there too. Government entities are now issuing reports on performance impacts to 5G networks from physical features not previously considered in network planning, including vegetation. The accumulation of new propagation data is now considered an essential prerequisite to 5G’s use of higher frequencies [210].

Unfortunately, such reviews are conducted as a component of cost-effective 5G buildout which will use the broadband spectrum spanning low-MHz-through-MMW, not as a tool to mitigate damage to flora which can be considerable. Ultimately the ‘greening’ of cities to offset impacts of climate change may prove incompatible with 5G. And there is no way to know at this point what 5G exposures from satellites may do to deep forested areas or to climate conditions given resonant factors involving water and oxygen molecules.

Military training over the Olympic National Forest and Olympic National Marine Sanctuary: a case study

One of the more dramatic intentional RFR incursions into pristine government protected forest lands was proposed in 2012 by the U.S. Department of the Navy’s Northwest Training & Testing program [211–213] to practice electronic war-gaming exercises in airspace over the Olympic National Park (a UNESCO World Heritage Site), Olympic

National Forest, and Olympic National Marine Sanctuary — all in or off Washington State. The Marine Sanctuary is the preferred key habitat for 29 species of marine mammals, including migrating gray whales. The National Park and National Forest are key habitats for two migratory bird species listed on the Endangered Species List — the Marbled Murrelet (*Brachyramphus marmoratus*), a diving seabird that nests in old growth forests, and the Northern Spotted Owl (*Strix occidentalis caurina*), which thrives only in quiet intact old-growth forest habitats. In fact, the entire Pacific Coast is on the critical Pacific flyway for migratory birds with an estimated one billion birds migrating along the pathway annually [214]. The Olympic National Park is widely seen as among the most beautiful wilderness areas on Earth where temperate rainforest lowlands are topped by majestic glacier peaks. Once designated the "quietest place" in America by the acoustic ecologist Gordon Hempton from the One Square Inch project [215–217], it is home to several plant and animal species that exist nowhere else on Earth.

The massive Navy project includes training over land, air, and sea as well as underwater, including offshore areas of northern California, Oregon, and Washington, the inland waters of Puget Sound, the San Juan Islands, many portions of the Olympic Peninsula, parts of Canada, and Western Behm Canal in southeast Alaska [218, 219]. The Navy has been conducting similar exercises — though nothing like the magnitude of the current upgrade — in this area for decades because it includes the complex environments that service personnel may encounter [220].

After significant community comment and a lengthy environmental review by experts opposing the proposal, the Navy released its Draft Supplemental Environmental Impact Statement (DEIS) calling for increased training and flights over Olympic National Park [221]. Potential adverse EMF effects from the upgraded exercises should not be underestimated. Manipulation of the electromagnetic spectrum has become a pre-eminent offensive and defensive war feature waged on land, in the air, and on/under the world's oceans. The Navy's exercises, conducted under the Northwest Training and Testing [222] program, has not given information (for stated security reasons) on all signaling characteristics, but for the overland activity they will be using frequencies between 4 and 8 GHz at a power output of 90–300 W, 45 min per hour, at thermal and nonthermal intensities, according to personal communications between the Navy and the U.S. Fish and Wildlife Service [223, 224].

While the Navy has operated the Naval Air Station on nearby Whidbey Island since World War II, the proposed upgrades could in time add up to 160 new "Growler" EA-18G supersonic jet warplanes — the loudest aircraft in the sky — to the Northwest Electromagnetic Radiation Warfare program [221, 222, 225]. Training exercises can fly as low as 1,200 feet (366 m) above sea/ground level (AGL) — well within the height of migratory and daily bird-flight movements of numerous avian species ranging from waterfowl, shorebirds, raptors, songbirds and more [226]. In studies conducted by USDA/APHIS Wildlife Services on movements of Osprey (*Pandion haldiaetus*) around Langley Air Force Base, Hampton, VA, Osprey frequently reached these altitudes on feeding and territorial forays and migrated at flight heights averaging 1,300 ft (396 m) AGL at speeds of around 35 mph (56 kph) [227].

On land, the exercises include mobile trucks carrying RFR emitters mounted 14 feet high along remote dirt roads that can reach elevated peaks/ridgelines deep within the forest to communicate with warplanes. There are also new fixed cell towers. There are 2,900 allowed exercises over wilderness and some communities, 260 days a year, lasting 8–16 h per day. There are additional training exercises over/under the water using sonar and lasers capable of causing adverse effects to fish and marine animals [228]; also see Part 2 for potential effects to aquatic mammals, fish, and turtles).

Growlers are equipped with extreme high intensity, multi-frequency detectors and radar jamming technology capable of thermal and non-thermal effects to humans and wildlife alike. One exposure estimate during exercises noted that spending more than 15 min in designated areas could result in thermal damage [213]. Mid-air two-way training involves RFR directionally aimed from plane-to-plane, ground-to-air, and air-to-ground. Despite environmental reviews which were limited in scope there is no clear understanding of what this may do to the environment [228].

After a long review process required by the National Environmental Policy Act [229], the Navy released a final Environmental Impact Statement (EIS) and an Overseas Environmental Impact Statement (OEIS) [230] but the final findings, which remained the same as in earlier drafts, had been widely criticized as inadequate for its broad findings of "no harm," grossly under-estimating present and proposed activities, improperly segmenting activities to minimize scrutiny of collective substantial impacts in violation of NEPA which does not allow such segmentation, and ignoring potential noise effects [225, 231–233]. In March 2017, the U.S. EPA requested more information on potential noise effects but mentioned nothing about EMF effects to wildlife or humans. The Navy's DEIS minimally addressed EMF but repeatedly adhered to parsed language from the Endangered Species Act, noting that electromagnetic devices used during training may affect — but are *not likely to adversely affect* — the various species reviewed, primarily marine animals and some birds. Their conclusions remained the same in 2020 [234].

The U.S. Fish and Wildlife Service (FWS) concurrence [235, 236] was despite former agency career scientists requesting more caution [212]. Extensive attention was paid to the endangered Marbled Murrelet known to nest there, and the Northern Spotted Owl which was said to be shielded from EMF exposures under the forest canopy. Forest canopies, however, are easily penetrated by RFR even though trees are efficient attenuators [237, 238]. U.S. FWS noted that clear line-of sight transmission would limit wildlife exposures; that only birds in flight over the tree canopy could be affected. They found Marbled Murrelets could be intermittently exposed to RFR during flight but that Spotted Owls under forest canopies are not. They then concluded that the effects of brief, intermittent exposures to 4–8 GHz would likely be insignificant to in-flight birds. They discounted physical effects from tissue heating and/or burns [235].

By most measures, the Navy and U.S. FWS conducted poor reviews [233]. Although they did include several bird/wildlife studies [9, 15, 20, 22, 95, 239, 240], they dismissed them for various reasons. Only Bruderer et al. [241], at approximately 9 GHz exposure, was deemed applicable but it found no effects to birds' flight patterns in the presence of radar. Other uninvestigated research that could have applied included in-field RFR behavioral studies [17, 242]; mortality [134, 243, 244]; reproductive outcomes [16, 18]; and bat insect foraging [36] in the presence of radar. Presence of exogenous RFR could also disturb the sensitive magnetoreception of many species, affecting bird and insect migration patterns.

There continues to be no monitoring for EMF/wildlife effects over the wide on-land/over-sea training areas, despite the fact that the final Navy EIS/OEIS noted sources of in-air electromagnetic exposures from a single ship would operate continuously across a wide range of frequencies from 2 MHz to 14,500 MHz, with maximum average power between 0.25 and 1,280,00 W [234]. A publication from one of the authors of this paper [96] was used to justify program approval based on birds' natural avoidance behaviors when physical discomfort is caused, such as thermal heating. The Navy and U.S. FWS conclusions that no long-term or population-level impacts to birds will occur may not be supportable.

Although the military is by law allowed use of public lands for training, this deep incursion into pristine protected public lands in Washington State sets a bad precedent. The Navy's project is possibly in violation of federal statutes including U.S. Code 475 (LII, 2018), which outlines the purposes for which national forests were established and how they are to be administered. The U.S. Forest Service, nevertheless, granted the Navy a preliminary Special Use Permit. The National Parks Conservation Association (NPCA) had submitted a Freedom of Information Act (FOIA) request in 2016 to the Navy regarding Growler noise and environmental disruption. After the Navy repeatedly withheld critical FOIA information on the aircraft overflight training, NPCA sued the Navy in mid-2019 for that information's release. As of this writing, no federal court decision has been reached on the FOIA lawsuit.

In 2020, after the upgraded training exercises commenced, noise levels from the flyovers were found by Kuehne et al. [245] at 110 ± 4 dB re 20 μ Pa rms and 107 ± 5 dB A, to exceed known thresholds of behavioral and physiological impacts for humans, as well as terrestrial birds and mammals. Even underwater sound levels from the aircraft, at 134 ± 3 dB re 1 μ Pa rms, exceeded thresholds known to trigger behavioral changes in fish, seabirds, and marine mammals, including endangered southern resident killer whales (*Orcinus orca*). Although soundwaves are not strictly considered EMF, their inclusion here illustrates adverse anthropogenic effects due to inadequate regulatory oversight.

The Navy has been allowed to introduce the loudest aircraft in the sky into one of the quietest places in the U.S. with accompanying complex close-range EMF. With the exception of this high-intensity RFR training program in Washington State, most of the studies cited throughout these consecutive papers found ambient exposures were below any international guidelines for humans but well within the range seen to affect flora and fauna.

New technologies: 5G and the internet of things (IoT)

We are on the cusp of introducing a dense and expansive new layer of RFR into the global built-environment and throughout rural regions using Extremely High Frequency (EHF) millimeter waves (MMWs) between 30–300 GHz for Fifth Generation (5G) telecommunications. On the electromagnetic spectrum, this band lies between the super-high-frequency (microwave) bands and optical (infrared) bands.

5G is a wireless network of machine-to-machine communications called the Internet of Things (IoT) that will allow remote communications between a host of devices and appliances, such as between cell phones and refrigerators, lights, furnaces, entertainment units, security systems for homes and businesses, medical appliances, driverless cars, and every imaginable and "… yet-to-be imagined …" thing [89]. Some of these applications are already available over 4G LTE for 'smart' home environments that consumers can remotely control via their own WiFi systems. Others are programmable, like thermostats, and require no real-time human interaction beyond setup. Since any one of these wireless portals opens access to all others, including computer systems as well as wireless phones, security is a serious concern. Numerous incidences of hacking through smart domestic appliances like refrigerators and baby monitors have already been reported [246]. While the above description is for 5G consumer applications, 5G is primarily for business data accumulation and uses like Internet/consumer tracking.

Because 5G functions in much higher frequencies with shorter wavelengths than previous iterations of wireless communications, a vast new layer of infrastructure requiring millions of new antennas placed very close together — by some estimates every 2–5 houses apart — will be needed to provide ubiquitous coverage. The reason for this densification is because MMWs are easily attenuated and diffracted by buildings, trees, other vegetation, topography and weather conditions (including rain), as well as the shift to higher frequencies because there is little room left in the ultra high frequency (UHF) microwave bands currently used for telecommunications between 800 MHz and 2,250 GHz. 5G networks work mostly off taller cell towers (macro cells) via Distributed Antenna Systems (DAS) and/or small cell antennas (micro cells) attached to buildings, powerline utility poles and municipal lampposts in very close proximity to the human population. Fiberoptic cable provides the backhaul between antennas. Environmentally safer 100% wired fiber-to-the premises networks and 5G wireless applications can no longer be kept separate. Where fiber networks exist, wireless small cells will piggyback onto them [247, 248]. At 28–95+ GHz, that frequency range is significantly higher than the 2.45 GHz used in today's telecom or in products like microwave ovens. In fact true 5G is designed to be an ultrawide-broadband network that can encompass a wide swath of frequencies between the low MHz range and eventually 95+ GHz. In addition, there are general categorizations for low (<1 GHz), mid (between 1 and 6 GHz), and high (>24 GHz) bands that may be used in various iterations of 4G LTE and eventually 5G [247].

The U.S. was among the first countries to approve the buildout of 5G with licensing auctions in the 24, 28, 37, 39, and 47 GHz ranges thus far with higher bands extending above 95 GHz allocated for future use [89, 249, 250]. As of this writing, there has been limited buildout of true 5G networks — some systems advertised as 5G are really enhanced 4G LTE — in select U.S. cities and on military reservations [251]. Other countries have leapt ahead with 5G, including China, South Korea, the United Kingdom, Italy, Spain, Germany, Ireland, Australia, and The United Arab Emirates [252]. But overall, broad 5G buildout has been somewhat slow in coming for technical, financial, human health, and societal reasons. Some countries in Europe, as well as Canada and Russia, are being cautious [92, 93, 253]. There has also been large-scale consumer resistance in many countries and numerous petitions by professionals calling for a slowdown until more is known about the impacts of 5G [254]. Space-based 5G networks are also being built, beaming MMWs back toward Earth from thousands of new mid-and-low Earth orbiting satellites.

All of this development has been done with virtually no environmental consideration or review [89, 249]. Beginning in 2017, the U.S. Congress passed several 5G-enabling bills but significant local and state resistance arose to what is widely seen as a giveaway of public utility corridors (where most ground-based 5G antennas will be mounted) to private enterprise without adequate compensation or local zoning review [255]. Nevertheless, industry pressure has successfully influenced U.S. legislators and the FCC to bypass local review for environmental and historical significance regarding infrastructure siting. No environmental review in the U.S. was recommended before buildout [89]. Indeed, the FCC streamlined local and state review for environmental effects and historic significance against overriding federal legislation requiring such reviews under the National Environmental Protection Act (NEPA) and the National Historic Preservation Act (NHPA). But the Natural Resources Defense Council challenged that ruling in court and won [205], thus preserving NEPA for now (for more, see Part 3).

Military use of millimeter waves

Millimeter waves have been used by the U.S. military since the early 1980s [256, 257]. Millimeter waves are so-called because the wavelengths are smaller (about 1/8th inch or 3.2–5 mm long) than microwaves used in cell phone/WiFi technology at 2.4 GHz (6.3 inch or 12.5 cm). The smaller the wavelength, the higher the energy density per wavelength unit. In this case, with MMW it is about 25 times higher than with cell technology microwaves [258]. This means MMW are capable of resulting in significant damage throughout the biome, including possibly to all flora and fauna present, but not due to wavelength alone. The multiple biological effects from intense energy absorption at very small wavelengths, e.g., in human skin cells or any thin-skinned species, and especially in insects which lack efficient heat dissipation, may cause intense heating with concomitant cellular destruction and organism death. Many of these effects are independent of power density, and therefore not covered by current regulations which are power-density and/or SAR-based. There is, however, a provision in the new ICNIRP standards that makes MMW and 5G subject to dosimetry measurements in power density in the higher frequencies, not SAR (see Part 3).

Millimeter waves have never been used before for civilian telecommunications although the U.S. military has used MMWs at 95 GHz for crowd control and perimeter defense in a skin-heating directed-energy technology called "Active Denial" as part of the U.S. Non-Lethal Weapons Program [259]. The military deployed MMW technology in 2006 in Afghanistan and in the second Iraq war with an Active Denial weapon mounted on Humvees. Named Project Sheriff, it is a Raytheon-designed device in their Silent Guardian Protection System. Biological effects have been researched for decades at the Directed Energy Bioeffects Division, Human Effectiveness Directorate, Air Force Research Laboratory at Brooks Air Force Base in San Antonio, TX [260], as well as other military laboratories and programs like the Defense Advanced Research Projects Agency [261]. Unfortunately, most of this tax-payer-funded research is classified even as there is a critical public need-to-know with the 5G buildout, the proliferation of media misinformation, and burgeoning conspiracy theories. Other countries, like Russia and China, have adopted directed energy technologies too.

Active Denial weaponry was originally developed by the military for large roof-mounts on military vehicles but much smaller mobile units have now been deployed in moving aircraft and ground vehicles. Raytheon has developed a smaller version of Silent Guardian for use by non-military law enforcement agencies and other security providers. That system is operated with a joystick plus an aiming screen that can target people over 820 ft (250 m) away. One Los Angeles county jail has installed a unit on their ceiling. Such systems base their response on an intolerable heating sensation in the skin with the accompanying instinctive avoidance behavior. The sensation supposedly stops quickly when the beam is turned off or a person moves out of range. However, several reports note that numbing sensations can last for hours and blistering has occurred [262].

The U.S. military continues to develop its non-lethal weapons program, announcing in 2019 a $30.8 million (U.S. dollars) contract to General Dynamics for research on directed energy systems, bio-mechanisms, human effectiveness analysis, and integration under the U.S. Air Force's Directed Energy Bio-effects Research (DEBR) program. The aim is to quantify the effects of directed energy weapons using optical, RFR, and MMW radiation, as well as electromagnetic propagation characteristics [263]. It remains to be seen if this information will be declassified or if any will be applied to impacts on wildlife.

Russia has taken a different approach using lower frequencies for 5G, and set up monitors in Moscow to measure/study 2G through 5G effects on citizens under The Izmerov Research Institute of Occupational Health. The Institute will send results to the Ministry of Health and the Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing for the final determination regarding human safety standards [264]. There are no similar epidemiology studies being conducted in the U.S. and it remains to be seen if Russia will release their findings or even the parameters of their research.

Adaptations for civilian telecommunications for 5G in frequencies lower than 95 GHz are theoretically below thermal power intensities [111, 265]. However that does not mean serious concerns are unfounded. Recent updates to the ICNIRP standards propose allowances that will permit exposures to exceed thermal thresholds under certain circumstances (see Part 3). This is a region of the electromagnetic spectrum that has had little attention from the civilian professional groups that set exposure standards, partly because few consumer devices have operated in this frequency range before and devices already using MMW have traditionally had little applicability to high levels of human exposure [111, 265]. All of this is about to change. The new 5G networks also use extremely complex signaling characteristics that are not well studied or understood, including beam steering, massive MIMO (multiple-input, multiple-output) and phased array that have unique biologically active properties.

Some assume minimal and/or reversible risk in humans due to MMW shallow energy penetration, short wavelength, and induced quick fleeing behavior. Damage to wildlife is considered collateral, if considered at all.

Millimeter waves and biological effects

It has been known for over 100 years that MMW are highly biologically active [266–268]. As noted in Pakhomov et al. [269], coherent oscillations in this frequency range are virtually absent in the natural electromagnetic environment, indicating important potential consequences since living organisms could not have developed adaptive mechanisms to MMW during evolution and development, unlike in other areas of the electromagnetic spectrum. In addition, Golant [270, 271] and Betzkii [272] noted that some specific features of MMW radiation, plus the absence of background MMW external "noise," may indicate this band is important for communication within and between living cells. In other words, there may be a reason for the absence of MMWs in the background environment, and more importantly, because of that absence, living cells may have developed their own dedicated uses in that area of electromagnetic spectrum.

Betskii et al. [273] also pointed out that MMW radiation is virtually absent from the natural environment due to strong absorption by the atmosphere and the fact that MMW waves are readily absorbed by water vapor. The authors elaborated on the hypothesis that low-intensity MMW may have broad nonspecific effects on biological structures/organisms and that vital cell functions may be governed by coherent electromagnetic EHF waves. Their results included alternating EHF/MMWs used for interaction between adjacent cells, thereby interrelating/controlling intercellular processes in the entire organism. The above authors [269–273] noted that while these ideas are theoretical, they may plausibly explain the high MMW sensitivity observed in biological subjects.

Chronic long-term, low-level ambient exposures to MMWs are yet to be studied but some extrapolations can be made based on the extensive database that does exist. These higher frequencies may also have unique biological effects to nonhuman species due to size differences, distinctive physiological characteristics, and diverse habitats. Both aqueous environments and the high water content in living organisms may make MMW exposures particularly unique due to the way MMWs propagate though water with virtually no impedance [274–279]. Also, unlike RFR at lower frequencies, in the EHF/MMW range a small power density can lead to a very high local SAR due to the concentration of energy in a small volume in an exposed organism. Heating may be inevitable [280].

Millimeter wave energy, with the very small wavelengths associated with such high-frequency radiation, couples maximally with human skin tissue. Because of this efficient skin coupling, beneficial/therapeutic effects have been known for decades, especially in former Soviet Union countries, from short-term MMW exposures, while longer exposures have produced potentially adverse effects [258, 269, 281, 282].

In humans, Gandhi and Riazi [257] estimated that 90–95% of incident energy of MMWs can be absorbed in human skin with dry clothing, with or without an air gap. Because of sub-millimeter depths of penetration in skin tissue, superficial SARs as high as 65–357 W/kg are possible. Eyes are of particular concern. MMW frequencies penetrate less than 1/64 of an inch (0.4 mm) — about the thickness of three sheets of paper. Except for adult human eyelids and exposure to infants, MMWs supposedly avoid the skin's second dermal layer [265].

However, skin tissue contains critical structures like blood and lymphatic vessels, nerve endings, collagen, elastin fibers, and hair follicles, as well as sweat, sebaceous and apocrine glands. MMW effects to skin have been found to be considerable in glandular tissue with multiple cascading effects throughout the human body even without deep penetration [283]. Effects to lipid cells decreased cell membrane water permeability, with partial dehydration of the cell membrane, and cell membrane thickening/rigidity was seen at 52–72 GHz at incident power densities of 0.0035–0.010 mW/cm^2 [284]. Human sweat ducts in particular may act as coiled helical antennas and propagate MMW energy as a waveguide at these higher frequency exposures causing uniquely higher specific absorption rates [285] not reflected in today's standards. A significant new look at the 5G standards is clearly called for.

Betskii et al. [273] noted that with MMW exposure, skin presented five mechanistic entry points capable of affecting an entire organism. For example, they noted that because MMWs penetrate human skin to a depth of 300–500 μm and are almost completely absorbed in the epidermis and the top dermis, MMWs are therefore capable of directly influencing central nervous system receptors. These include mechanoreceptors, nociceptors, and free nerve endings; APUD cells such as diffuse neuroendocrine cells, mastocytes, and Merkel cells; and immune cells such as T-lymphocytes. In addition, they noted that MMWs produce direct effects on the microcapillaries and other biologically active cells. These five "entry gates" can determine both therapeutic and/or adverse effects as a novel trigger to basic regulatory systems, involving the complete organism. Depending on the parameters of the MMW stimulus and the functional state of the subject exposed, effects produced can be both nonspecific and specific.

In their review, Betskii and Lebedeva [286] also discussed MMW effects on human and non-human models as dependent on exposure sites and noted such effects were highly frequency sensitive. They also described the complex hypothetical mechanism that stochastic resonance (see Part 2) may play in very sensitive water-containing biological species to very-low intensity EMF (in µm ranges) based on the generation of intrinsic resonance frequencies by water clusters that fall between about 50 and 70 GHz. When biological species are exposed to extremely weak EMF at these frequencies, their water-molecule oscillators lock on to the external signal frequency and amplify the signal by means of synchronized oscillation or regenerative amplification. Since MMWs pass through aqueous media almost without loss but also with high absorption, in the process they are capable of deep penetration involving internal tissue and organ structures. The researchers summarized what is known about effects of MMWs. These included a long list of findings in human and non-human models, e.g., EHF's strong absorption by water and aqueous solutions of organic and inorganic substances; affects to the immune system; changes in microbial metabolism; stimulation of ATP (adenosine 5′-triphosphate) synthesis in green-leaf cells; increases in crop capacity (e.g., pre-sowing-seed treatment); changes in certain properties of blood capillaries; stimulation of central nervous system receptors; and the induction of bioelectric responses in the cerebral cortex. Biological effects depend on exposure site, power flux density and wavelength in very specific ways. In addition, low-intensity MMWs were detected by 80% of healthy people, but perception was asymmetrical. Peripheral applications were found to affect the spatiotemporal organization of brain biopotentials, resulting in cerebral cortex nonspecific activation reactions. MMW-induced effects are perceived primarily by the somatosensory system with links to almost all regions of the brain. The authors also discussed water and aqueous environments' unique role on MMW effects, which induce convective motion in the bulk and thin fluid layers and may create compound convective motion in intra- and intercellular fluid. This can result in transmembrane mass transfer and charge transport can become more active. EHF can also increase protein molecule hydration.

In wildlife, especially small thin-membrane amphibians like frogs and salamanders, even at penetration less than 1/64 of an inch (0.4 mm), deep body penetration would result. Effects to wildlife could be significant. In some insect species that would equal deadly whole body resonance exposure [90]. In a recent study, Thielens et al. [287], modeled three insect populations and found that a shift of just 10% of the incident power density to frequencies above 6 GHz would lead to an increase in absorbed power between 3 and 370% in some bee species, possibly leading to behavior, physiology, and morphology changes over time, ultimately affecting their survival. Insects smaller than 1 cm showed peak absorption at frequencies above 6 GHz. In a follow-up study of RFR, Thielens et al. [288] used *in-situ* exposure measurements near 10 bee hives in Belgium and numerical simulations in honey bee (*Apis mellifera*) models exposed to plane waves at frequencies from 0.6–120 GHz – frequencies carved out for 5G. They concluded that with an assumed 10% incident power density shift to frequencies higher than 3 GHz, this would lead to an RFR absorption increase in honey bees between 390 and 570% — resulting in possible catastrophic consequences for bee survival.

In birds, hollow feathers have piezoelectric properties that would allow MMWs to penetrate deep within the avian body cavity [26, 27]. 5G's complex phased MMWs may also be capable of disrupting crucial biological function in other species. In theory this one technology has the ability to disrupt critical ecosystems and the living organisms within them with broad effects throughout their entire food webs. In addition, the top end of these ranges reach infrared (IR) frequencies, some of which are actually visible to other species, especially birds, and could impede their ability to sense natural magnetic fields necessary for migration [91] as well as other crucial aspects of avian life.

There were several early reviews of MMW studies beginning in the 1980s that examined subjects like theoretical modeling and possible interaction mechanisms [289–293]. Pakhomov et al. [269] also published an extensive review of MMW research, examining over 300 former Soviet Union Block studies, which had focused primarily on therapeutic/clinical applications of MMWs, as well as about 50 studies from other countries that had focused on public health effects. They were looking to close the gap between those very different orientations between countries. Much of the Soviet Block research had never previously been seen by Western scientists and because of the language barrier, as well as differences in test protocols, measurements, and reportage styles, Western scientists often dismissed Russian research as incomplete. The large review included effects from low-intensity exposures (MMWs 10 mW/cm^2 and less) in everything from molecules, microbes, and cells, to the unique qualities of water, resonance, and MMW therapy. Studies covered dosimetry/spectroscopy issues, as well as cell-free systems, cultured cells, and isolated organs in animals and humans. Pakhomov et al. [269] found effects to cell growth/proliferation, enzyme activity, genetic structures, excitable membrane function, peripheral receptors, and other biological systems. In human and animal models, local MMW therapeutic applications stimulated tissue repair and regeneration, alleviated stress reactions, and facilitated recovery from a wide range of diseases. Former Soviet Block countries claim to treat approximately 50 diseases with MMW. The reviewers reported that many effects could not be readily explained by temperature changes alone.

Some of the animal models with potential significance to wildlife cited in Pakhomov et al. [269] included: yeast: *Saccharomyces cerevisiae*, [294–298]; *Candida albicans* [299]; *barley seeds* [300]; protozoans *Spirostum* spp. [301]; blue-green algae *Spirulina platensisby* [302]; midge *Acricotopus lucidus* [303]; *Escherichia coli* [304]; rats [305]; frog/nerve cells [306–310]; antibiotic resistance to *Staphylococcus aureus* [311] and others.

Of particular challenge to the popular wisdom that MMWs are “safe” due to superficial skin penetration, is the research on peripheral nerve receptors cited in Pakhomov et al. [269]. Akoev et al. [312] studied MMW effects to the specialized electroreceptor cells called Ampullae of Lorinzini in anesthetized rays and found that the spontaneous firing in the afferent nerve fiber from the cells could be enhanced or inhibited by MMWs at 33–55 GHz continuous wave (CW). The most sensitive receptors increased firing rates at intensities of 1–4 mW/cm^2, which produced less than a 0.1 °C temperature increase. Higher intensities (10 mW/cm^2 and up) evoked delayed inhibition of firing, indicating that the response became biphasic. The authors emphasized they were not observing just a MMW bioeffect but rather a specific response to that frequency range by an electro-receptor cell.

Work also cited in Pakhomov et al. [269] regarding similar nerve cells/pathways and MMW-induced arrhythmia included a paper by Chernyakov et al. [307] where they observed induced heart rate changes in anesthetized frogs from MMW irradiation to remote skin areas. This suggested a reflex mechanism possibly involving specific peripheral receptors. Later, Potekhina et al. [313] similarly found that certain frequencies from 53–78 GHz band (CW) effectively changed the natural heart rate variability in anesthetized rats when applied to the upper thoracic vertebrae for 20 min at 10 mW/cm^2 or less. MMWs at 55 and 73 GHz caused pronounced arrhythmia: the variation coefficient of the regular rhythm (R-R) interval increased 4–5 times while exposure at 61 or 75 GHz had no effect, and other frequencies caused intermediate changes. Skin and whole-body temperatures remained unchanged. Similar frequency dependence was observed in additional experiments with 3 h exposures. However, approximately 25% of experiments were interrupted because of sudden animal death that occurred after 2.5 h of exposure at 51, 61, and 73 GHz. This body of work suggests that the link between superficial cellular effects and whole-organism effects — the least understood aspect of MMWs — may be due to peripheral receptors and afferent nerve signaling, leading to larger systemic reactions from what are assumed to be superficial exposures. This may prove particularly significant in non-human species.

While some of the above cited studies are at a higher power density than most of the focus in this paper, because of the ubiquity of millions of new antennas planned for 5G small cells, near-field exposures to wildlife, even in rural areas, are far more likely than from distant infrastructure.

In 2000, the U.S. Central Intelligence Agency declassified and released a compendium of theoretical and experimental papers, primarily from Russia, many already covered in Pakhomov et al. [269] on high frequency MMW and ELF studies. Cited works included a review of 6,000 papers by Kholodov [314] that appeared in Markov and Blank [315] demonstrating EMF interactions with a variety of animal and human biological systems. Effects were seen in the central nervous system with the degree of response dependent on myriad radiation parameters, including frequency, pulse shape and exposure duration. Wide ranging effects were documented from microbiota to mammals. They included: MMW effects on the central and peripheral nervous system [316] with a majority (80%) of human subjects detecting and being cognitively aware of exposures as low as 10 billionths of a W/cm^2, i.e., 10 nW/cm^2; 50 μ/W affected *Proteus* bacteria [317]; MMW as low as 1 μW/cm^2 within a very narrow frequency range (51.62 < vs. 51.85 GHz) induced changes in *E coli* bacteria, indicating a resonance response; and sharp resonances in HF/MMW ranges were seen, indicating that MMW act as a catalyst for intra- and inter-cellular communication. HF/MMW may trigger complex non-linear oscillations capable of affecting fundamental processes in whole living systems [270, 271, 318–324]. See below for more on MMW and nonlinear effects.

There are more updated reviews of the MMW frequency range [273, 325] with the most recent from Simko and Mattson [326] and Alekseev and Ziskin [327].

Simko and Mattson [326] focused on potential 5G safety and nonthermal effects. They investigated works (between 6 and 100 GHz MMW divided into seven ranges) for health impacts, analyzing 94 studies, characterized for type (*in vivo, in vitro)*; biological material (species, cell type, etc.); biological endpoints; exposure parameters (frequency, duration, power density); results; and critical study quality. They found 80% of *in vivo* studies and 58% of *in vitro* studies showed effects, with responses affecting all biological endpoints investigated. They also found no consistent relationship between power density, exposure duration, and frequency with exposure effects across the studies investigated although there were consistencies within some groupings for effects that were frequency dependent. They concluded that overall the studies did not provide adequate information to determine meaningful safety assessments, or to answer questions about non-thermal effects, adding there is a need for research on small surface local heating developments (e.g., skin or eyes), and on environmental impacts. They called for significant quality improvement in future study design and implementation. They also noted that no epidemiology studies exist for these frequency ranges — an important observation — and that it is important to investigate effects to wildlife as the depth of MMW penetration in very small organisms can result in potentially significant heating.

Alekseev and Ziskin [327] reviewed MMWs, sub-MMWs and THz ranges with close attention to skin properties/permittivity as well as other physiological endpoints in the early literature. Their focus was primarily on thermal intensities although some nonthermal works are included. They concluded that effects below thermal intensities were negligible.

One U.S. MMW study by Siegel and Pikov [328] at very-low-intensity produced effects far below regulatory standards. The authors noted the growing need to understand MMW mechanisms of interaction with biological systems for both adverse effects and therapeutic uses and said that independent of health impacts of long-term high-dose MMW exposure on whole organisms, that potential subtle effects on specific tissues or organs also exist. Their focus was on quantifying real-time changes in cellular function as energy was applied in a series of experiments. Effects found changes in cell membrane potential and the action potential firing rate of cortical neurons under short (1 min) exposures to continuous-wave 60 GHz radiation at mW/cm^2 power levels more than 1,000 times below the FCC maximum permissable exposure (MPE). After review of papers on neuronal activity in MMW frequencies at low intensities, Siegel and Pikov [328] examined MMW-induced apoptosis and transient membrane permeability in epithelial cells *in vitro*, as well as real-time changes in the activity and membrane permeability of individual pyramidal neurons in patch-clamp probed cortical slices. One study, using *in vitro* cerebral cortex slices from 13-to-16-day-old rat pups, was exposed to MMW 60 GHz (at 7.5, 15, 30, 60, 120 and 185 mW exposures) introduced in random sequences, held fixed for 1 min for three current cycles, then turned off. Bath temperature was constantly monitored with temperature rise between 0.1 to 3 °C. They found changes in firing at power levels of 0.3 $\mu W/cm^2$ and above after four different MMW power levels at approximately 0.1–1 mW/cm^2. Rise and decay slopes of individual action potentials and membrane resistance were also strongly correlated with MMW power levels indicating opening of membrane ion channels. They concluded that at power levels of approximately 300 nW/cm^2 and above, a strong inhibition of the action potential firing rate in some neurons existed, as well as an increased firing in others. This indicated possible functional heterogeneity in the studied neuronal population. Further they said that rise in bath temperature could not fully account for such dramatic changes in membrane permeability. These results are believed to be the first positive correlative measurements of real-time changes in neuronal activity with ultra-low-power MMW exposures. They said that although there was a lack of high-accuracy SAR data for each sample, further investigation was warranted as effects recorded were at levels well below recommended MPE's. Their findings also have therapeutic implications for non-contact stimulation and neurologic function control in suppression of peripheral neuropathic pain and other central neurological disorders.

There are hundreds of MMW studies at high intensities not included in this paper that may also be environmentally relevant to ambient near-field 5G exposures.

5G's unusual signaling characteristics: phased array, MIMO, Sommerfeld and Brillouin precursors

5G employs unusual signaling characteristics not broadly deployed before now. Phased array (multiple antennas that fire at different rates/times) has been used for decades in military radar and a few other industrial applications. Phased arrays can boost signal strength which in turn helps signals penetrate deeper into buildings. In its adaptation to civilian-based wireless networks, phased array is considered a unique characteristic that has not been well studied as a specific biologically active entity although that was called for over 20 years ago [329, 330]. However, enough research does exist in similar frequencies to raise safety questions. Still, all extrapolations for safety regarding 5G transmission designs have been made from inapplicably different radiation models for continuous (always-on) or pulsed (intermittently on) wave forms using single element or non-phased systems. While phased array is pulsed, it is a system in which the pulses overlap (thus the term "phased") which constitutes a unique biological exposure since there is no cellular recovery time between exposures. It is therefore in essence always "on."

Although not everyone agrees this is a unique enough characteristic to warrant further research or different safety considerations from what traditionally have been used [111, 112, 130, 131, 331, 332], there are nevertheless serious concerns regarding phasing because it interacts with living cells in extremely complex ways that have nothing to do with traditional thermal thresholds. The wave form itself is the biologically active component [329, 330, 333–338].

Phasing is created by multiple antennas and sub-antennas transmitting at simultaneous or slightly different intervals at different frequencies, creating what can become steep wave banks that interact with living cells from many different angles and time sequences. Because of varying impedance factors of radiation moving through air and microsecond differences in transmission rates, each antenna in a multiple radiating element reaches the body — human and non-human alike — at slightly different times, creating multiple overlapping wave fronts. Each wave front strikes from a slightly different location and/or angle, creating a characteristic sequence of layered modulation unlike any other electromagnetic propagation source. Nothing like this exists in nature. Although phased array has been around since the 1940s, it has not heretofore been used for broadband civilian telecommunications infrastructure or in widely used consumer devices until now.

5G is a combination of line-of-sight transmission with simultaneous ground-level side-lobe pulsed phased exposures, involving an incredibly complicated infrastructure with accompanying extensive ambient exposures from what is projected to be millions of new antennas in the U.S. alone. 5G will use phased broadband signals emitted in constant pulsed overlapping waves that gradually rise in frequency, simultaneously transmitted from slightly different locations and angles that build up in a kind of stair-step fashion. As designed, 5G will employ 'Massive' MIMO (multiple input, multiple output) compound-element transceivers — over 100 per physical antenna encasement — for simultaneous signal/data sending and receiving. Because the EHF frequency is higher on the electromagnetic spectrum with shorter wavelengths, individual antenna elements are smaller so more elements can be located in the same place. Multiple antenna elements are also necessary for phasing. In time, user devices will also contain EHF MIMO and phased array technology embedded in devices like iPhones, which already contain multiple antennas. 4G LTE technology already uses compound elements and although the two systems will be interdependent in the near future, 5G as designed is substantially different enough that new phones will eventually be needed.

In addition, 5G will employ beam steering technology (of which there are several types) that allow antennas to produce and focus very narrow beams in a specific direction. By concentrating and focusing the signal, the effective radiated power is boosted which means narrow signals can travel farther and more effectively penetrate buildings and other obstacles. Beam steering also allows antennas to direct signals to user devices rather than the 360° radiation patterns of omnidirectional antennas now commonly used in telecommunications infrastructure. Beam steering is accomplished by changing phases and/or switching antenna elements. To plot the best route between signal and user, highly advanced signal processing algorithms are required.

Proponents of 5G are enamored with the network's brilliant RF engineering and hypothesize that 5G will increase system efficiency, reduce RF interference from other sources, reduce overall ambient exposures because it is a highly directed network, and be faster and more energy efficient. But 5G's sheer scale will prove some of these projections incorrect and one industry estimate holds that 5G will require 10 times more energy than is used today for telecommunications [340]. Additionally, beam steering does not reduce ambient exposures with systems at such a scale. It does, however, with the densification of infrastructure create a whole new layer of novel RFR exposures.

Any exposure standards in place today being applied to 5G control mostly for near-field exposures. But phasing creates unpredictable far-field biological effects. With phased array transmission, the wave front arrival rate and buildup can increase as it moves away from the radiating source, creating multifaceted wideband dispersion/exposures ([341], see Figures 1 and 2 below), making exposures potentially more complex in far field environments in many different frequency ranges.

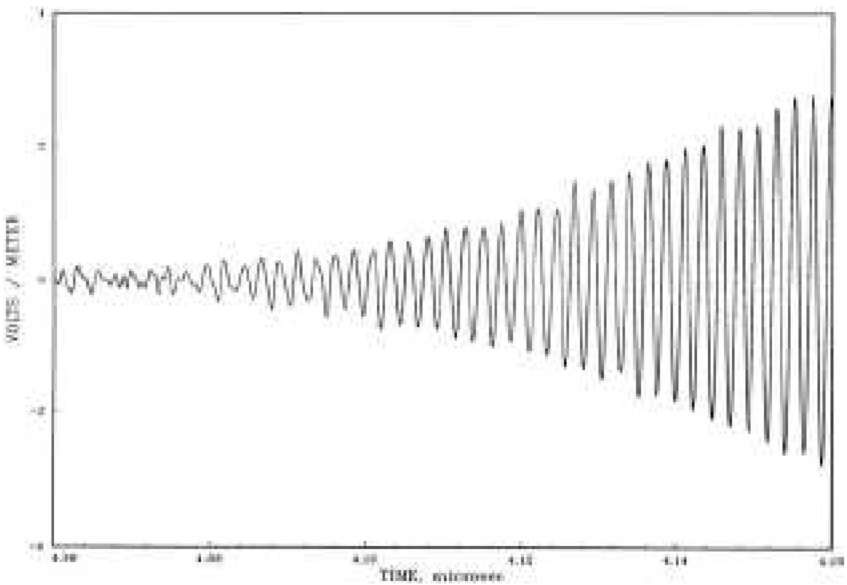

Figure 1: Phased array transmission can create wideband dispersion.
Near normal at the array face, buildup can occur as signal moves away from the generating source. Illustration shows how phased array radar buildup occurs in radar frequencies between 420 and 450 MHz [341]. From National Research Council, 2005. An Assessment of Potential Health Effects from Exposure to PAVE PAWS Low-Level Phased-Array Radiofrequency Energy, p 63. https://doi.org/10.17226/11205. Reproduced with permission from the National Academy of Sciences, Courtesy of the National Academies Press, Washington, D.C.

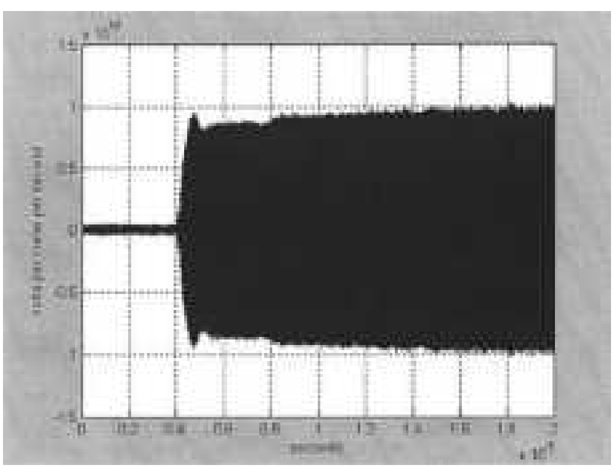

Figure 2: MMW bank buildup can also be near instantaneous.
At 500 m: the variation in slopes or rise times encountered through a pulse with many slopes being significantly greater than ±1 V per meter per nanosecond. Used with permission from Richard Albanese. Appeared in, An Assessment of Potential Health Effects from Exposure to PAVE PAWS Low-Level Phased-Array Radiofrequency Energy. National Research Council, 2005 p. 70. https://doi.org/10.17226/11205 [341].

The reason that phasing may have a unique biological impact is because very fast peak radiation pulses generate bursts of energy that can give rise to what are called Sommerfeld and Brillouin precursors in living cells that can in turn penetrate and disperse much deeper than traditional models predict [333–338, 339, 342–347]. Sommerfeld/Brillouin precursors most notably form with ultra wideband exposures as proposed with 5G.

Arnold Sommerfeld's [348] and Léon Brillouin's [349] writings on how wave fronts enter and move through 'lossy' materials (materials that absorb radiation like soil, water or living tissue) go back at least 100 years but their interest was in energy penetration and movement, not biological effects, and their orientation was on physics, not medicine. Sommerfeld and Brillouin's work noted that with the movement of a sinusoidal wave through a Lorentz medium, two transients formed. The first — now called the Sommerfeld precursor — travels at the speed of light and oscillates at very high frequencies, while the second — now called the Brillouin precursor — follows the first at slower speed. Oughstun and Sherman [339] established more current mathematical modeling for precursor formation. Both Sommerfeld and Brillouin precursors were observed in a waveguide apparatus by Plesko and Palotz [350]. The Sommerfeld precursor is estimated to have small amplitude in water-based materials like cells and tissue but has not actually been seen in such materials, while Brillouin precursors have been seen in water-based materials. Wide bandwidths in general — like 5G broadband which uses multiple frequencies — have been found to produce more precursors than narrow bandwidths; precursor formation is directly related to bandwidth (or rise time) and dispersion, but not always to electric field slope (V/m/nsec). Once generated, pulses can propagate without much attenuation and are thought to decay slowly only after significant attenuation has occurred in cellular media. That means precursors are long lasting in tissue. Precursors can occur any time during exposure [341].

With precursor formation, the salient factor is the speed at which energy is introduced. A slow introduction into material will not result in precursor formation. Precursors result from an external field being introduced at a rate faster than the motional response times of the medium itself [329, 351]. While typical continuous sinusoidal waves and pulsed exposures do not create wave fronts but are capable of causing thermoregulatory changes and other effects, phased array's sequence of wave fronts under certain circumstances may be capable of both thermoregulatory changes and electrostrictive perturbations thereby creating an unpredictable nonlinear feedback loop in living systems [329, 333–338, 351]. In other words, with 5G functioning in the EHF ranges with phased array signals, these are no longer simply physics theories. Precursors are capable of overwhelming living cells in highly unpredictable nonlinear patterns, potentially causing structural cellular fatigue and material changes throughout the entire organism.

According to Richard A. Albanese, M.D., (per. comm. 4/5/2021), when leading or trailing edge slopes (rise times) are ±1 V per meter per nanosecond or greater, a precursor will occur. Also when the signal spikes up or down such that the absolute difference between slopes/rise times is ±1 V per meter per nanosecond or greater, a precursor will occur. An example precursor is shown below in Figure 3.

Also note in Figure 3 that the slope/rise time caused by the precursor frequently exceeds ±5 V per meter per nanosecond – a factor of considerable concern. Of equal concern is that when such exposures are averaged the way that ICNIRP and FCC standards currently are (see Part 3), the slope/rise times theoretically "disappear" but not the actual biologically pertinent exposure itself in ambient field conditions.

With phased arrays, peak wave fronts arrive with time differentials in pico- and nanosecond ranges from multiple angles and distances. When wave fronts are sufficiently sharp, there is evidence that molecular re-radiation can occur as cell membrane potentials change. In other words, cells can function as small internal antennas [333, 339, 352, 353]. Wave fronts are thought to place energy quickly into molecules. When that happens, molecules are shown to re-radiate energy rather than produce heat according to the classic thermoregulatory models, and therefore travel deep into a living organism [339, 344, 347]. Rogers et al. [354] found that short pulses of 5 ns stimulated excised frog muscle contraction, demonstrating that wave fronts can depolarize membrane potentials. D'Ambrosio et al. [355] contrasted continuous waves with GMSK phased signals at 1.7 GHz and found a statistically significant rise in genotoxicity at the same SAR levels with phasing but not continuous waves.

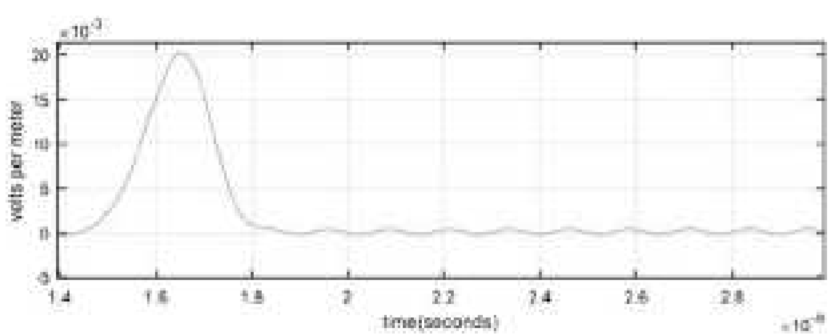

Figure 3: The above illustration shows a 20 mV precursor arising from a 1 V per meter square sinusoidal wave modulated at ~8 GHz. Of significance is the slope or rise time measured in volts per meter per nanosecond, not the carrier frequency. The above graph shows that the small amplitude of the carrier wave in tissue and the precursors that form can carry into the medium at a short duration direct-current level. However, if a sequence of these occurs – such as in phased exposures – and if the incident amplitudes are of higher magnitude, a living subject will receive a DC exposure that can depolarize cell membranes. Used with Permission by Richard A. Albanese.

Oughstun and colleagues have published many predictive mathematical and experimental papers on precursors,[1] especially those occurring in infrared (IR) laser waveforms. Infrared is visible to some species, especially birds, where it is thought to relate to breeding vigor. Although 5G is not yet licensed in IR wavebands, the upper ranges of EHF allocated for 5G are near the IR range with very similar biological effects; other technologies plan to use IR for communications purposes.

Similar observations to those described above regarding unusual propagation characteristics at these significantly higher frequencies have recently been made in studies of THz waves (between 0.3 and 30 THz in the far infrared range) by Yamazaki et al. [356]. They found that despite strong absorption by water molecules, the energy of THz pulses (250 μJ/cm^2) transmits at a millimeter thick in aqueous solution, possibly as a shockwave, and demolishes cellular actin filaments. Collapse of actin filaments induced by THz irradiation was also seen in living cells under an aqueous medium. They found that while the viability of the cell was not affected by THz pulses, the potential of THz waves as an invasive method to alter protein structure in the living cells still existed.

While our present paper does not include studies in the THz range, it is briefly mentioned here because technology in the THz range is already deployed in airport scanners and is planned for use in future Li-Fi wireless and some 5G applications [357]. The Yamazaki et al. [356] study in the THz range mentioned above challenges popular assumptions that THz radiation effects are negligible on deep tissues due to strong absorption by water molecules. The researchers found the potential opposite.

Satellites

The use of satellites for two-way broadband communications goes back to the 1960s for military applications, academic/government research, and weather prediction. Widespread adaptations for civilian use only began in the late 1980s and 1990s for radio/TV broadcast and Internet connectivity. Today civilian use has exploded, along with significant concerns.

Satellites cover entire regions, mostly broadcasting back toward Earth in both line-of-sight arrays and wide radiation patterns much like a flashlight's beam. The farther away the satellite, the broader the beam and higher the power density needed to reach Earth; some satellites transmit at millions of watts of effective radiated power. Satellites have the ability to reach rural and remote areas in ways terrestrial networks cannot, and therefore affect wildlife in ways that may never be detected.

There are already thousands of satellites circulating the Earth today. Like earth-base systems, the radiofrequency bands traditionally used for satellites have become so crowded that engineers are turning to two-way systems using laser frequencies. In 2013, the U.S. NASA Lunar Atmosphere and Dust Environment Explorer used a pulsed laser beam to transmit data over 239,000 mi (384,633 km) between the moon and Earth at a record-breaking download rate of 622 MB/s [358]. The laser frequencies are close to the upper ranges planned for 5G, and are visible to many species which see far broader light spectra than humans.

There are three general categories of satellites based on their height above the Earth's surface [359]. The first is in low Earth orbit (LEO) at about 111–1,243 mi (180–2,000 km, respectively) above Earth, used for Earth surface observations, military purposes and weather data. Medium Earth orbit (MEO) occurs at about 1,243–22,223 mi (2,000–36,000 km, respectively) used for navigation like GPS and telecommunications. High Earth orbit occurs at an altitude greater than 22,223 mi (36,000 km). High Earth orbits are also called geosynchronous orbits (GEO). Satellites there orbit every 24 h, the same as Earth's rotational period. GEO's can be fixed over one spot or circle elliptically. Some are aligned with the Earth's equator; others not. There are several hundred television, communications and weather satellites in geostationary orbits.

Space above us has now become very crowded. Satellites vary enormously in size, design, and construction according to their purpose. They are used for everything from weather-data gathering, communications (cell/Internet), broadcast radio/TV, scientific research, navigation, emergency rescue, Earth observation and military purposes. Many — though not all — weather and some communications satellites are in high Earth orbit; satellites in a medium Earth orbit include navigation and specialty satellites used to monitor a particular region, while most scientific satellites, including NASA's Earth Observing System fleet, have a low Earth orbit. A small number of satellites turn their attention (and radiation) toward space for research purposes.

There are many satellite companies, all with different models and configurations depending on their goals. Historically, satellites have relied on C band frequencies

1 For a list of 30 Oughstun studies current to 2005, see An Assessment of Potential Health Effects from Exposure to PAVE PAWS Low-Level Phased-Array Radiofrequency Energy PAVE PAWS 2005, Annex 5-5, pp. 90–93. http://www.nap.edu/catalog/11205.html and Dr. Oughstun's website, www.emba.uvm.edu/~oughstun.

between the 4 and 8 GHz portion of the microwave range with the least amount of attenuation through Earth's atmosphere — best for long distance transmission. But that traditional range has a lower data-carrying capacity than today's demands, so increasingly the Ku band between 12 and 18 GHz and the Ka band between 26 and 40 GHz are being used. The 60 GHz band has been used by the military for satellite-to-satellite communication. Increasingly satellite systems like Telstar will use a combination: C band for wide area coverage mixed with higher frequency Ku and Ka bands for more focused spot beams, also called high-capacity beams. One apt analogy of this combination likens the human eye to the "wide view" whereas an insect's eye is a compound structure, like spot beams capable of pointing in different directions.

New complex multifrequency satellite networks are increasing and therefore Earth exposures are too. Large or small, most satellites communicate with earth-based stations at significant power outputs.

Recent increases in satellites

Today's entrepreneurs — including Elon Musk with SpaceX/Starlink, Jeff Bezos with Amazon's Project Kuiper, Mark Zukerberg with Facebook's Athena, Telestat in Canada, OneWeb in the UK, the Russian Roscosmos, the Hongyun Project in China, and several others — are extending satellite communication to 5G technology, employing thousands of new low-to- mid-earth orbiting satellites that will create another low-level layer of novel exposures that do not now exist. There have been no Environmental Assessments (EAs) or Environmental Impact Statements (EISs) reviewed under NEPA by the FCC, which determined in 1986 that satellites were categorically excluded ([360]; also see Part 3).

By 2021, Musk plans to have launched 1,584 satellites, with another 11,943 by 2025, in contrast to the approximate 1,500 in obit as recently as 2019 [361].The ultimate plan, if allowed by FCC, is for 42,000 Starlink satellites covering the globe (placed at three different atmospheric stratas: 211 mi/340 km, 342 mi/550 km, and 715 mi/1,150 km). In October 2019, Musk sought permission for 30,000 more, to orbit between 203 mi/328 km and 380 mi/614 km, using frequencies between 10.7 and 86 GHz in overlapping phased array cells — and that's just one provider [362]. As of this writing, SpaceX/Starlink has deployed 597 satellites with 14 more multi-satellite launches planned by 2021. About 500 are functioning, ready to provide internet to some locations on Earth [363].

The FCC also granted Starlink a 15-year license for up to one million fixed-earth user terminals to communicate with Starlink's network [364], plus the FCC granted temporary approval for test stations in six states (California, Minnesota, Idaho, Alabama, Georgia and Montana) as proof of concept in advance of Starlink's official commercial opening by the end of 2020. The company intends to use the 28.6–29.1 and 29.5–30.0 GHz spectra for uploading data from the Earth stations to Starlink satellites; and 17.8–18.6 and 18.8–19.3 GHz for downlinks [365]. In addition to Starlink, Amazon's Kuiper Systems won the endorsement of the FCC's chairman, Ajit Pai, in July 2020 for 3,236 new satellites [366].

Satellite transmission in the upper atmosphere has always suffered from cloud cover interference and high latency (the time for signal to get from one place to another). SpaceX's 5G Earth orbiting design bypasses some of these problems by putting satellites in low and very-low orbits above Earth, unlike typical internet satellites in geostationary orbit at or above 22,000 mi (35,405 km) [367]. Being closer to the ground means more satellites will be needed as each satellite will cover a smaller area. While SpaceX plans to create global Internet coverage with its initial deployments in low Earth orbit in the U.S., it will then fill in gaps with thousands more at very low Earth orbit (VLEO) at approximately 211 miles (340 km) above Earth. SpaceX plans to cover rural areas first which theoretically could affect wildlife that likely will go undetected.

The U.S. is also implementing the new U.S. Space Force under the Department of Defense (DOD) and will deploy five new missile-warning satellites by 2029 in high altitude stationary orbits [368]. Additionally, DOD will augment with satellites in low Earth orbits for hypersonic missile defense [369]. SpaceX is expected to handle 40% of national security satellites that will be deployed within the next decade [370].

There have been numerous negative comments to FCC from NGO's, businesses, government agencies, and legislators about this unprecedented commercial satellite increase, especially regarding projects earmarked for 5G civilian communications due to potential interference with other agencies' use of similar frequency bands for critical weather forecasting, GPS communications, and astronomy, among others. One focus has been on FCC's 2020 licensing of Ligado Networks' (formerly LightSquared) use of the L-Band for a national civilian mobile broadband network. The L-Band is spectrum for GPS used by the military, businesses, and consumers. FCC's decision is opposed by the Pentagon; numerous U.S. agencies including The Department of Transportation; professional organizations like the Air Line Pilots Association and the International Air Transport Association; and industries like Iridium Communications and Lockheed Martin. Thirty-two U.S. senators have also asked FCC to reconsider [371].

Comments to FCC include those from the National Oceanic and Atmospheric Administration (regarding weather forecasting and research), and the Department of Energy (regarding power grid security) among others. In January 2020, The International Astronomers Appeal was filed at FCC stating "extreme concern" over tens of thousands of satellites greatly outnumbering the 9,000 stars visible to the unaided human eye, permanently blocking visibility and altering astronomical research forever. They warned there could be over 50,000 small satellites encircling the Earth at different altitudes for telecommunications purposes, primarily 5G Internet connectivity. Night-time migrating species also use stars for orientation. This sudden infusion of artificial "stars" may have adverse effects that go undetermined.

None of these agencies or companies appear concerned about the massive infusion of novel RFR into various strata of the atmospheric or ground-based environment, and the U.S. Environmental Protection Agency — the agency with primacy over environmental radiation effects — has been defunded for nonionizing radiation research and regulatory oversight since 1996 [372].

Since the ionosphere is a dynamic system capable of nonlinear excitation from external stimulation, there are reasonable concerns that satellites may be contributing to atmospheric perturbation, climate change, and weather instability [373, 374]. In addition, oxygen (O_2) molecules readily absorb the 60 GHz frequency range and rain easily attenuates signals [208, 209, 375]. At 60 GHz, 98% of transmitted energy is absorbed by atmospheric oxygen. This makes that frequency spectrum good for short-range transmission but no one understands how a large infusion of RFR in that band — or any other — may affect atmospherics. It could be highly destabilizing [376].

The FCC has allocated MMW from 57.05-to-64 GHz for unlicensed use. While all wireless equipment operating at 60 GHz must obtain FCC certification, once certified, products can be deployed license-free throughout the United States [209]. This frequency band may prove popular for myriad uses. It may also be capable of destabilizing both local micro-climate weather systems as well as broader atmospheric events due to maximal coupling with oxygen and resonance factors with water molecules [208].

By the time satellite transmissions reach the Earth's surface, the power density is low but with 5G's phased array signals, the biologically active component is in the waveform, not power density alone. There is no research to predict how this will affect wildlife in remote areas but given what is known about extreme sensitivity to EMFs in many species, it is likely that effects will occur and likely go undetected. Because much of the research on phased array and precursors has been done in lossy materials like water, we have models to suggest that 5G may have particular effects not only on insect populations (due to resonance factors) and amphibians (due to thin membranes and deep body penetration) but also in some aqueous species since water is a highly conductive medium. Even weak signals from satellites using phased array characteristics may be a significant contributor to species effects in remote regions.

There have been no EAs or EISs conducted through NEPA reviews to study this [377]. FCC exempted satellites from NEPA review in 1986 [360] largely based on the fact that NEPA applies to the human environment and satellites are far away. There appears to be no specific mention of satellites being specifically exempt from NEPA but the tradition of exemption continues to the present [378] although the FCC is being asked to reconsider [379].

Conclusion

Ambient background levels of EMF have risen sharply in the last four decades, creating a novel energetic exposure that previously did not exist at the Earth's surface, lower atmospheric levels, or underwater environments. Recent decades have seen exponential increases in nearly all environments, including remote regions. There is comprehensive but outdated baseline data from the 1980s against which to compare significant new surveys from other countries which found increasing RFR levels in urban, suburban and remote areas, primarily from cell infrastructure/phone/WiFi exposures. One indicative comparison of similar sites between 1980 and today found a 70-fold (7,000%) increase in ambient RFR [149]. The increased infrastructure required for 5G networks will widely infuse the environment with new atypical exposures, as are increasing satellite systems communicating with ground-based civilian networks. The new information provides broader perspective with more precise data on both potential transient and chronic exposures to wildlife and habitats. Biological effects have been seen broadly across all taxa at vanishingly low intensities comparable to today's ambient exposures as examined in Part 2. The major question presented in Part 1 was whether increasing anthropogenic environmental EMF can cause biological effects in wildlife that may become more urgent with 5G technologies, in addition to concerns over potentially more lenient allowances being considered by major standards-setting committees at FCC and ICNIRP (examined in Part 3). There are unique signaling characteristics inherent to 5G transmission as currently designed of particular concern to non-human species. Background levels continue to rise but no one is studying cumulative effects to nonhuman species.

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Part 1, Supplement 1
Environmental EMF measurements from around the world

Locations of measurements	Type of RFR	Level ($\mu W/cm^2$)	Reference
Australia	870-1200 MHz	0.8	Henderson and Bangay (2006)
Australia and Belgium	In various public places	Australia : 0.15-4.97 (0.75-4.33 V/m) ; Belgium : 0.2-1.008 (0.90-1.95 V/m)	Bhatt et al. (2016)
Australia (Melbourne kindergartens)	88 MHz – 5.8 GHz	0.0017 (total all bands) (0.179 V/m)	Bhatt et al. (2017)
Belgium	FM, GSM900, GSM1800 and UMTS	0.07	Joseph et al. (2008)
Belgium, Switzerland, Slovania, Hungary, the Netherlands	Several fréquency bands	outdoor urban fields: 0.021-0.057	Joseph et al. (2010)
Brazil	Cell tower	0.04 - 40.78 (0.4-12.4 V/m)	Dode et al. (2011)
Denmark, the Netherlands, Slovenia, Switzerland, and Spain (children)	16 frequency bands including DECT, radio and TV, mobile phone,mobile phone base stations, and WiFi,	Median total field 0.00755 Outdoor : 0.0157-0.0171 Home/in school: 0.0033-0.00351	Birks et al. (2018)
France	12 bands: FM to mobile phone	0.6	Viel et al. (2009)
Germany (Cities of Bamberg and Hallstadt)	Mobile phone base station	0.001-1.69	Waldmann-Salsam et al. (2016)

Ghana	900-1800 MHz	0.001	Amoako et al. (2009)
Ghana	GSM 900, 1800 and UMTS 2100 (61.1-25.7 m from a basestation)	0.00717-0.0895	Deatanyah et al (2018)
Greece	62 primary and secondary schools in Athens (2- MHz – 3 GHz)	Average 0.049 (0.4292 v/m)	Aris et al. (2020)
Hungary	9 bands between 80-2200 MHz	0.025	Thuroczy et al. (2006)
India	10 MHz-8 GHz	1.148	Dhami (2012)
Korea	CDMA800 and CDMA1800	0.6	Kim et al. (2010)
Southern Spain	100 KHz – 6 GHz	0.0286	Calvente et al.(2015)
Sweden	30 MHz- 3 GHz	rural area 0.0016; urban area 0.027; city area 0.24	Estenberg and Augustsson (2014)
Sweden (Stockholm Central Railway Station)	88-5850 MHz	0.092 (median) 0.2817 -0.4891(mean total)	Hardell et al. (2016)
Sweden (Stockholm Old Town)	87-5850 MHz	0.0404 – 2.43	Hardell et al. (2017)
Switzerland	12 different bands from FM (88 MHz-108 MHz) to W-LAN (2.4-2.5 GHz)	0.013 (0.0014- 0.0881)	Frei et al. (2009)
Switzerland (Basel) and the Netherlands (Amsterdam)	Base stations	downtown: 0.024-0.0745 residential areas: 0.0021- 0.0445	Urbinello et al. (2014)

Switzerland, Ethiopia, Nepal, South Africa, Australia, USA	Public RFR emitting devices	Outdoor: 0.014-0.91 Public transport vehicles: 0.027-0.49	Sagar et al. (2018)
Turkey	GSM9 00 MHz	3	Firlarer et al. (2003)
USA (cities of Spokane, WA and Raleigh, NC)	VHF-FM-UHF-mobile phone	0.11- 0.00028	Tell and Kavet (2014)
West Bank-Palestine major cities, outdoor levels	FM and TV broadcasting stations and mobile phone base stations	Average 0.37 Maximum 3.86	Lahham and Hammash (2012)
West Bank-Palestine, City of Hebron, indoor levels	FM and TV broadcasting stations, mobile phone base stations, cordless phone (DECT) and WLAN	Average 0.08 Maximum 2.3	Lahham et al. (2015)
West Bank-Palestine	WLENS (Wi-Fi), 1 meter from access points, 75 MHz – 3 GHz	0.12 (0.001-1.9)	Lahham et al. (2017)

The above table shows a large variation in levels, ranging from 0.002 to 41 $\mu W/cm^2$ (median =0.18 $\mu W/cm^2$). The variation could most likely be due to the extent of deployment of wireless systems in different areas. Since each study measured only a section of the RF-spectrum, the total levels summing emissions in all parts of the spectrum are expected to be higher. These levels also are bound to increase with time given the constant deployment of new wireless communication devices and infrastructure. Some of the above are old measurements that probably are now higher as the wireless communication systems proliferated. For other relevant studies, readers should also read the review by Sagar et al. (2017)

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Review Article

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Effects of non-ionizing electromagnetic fields on flora and fauna, Part 2 impacts: how species interact with natural and man-made EMF

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Abstract: Ambient levels of nonionizing electromagnetic fields (EMF) have risen sharply in the last five decades to become a ubiquitous, continuous, biologically active environmental pollutant, even in rural and remote areas. Many species of flora and fauna, because of unique physiologies and habitats, are sensitive to exogenous EMF in ways that surpass human reactivity. This can lead to complex endogenous reactions that are highly variable, largely unseen, and a possible contributing factor in species extinctions, sometimes localized. Non-human magnetoreception mechanisms are explored. Numerous studies across all frequencies and taxa indicate that current low-level anthropogenic EMF can have myriad adverse and synergistic effects, including on orientation and migration, food finding, reproduction, mating, nest and den building, territorial maintenance and defense, and on vitality, longevity and survivorship itself. Effects have been observed in mammals such as bats, cervids, cetaceans, and pinnipeds among others, and on birds, insects, amphibians, reptiles, microbes and many species of flora. Cyto- and geno-toxic effects have long been observed in laboratory research on animal models that can be extrapolated to wildlife. Unusual multi-system mechanisms can come into play with non-human species — including in aquatic environments — that rely on the Earth's natural geomagnetic fields for critical life-sustaining information. Part 2 of this 3-part series includes four online supplement tables of effects seen in animals from both ELF and RFR at vanishingly low intensities. Taken as a whole, this indicates enough information to raise concerns about ambient exposures to nonionizing radiation at ecosystem levels. Wildlife loss is often unseen and undocumented until tipping points are reached. It is time to recognize ambient EMF as a novel form of pollution and develop rules at regulatory agencies that designate air as 'habitat' so EMF can be regulated like other pollutants. Long-term chronic low-level EMF exposure standards, which do not now exist, should be set accordingly for wildlife, and environmental laws should be strictly enforced — a subject explored in Part 3.

Keywords: cell phone towers/masts/base stations; Earth's geomagnetic fields; magnetoreception, radiofrequency radiation (RFR); nonionizing electromagnetic fields (EMF); plants; wildlife.

Introduction: electromagnetic fields — natural and man-made

In Part 1 of this three-part series, rising ambient EMF levels were explored. Part 2 focuses specifically on the unique magnetoreception physiologies found in wildlife as well as the mechanisms by which they interact with the Earth's natural geomagnetic fields and man-made EMF at intensities now commonly found in the environment. Part 2 Supplements contain tables of studies showing effects at extremely low intensity exposures comparable to today's ambient levels.

Energy is a part of nature affecting every living thing in positive, negative and neutral ways. The Earth itself is a dipole magnet with a north and a south pole. All living things have evolved within the protective cradle of the Earth's natural geomagnetic fields. In fact, magnetic oscillations emanate from the Earth's molten iron core around 10 times per second (10 Hz) where relaxed but alert human thought/brainwaves occur between 8 and 14 Hz.

In addition to the Earth's natural emanations, vast Schumann Resonances (SR) that constantly circle the globe

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were theorized in 1952 by physicist Windfried Otto Schumann and reliably measured in the 1960s [1, 2]. SR are a global electromagnetic phenomenon caused by a complex relationship between lightening at the Earth's surface and the ionosphere. Excited by the 2,000 thunderstorms that occur globally at any given time and approximately 50 flashes of lightening every second, the space between Earth and the ionosphere 60 miles (97 km) above it form a resonant cavity and closed waveguide [3]. Schumann Resonances occur in the ELF bands between 3 and 60 Hz with distinct fundamental peaks around 7.83 Hz. Since the 1960s, scientists have discovered that variations in the resonances correspond to seasonal changes in solar activity, the Earth's magnetic environment, in atmospheric water aerosols and various other earth-bound phenomena, including increased weather activity due to climate change. There are an estimated 1.2 billion lightening flashes globally each year, 25 million in the U.S. alone [4], not all of which are of sufficient length to contribute to the resonances.

Many behavioral aspects in biology are thought to be synchronized with both the Earth's natural fields and the Schumann Resonances. Many species rely on the Earth's natural fields for daily movement, seasonal migration, reproduction, food-finding, and territorial location, as well as diurnal and nocturnal activities. Human circadian rhythms, mainly regulated by light targeting signaling pathways in the hypothalamic suprachiasmatic nucleus, are known to be finely tuned to the Earth's day/night cycles as well as natural seasonal variations, as are most species [5–8]. Artificial ELF-EMF is also known to adversely affect human circadian clocks, possibly through modulation in circadian clock gene expression itself [9].

Nonionizing electromagnetic fields (EMF; 0–300 GHz) include all the frequencies that fall between visible light below the ultraviolet range and the Earth's natural static fields. The nonionizing bands are used in virtually everything involved with communications and energy propagation so useful in modern life, including electric power production/distribution, all wireless technologies and accompanying infrastructure for cell phones, WiFi, baby/home monitoring systems, 'smart'grid/meters, all 'smart' technology/devices, 2-through-5G Internet of Things, AM/FM broadcast radio and television, shortwave and HAM radio, surveillance/security systems, satellites, radar, many military applications, and myriad medical diagnostic tools like MRI's, to name but a few (see Figure 1).

In its natural state, very little radiofrequency radiation (RFR) reaches the Earth's surface. Aside from the Earth's natural extremely low frequency (ELF) direct current (DC) magnetic fields, lightening and sunlight would primarily comprise our normal exposures to the electromagnetic spectrum. Most harmful radiation coming from outer space is blocked by the Earth's magnetosphere. But now, for the first

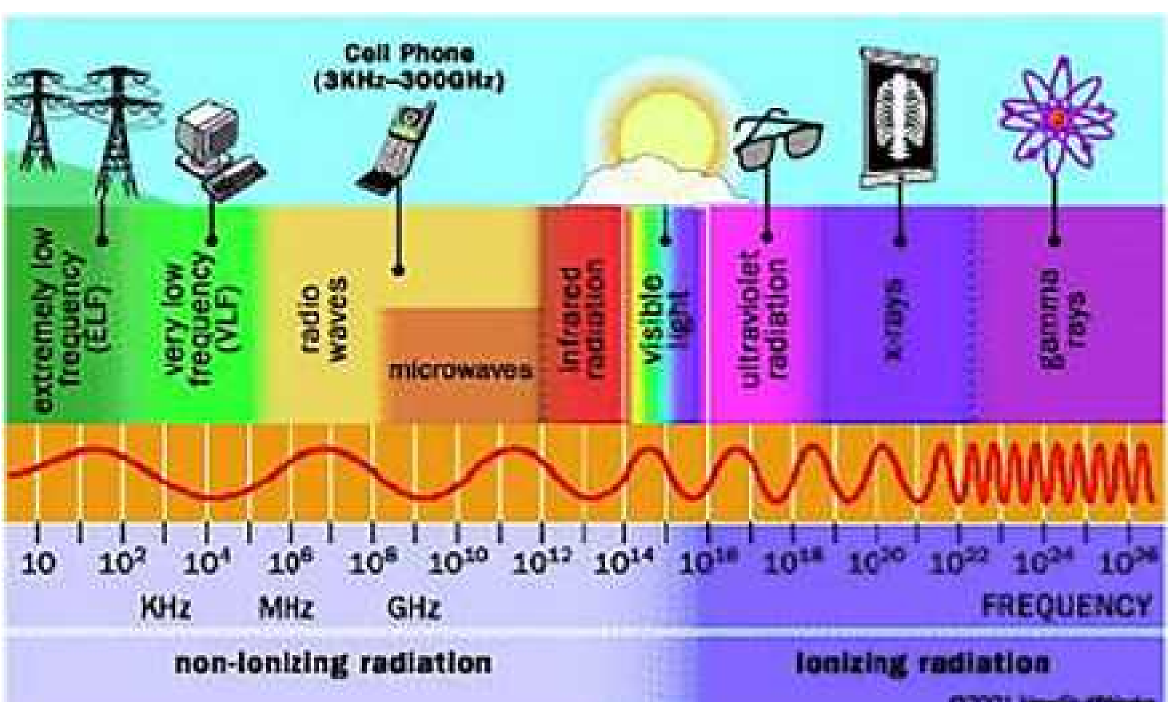

Figure 1: The electromagnetic spectrum.
The electromagnetic spectrum is divided into ionizing and nonionizing radiation. Ionizing radiation falls at and above the ultra violet range in the light frequencies. Examples of ionizing radiation include gamma rays, cosmic rays, X-rays and various military and civilian nuclear activities. It is the nonionzing bands that we have completely filled in with modern technology.

time in evolutionary history, we have infused the Earth's surface with a blanket of artificial energy exposures with no clear understanding of what the consequences may be.

And although "natural," not all energy is alike. Man-made exposures contain propagation characteristics — such as alternating current, modulation, complex signaling characteristics (e.g., pulsed, digital, and phased array), unusual wave forms (e.g., square and sawtooth shapes), and at heightened power intensities at the Earth's surface that simply do not exist in nature. These are all man-made artifacts. In our embrace of technology, we have completely altered the Earth's electromagnetic signature in which all life has evolved, in essence bypassing the magnetosphere's protection. And because so much of wireless technology is satellite based, increasing exposures are no longer just ground-generated. All atmospheric levels are now affected by increasing ambient exposures (see Part 1 and Part 1 Supplement). This is especially true in the lower atmosphere, which is 'habitat' (beyond mere oxygen and clean air standards) for all species that mate, migrate, and feed in the air — including birds, mammals (such as bats), insects and some arachnids.

Species extinctions

There has been an unprecedented rate of biodiversity decline in recent decades according to the International Union for Conservation of Nature [10] which maintains a "Red List of Threatened Species" that is considered the world's most comprehensive source on the global conservation status of animal, fungi and plant species — all critical indicators of planetary health.

IUCN's 2018 list showed that 26,000 species are threatened with extinction, which reflected more than 27% of all species assessed. This was greatly increased from their 2004 report that found at least 15 species had already gone extinct between 1984 and 2004, and another 12 survived only in captivity. Current extinction rates are now at least 100 to 1,000 times higher than natural rates found in the fossil record.

The more recent May 2019 report by the Intergovernmental Science and Policy Platform on Biodiversity and Ecosystem Services, Paris, France [11] projected that at least 1 million plant and animal species worldwide are at imminent threat of extinction if our current human actions and activities are not immediately reversed. A review of 73 reports by Sanchez-Bayo and Wyckhuys [12] found those rates had greatly accelerated. The authors noted that biodiversity of insects in particular is threatened worldwide with dramatic declines that could lead to a 40% extinction of insect species over the next several decades. In terrestrial ecosystems they found *Lepidoptera, Hymenoptera, and Coleoptera* (dung beetles) were most affected, while in aquatic ecosystems *Odonata, Plecoptera, Trichoptera and Ephemeroptera* have already lost a considerable proportion of species. Affected insect groups included niche specialist species, as well as common and generalist species, many of which are critically important for pollination, as well as seed, fruit, nut and honey production, and natural pest control, among others of immeasurable economic and ecological value.

Humans are the primary cause for most declines via habitat destruction/degradation; over-exploitation for food, pets, cattle and medicine; artificially introduced species; pollution/contamination; pesticides; and disease. Climate change is increasingly established as a serious threat, as well as agricultural practices like monoculture crops for cattle feed, biofuels, and timber. New pesticides and weed killers introduced within the last 20 years, using neonicotinoids, glyphosphate, and fipronil, are especially damaging since they are long-lasting and capable of sterilizing soil of beneficial microorganisms, including worms and grubs, which can then extend to areas far beyond applications sites.

One example of multi-factorial damage includes the iconic American Monarch butterfly (*Danaus plexippus)* which is found across America and Southern Canada and generally geographically divided into eastern and western migratory groups by the Rocky Mountains. That species has declined by a full 99.4% in the west since the 1980s — 85% of that being since 2017 [13, 14]. According to the Center for Biological Diversity [15], the eastern monarch population has shrunk by 90% in the past two decades. Massive habitat loss, wildfires, climate change, droughts, enhanced storm ferocity, and the 1990s introduction of Monsanto "Roundup Ready" crops capable of surviving herbicides that kill other weeds — including milkweed, which monarchs need for breeding and as their sole food supply along their migratory routes — are thought to be the primary culprits.

Here, we argue, environmental EMF should be added to this list since many insects and other living species have sensitive receptors for EMF, e.g., monarchs were found to have light sensitive magnetoreceptors in their antennae that serve as an inclination compass when daylight is absent [16]. RFR is also known to alter the time period needed for a butterfly to complete morphogenesis, plus gastrulation and larval growth can be accelerated [17]. And the devastating loss of pollinating insects like honey bees and other wild pollinators may also be related to environmental EMF (see "Insects" below.)

Anecdotally, many people recall when there were significantly more insects and far more abundant wildlife. Since about 1980, there has been a steady, almost imperceptible, biodiversity diminishment among many species globally [18–20]. In 2018, scientists estimated that the largest king penguin colony shrank by 88% in just 35 years [21] due in major part to effects from climate change, while according to the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, over 97% of bluefin tuna have disappeared from the world's oceans, primarily due to industrial overfishing but exacerbated by oil spills, contamination, and climate change. Tree and cave-dwelling bats until recently were common, including in the Eastern United States. Now with the massive impacts from White-nosed Syndrome (a fatal bat fungal disease), annual wind-turbine bat collision mortality estimated at nearly 1 million per year in the U.S. alone [22, 23], and pesticide use, few bats are seen. Bats species are also sensitive to EMF. Impacts from EMF as now seen in extensive reviews add only yet another troubling variable for all wildlife [24–36].

Since all food webs are uniquely tied together, there are negative cascading effects across all ecosystems. Birds that eat insects are hard hit: 8-in-10 partridges have disappeared from French farmlands while there has been a 50–80% reduction in nightingales and turtledoves respectively in the UK. Since 1980 the number of birds that typically inhabit Europe's farmlands has shrunk by 55%, while in the last 17 years, French farmland-bird counts dropped by a full third. Intensified agricultural practices are thought responsible, with loss of insects being the largest contributor [12, 37]. In the United States, of the 1,027 species of migratory birds currently protected under the Migratory Bird Treaty Act of 1918, an estimated 40% are in decline based on breeding bird surveys [38], Christmas Bird Counts [39], and other monitoring tools [22, 23]. This trend is comparable to what is happening globally. What role EMF plays in these declines is unclear but remains a disturbing possibility. Nor do we understand the limits of tolerance any given species has for environmental disturbance — some show high flexibility while others thrive only within the narrowest ranges.

One estimate of Earth's species finds that since 1970, wild animal populations have been reduced on average by 60%. Popularly called the "sixth mass extinction" [40], the term connotes the sixth time in the Earth's history that large numbers of species have rapidly disappeared over a relatively short period, this time due to human activity, not asteroid strikes or volcanic activity. Though not officially so-designated, many now refer to this most recent geologic/ecosystem period as the "Anthropocene" — the Age of Man [41–46].

Insect populations have been especially hard hit with extinctions eight times faster than that of mammals, birds and reptiles [12]. Insect total mass is falling by an estimated 2.5% per year, suggesting they could vanish by the next century. And what affects insect populations affects everything in the food web in one way or another. Loss of insect diversity and abundance can cause devastating effects throughout food webs and endanger entire ecosystems [12]. In Europe, Hallmann et al. [47] found a more than 75% decline over 27 years in total flying insect biomass in 63 protected areas, many throughout Germany. There was an 82% decline in mid-summer flying insect mass. Many European insect species migrate from distances as far away as Africa. The researchers noted that changes in weather, land use, and habitat characteristics alone cannot explain the overall decline and that there may be more than one unrecognized factor involved in evaluating declines in overall species abundance. That unrecognized factor may be the steadily rising ambient EMF that directly parallels these declines (see Part 1, Supplement 1).

Similar alarming invertebrate declines were discovered in the Western Hemisphere in 2017 when American entomologist Bradford Lister, after 40 years, revisited the El Yunque National Forest in Puerto Rico to follow up on a study begun in 1976 [48]. In the ensuing decades, populations of arthropods, including numerous flying insects, centipedes and spiders, had fallen by 98% in El Yunque, a pristine tropical rainforest within the U.S. National Forest System. Insectivores — including birds, lizards, and toads — showed similar declines, with some species vanishing entirely. After controlling for factors like habitat degradation or loss and pesticide use, the researchers concluded that climate change was the primary factor since the average maximum temperature in that rainforest had increased by 4 °F during that period. They did not factor in the large U.S. military VLF installation in Aquada that communicates with submarines all over the world, or the multiple sweeping over-the-horizon phased array radar units aimed at Puerto Rico from coastal sites in the U.S. that irradiate deep into that forest, or the multiple NOAA Doppler weather radar sites scattered all over the small island to track hurricanes, or the many cell towers there too.

These global declines are truly alarming with implications for planetary health as well as human and wildlife integrity. Many who study this say that climate change alone is not the only factor and that something new is going on [47]. The question is: could steadily rising environmental EMF, as one of the most ubiquitous but unrecognized new environmental genotoxins introduced since the 1980s, be contributing to these unprecedented species losses, beginning with insects but now manifesting in other species too? The upper microwave bands couple maximally with some insects the size of fruit flies and are capable of creating devastating resonance and other effects. Historically, radiofrequency radiation (RFR) impacts to insects were among the first biological effects to be studied [49] with the hope of discovering new forms of insect control [50]. All insect metamorphic developments have been studied, including egg, larva, pupa, and adult stages. One hypothesis holds that some adult species are more sensitive than at larval stages because adult appendages act as conducting pathways to the body (see "Insects" below).

It is these exact frequency bands between 30 kHz and 3 GHz used in telecommunications technology that have been on the rise during this period. And 5G is on the horizon which may specifically target insect populations (see Part 1).

Species sensitivity to EMFs

Other species have vastly more complex electromagnetic sensing tools than humans, as well as unique physiologies that evolved to sense weak fields. Many species are highly sensitive to the Earth's natural electromagnetic fields, as well as geographic and seasonal variations. In fact, it appears that most living things — including many species of mammals, birds, fish, and bacteria — are tuned to the Earth's electromagnetic background in ways once considered as "superpowers" but are now known to be physiological, even as mechanisms are still imperfectly understood. For example, many animals have been observed sensing earthquakes long before human instruments detect them, including snakes and scorpions that seek shelter; cattle that stampede; birds that sing at the wrong times of day; and female cats that frantically move kittens [7].

This ability is likely due, in part, to numerous species reacting to changes in the Earth's magnetic field and electrostatic charges in the air detected through a naturally occurring mineral called magnetite found in many species [51, 52]. In fact, honey bees are able to detect static magnetic field fluctuations as weak as 26 nT against background earth-strength magnetic fields that are much higher [53] and to sense weak alternating fields at frequencies of 10 and 60 Hz [54]. Magnetite reacts a million times more strongly to external electromagnetic fields than any other known magnetic material. Authors Kobayshi and Kirchvink [52] and Kirchvink et al. [53, 54] hypothesized results were consistent with biophysical predictions of a magnetite-based magnetoreceptor. Other mechanisms, like radical pair mechanisms and cryptochromes, may also be responsible (see "Mechanisms" below).

Much has been written about magnetoreception — the term used to describe how species sense electromagnetic fields — which is well established but not well understood. Many species use information about the Earth's natural fields for migration, mating, food-finding, homing, nesting, and numerous other activities. Migratory bird species [55, 56], honey bees [57], fish [58], mammals [59], bats [60], numerous insect species [61], mollusks [62], and even bacteria [63] are known to sense Earth's magnetic fields in various ways. Magnetoreception may enable some bird species to actually see the Earth's fields [64].

Some insect and arachnid species (e.g., Trichobothria) can detect natural atmospheric electric fields [65] which trigger ballooning behavior — e.g., climbing to the highest place, letting out silk, and traveling on wind currents using hair-like Trichobothria that detects airborne vibrations, currents, and electrical charge. Some have been found as high as 2.5 mi (4 km) in the sky, dispersing over hundreds of kilometers. Morley and Robert [65] found that the presence of a weak natural vertical e-field elicited ballooning behavior and takeoff in the spiders; their mechano-sensory hairs function as putative sensory receivers which are activated by natural weak electric-fields in response to both e-field and air-flow stimuli. The researchers hypothesized that atmospheric electricity was key to the mass migration patterns of some arthropod fauna.

Even soil nematodes (*Caenorhabditis elegans)* orient to earth-strength magnetic fields in their burrowing behaviors and a recent study by Vidal-Gadea [66] found that weak static fields slightly above Earth's natural fields determined stem cell regeneration in flatworms (*Planaria*) [67].

Large ruminant mammalian species also orient to the Earth's fields. Grazing cattle and deer were first observed aligning to geomagnetic field lines by Begall et al. [68]. Using satellite imagery, field observations, and measuring "deerbeds" in snow, they noted that domestic cattle across the globe, as well as grazing and resting red (*Cervus alphas*) and roe (*Capreolus capreolus*) deer, consistently align their body axis in a general north–south direction and that roe deer also orient their heads northward when grazing or resting. Burda et al. [69] discovered, however, that man-made ELF-EMF disrupted the north-south alignment with the geomagnetic field in resting cattle and roe deer when they found body orientation was random on pastures under or near power lines, with the disturbed pattern diminishing with distance from conductors. Cattle exposed to various magnetic field patterns directly beneath or near power lines exhibited distinct patterns of alignment. They concluded there was evidence for magnetic sensation in large mammals, as well as overt behavioral reactions to weak ELF-MF in vertebrates, implying cellular and molecular effects. Slaby et al. [70] also found cattle align along a north-south axis but suggested that such alignment may depend on herd density as the affect disappeared in herds with higher numbers. Fedrowitz [71] expanded this to include bovine sensitivity to other weak ELF-EMF from powerlines but with observed effects due to combined electric and magnetic fields rather than the electric field exposure alone (see "Bovines"below).

Cerveny et al. [72] found red fox (*Vulpes vulpes)* use geomagnetic fields during hunting. Even domestic dogs were found by Hart et al. [73] to be sensitive to small variations in the Earth's orientation in their excretion habits, preferring a general north-south axis for both defecation and urination depending on geomagnetic field changes. And Nießner et al. [74] found dogs and some other species may actually "see" geomagnetic fields through blue-light sensing photoreceptor proteins in their eyes called cryptochromes.

According to the US/UK World Magnetic Model [75], sensitivity to the geomagnetic field may further complicate issues for migratory species (e.g., some turtles, sea animals, birds, and insects) because the Earth's magnetic north pole is shifting faster than at any time in human history. Compared to the period between 1900 and 1980, it has greatly accelerated to about 30 mi (50 km) distance per year — moving west from over Canada's Ellesmere Island, its traditional allocation for most of recorded history — toward Russia [76]. Magnetic north fluctuates according to changes in the Earth's molten core, unlike true north which aligns according to the Earth's axis. This trend may indicate a coming pole reversal with north and south trading places, something that occurs approximately every 400,000 years with the last being about 780,000 years ago. Some animals may be capable of recalibrating navigational cues but that remains to be seen. Since some migratory bird species may see geomagnetic fields through special receptor cells in their eyes and via other mechanisms, they could be thrown off course. It is unclear how many other species also see geomagnetic fields but some crustaceans and several insect species, especially those with compound eye structures consisting of thousands of ommatidia — tiny independent photoreception units with a cornea, lens, and photoreceptor cells that orient in different directions and distinguish brightness and many more bands of color than humans — are good candidates. Compared to single-aperture eyes, compound eyes have a very large view angle that can detect fast movement and in some cases light polarization.

In aquatic environments, some lakes have more than 200 species of fish that use some form of electromagnetism to locate food and reproduce. Electric eels can deliver a 500-V zap to kill prey. Sharks have an array of electromagnetic sensors. These include: magnetic field receptors in their mouths, eyes that are 10 times more sensitive than humans, and their perception of tiny electric neuronal discharges from the moving muscles in prey (including humans) guides their attacking/feeding behavior (see "Fish"below). Sharks are often attracted by low-level electromagnetic fields surrounding underwater electric cables and are sometimes electrocuted when they mistake the conduit for living prey and bite into it. Many fish have lateral lines on either side of their bodies that are composed of magnetite, which allows fish to swim in synchronous schools [52].

Many other animals evolved special receptor organs to detect environmental EMF. The duck-billed platypus (*Ornithorhynchus anatinus),* a semi-aquatic primitive egg-laying mammal, has thousands of electric sensors on its bill skin. As noted in Lai [77], using these electroreceptors and interacting with another type of mechanoreceptor, a platypus can detect an electric field of 20 μV/cm [78] — equivalent to that produced by the muscles of a shrimp. The information is processed by the somatosensory cortex of the platypus to fix the location of prey. This type of electroreception is common in the three species of monotremes: platypus, and long (*Zaglossus bruijni)* and short-bill (*Tachyglossus aculeatus*) echidna. Electric fish (elasmobranchs) emit EMF that covers a distance of several centimeters [79, 80]. This allows location of potential prey by comparing its electrical properties with that in its immediate vicinity. Their electroreceptors have been shown to detect a field of 5 nV/cm. Such EMF-sensing systems are highly sensitive and efficient but also highly vulnerable to disruption by unnatural fields. Organisms that use the geomagnetic field for migration have the capability not only to detect the field but also the orientation of the field.

Anthropogenic light frequencies affect wildlife in ways we have only recently grasped. Ecological studies have found that artificial light-at-night is disrupting nocturnal animals in devastating ways, including disorientation and disruption in breeding and migration cycles in turtles, flying insects, birds, butterflies and a host of other wildlife including mammals [81–84]. As much as 30% of nocturnal vertebrates and over 60% of invertebrates may be affected by artificial light [85]. Illumination reflected off of clouds known as "sky glow" can produce unnaturally bright conditions at night from various wavelength spectra that impact different species, with the potential to alter the balance of species interactions [86, 87]. It has been found that changing the color of the light can help some species yet harm another [88]. For instance, low-pressure sodium lights that have more yellow in their spectrum reduce moth deaths around the bulbs, but salamanders cannot navigate from one pond to the next under yellow or red light. Some frogs have been observed to freeze for hours, even after lights have been turned off, and to suspend both feeding and reproduction [83].

One of nature's great mysteries involves "natal homing behavior" — the ability of some animal species to return to their original location of birth in order to reproduce, sometimes over great distances. Natal homing behavior is known in sea turtles [89]; eels [90]; and salmon [91], among other species. The underlying mechanism, though imperfectly understood, involves such species "remembering" the geomagnetic field configurations of their birthplace via a process known as "imprinting," and thus can locate and return to it even if they are thousands of miles/kilometers away at reproduction time. Apparently, newborns of these species are imprinted with the memory of the intensity and the inclination angle of the local geomagnetic field. This information is then later used to locate their place of birth where they return to breed.

The question is whether man-made EMF could distort this imprinting memory in later locating the site. For example, what if RFR-emitting facilities are located near turtle breeding sites? Could that interfere with imprinting? There is some evidence from Landler et al. [92] of adverse effects in turtles. The researchers found that RFR could disrupt a natural orientation, establish its own orientation, and reverse completely a natural orientation, indicating a need for research to further investigate as we simply do not know the full effects to other species from anthropogenic EMF.

Energy conduction in different species: unique physiologies and morphologies

The unique physiology and morphology of non-human species create additional complexities. For instance, quadrapedal species with four feet on the ground have different and potentially more efficient conductivity than bipedal species with two feet. One example is bovine heightened sensitivity to increased ground current near high tension lines [93, 94] and cell towers [95–97]. Also, bodies that are predominately parallel to the ground, which includes most four-legged mammals, rather than a perpendicular upright gait, conduct EMF in different ways than vertical species like humans, apes, and other primates. Species that hug the ground, like snakes, salamanders, and frogs, have unique exposures to ground currents, especially on rainy nights when water, as a conductive medium, can increase exposures [98]. This may make some species more sensitive to artificial ground current caused by electric utility companies using the Earth as their neutral return back to the substation for excess alternating current on their lines instead of running additional neutral lines on utility poles [99].

Hair and whiskers and related appendages in various species are known to detect small variations in electromagnetic fields as well as water and weather alterations [100]. In fact, ants have been observed to use their antennae as "EMF antennas" when subjected by researchers to external electromagnetic fields, aligning themselves to "channel" RFR away from the colony [7]. Species such as birds, as well as some insects with compound eyes structures, can see vastly more colors than humans, while cats, dogs, and owls, for instance, hear many more sound frequencies at incredibly low levels.

Magnetoreception mechanisms: electroreceptor cells, magnetite, cryptochromes/radical pairs

According to Lai [77], "…in order for an environmental entity to affect the functions of an organism, the following criteria have to be met: the organism should be able to detect the entity; the level of the entity should be similar to those in the normal ambient environment which is generally much lower than the level of the entity used in experimental studies; and the organism must have response mechanisms tuned to certain parameters of the entity that allow immediate detection of the presence and changes of the entity. Thus, a variation of the entity would be detected as an aberrant input and trigger a response reaction. In order to understand how man-made EMF affects wildlife, the above criteria must be considered, including multiple sensory mechanisms that vary from species to species."

The questions are: How do diverse species detect weak natural geomagnetic signals, distinguish the subtle internal microcurrent and magnetic fields inherent to all biology from external fields, then get beyond both internal and external background noise to make use of that electromagnetic information?

There are three primary mechanisms used to understand magnetoreception:

(1) Magnetic induction of weak electrical signals in specialized sensory receptors [101].
(2) Magnetomechanical interactions with localized deposits of single-domain magnetite crystals [52, 102, 103].
(3) Radical-pair photoreceptors, which may be the most plausible [104–111].

In the induction model (mechanism 1), according to Lin [102], the first category of electrodynamic interactions with weak magnetic fields is epitomized by elasmobranchs, including sharks, rays, and skates, with heads that contain long jelly-filled canals with high electrical conductivity known as the Ampullae of Lorenzini. As these fish swim through the Earth's geomagnetic lines of flux, small voltage gradients are induced in these canals with electric field detections as low as 0.5 μV/m [101] The polarity of the induced field in relation to the geomagnetic field provides directional cues for the fish. However, in birds, insects, and land-based animals, such cells have not been found, indicating this may not be a universal mechanism but rather are environment/species-specific factors [111].

The magnetomechanical model (mechanism 2) involves the naturally occurring iron-based crystalline mineral called magnetite found in most species [52]. Its function is most simply demonstrated in magnetotactic bacteria [63] with high iron content where biogenic magnetite is manufactured in 20–30 single domain crystal chains [112]. Orientation is patterned according to the geomagnetic field. Blakemore et al. [113] found that magnetotactic bacteria in the northern hemisphere migrate toward the north pole of the geomagnetic field whereas the same strains migrate toward the South Pole in the southern hemisphere. At the equator, they are nearly equally divided in north- and- south seeking orientations [114]. And they all migrate downward in response to the geomagnetic field's vertical component, which, in aqueous environments may be essential for their survival in bottom sediments.

Among the many species where magnetite has been found include the cranium and neck muscles of pigeons [115, 116]; denticles of mollusks [117, 118]; and the abdominal area of bees [119]. Tenforde [103] delineated other species with localized magnetite, including dolphins, tuna, salmon, butterflies, turtles, mice, and humans.

The third mechanistic model (mechanism 3) getting research attention today involves a complex free-radical-pair reaction and conversion of the forms of electrons (singlet-triplet inter-conversion) in a group of protein compounds known as cryptochromes. Cryptochromes have been found in the retinas of nocturnal migratory songbirds by Heyers et al. [55] and Moller et al. [56], showing complex communication with the brain for orientation when relying on magnetoreception. Gegear et al. [61] found cryptochromes to be a critical magnetoreception component in fruit flies (*Drosophila melanogaster)*. As noted in Lai [77], cryptochrones are also present in the retinas of some animals [120]. RFR [121] and oscillating magnetic fields [122] have been reported to disrupt the migratory compass orientation in migratory birds. There are also reports that indicate the presence of cryptochromes in plants, which may be responsible for the effect of EMF on plant growth [123]. Cryptochromes are also known to be involved with circadian rhythms [56, 124]. For an excellent review on plausibility, theories, and complexities of cryptochrome/radical pairs, see Ritz et al. [111].

Many species likely use a combination of these mechanisms as well as more subtle influences as yet undetected. The vector of the geomagnetic field may provide the directional information, while intensity and/or inclination provide the positional information needed for orientation. In behavioral studies [125, 126], Wiltschko et al. found that birds used both magnetite and cryptochrome mechanisms when they responded to a short, strong magnetic pulse capable of changing magnetization of magnetite particles, while their orientation was light-dependent and easily disrupted by high-frequency magnetic fields in the MHz range indicating radical pair processes. These findings suggest that along with electrophysiological and histological studies, birds have a radical pair mechanism located in the right eye that provides compass-like directional information while magnetite in the upper beak senses magnetic intensity, thus providing positional information. However, Pakhomov et al. [122] pointed out that the songbird magnetic compass can be disrupted by an oscillating 1.403-MHz magnetic field of 2–3 nT, at a level that cannot be explained by the radical-pair mechanism.

Light plays a significant role [127], which is of environmental concern today as more technology moves toward using the infrared bands for communications and the increase of satellites create artificial/unfamiliar star-like lights in the night sky that are potentially capable of impacting night migration patterns. There is other evidence that species use a combination of photoreceptors and magnetite-based magnetoreception. As mentioned above, in birds the two mechanisms exist side by side, mediating different types of magnetic information as needed, such as flight on sunny vs. cloudy days or nocturnal flights, and they can be easily disrupted [106, 128–130]. Birds may co-process visual information with magnetic information and be able to distinguish between the two [131, 132]. This function likely occurs in the eye or higher avian brain areas via light-dependent information processing and radical pair cryptochromes [131, 133]. Birds' magnetic compass is an inclination compass and RFR fields in the Larmor frequencies near 1.33 MHz were found to disrupt birds' orientation in an extremely sensitive resonance relationship. Blue-light absorbing photopigment cryptochromes have been found in the retinas of birds. RFR appears to directly interfere with the primary processes of magnetoreception and disable the avian compass as long as the exposure is present [126, 128].

Mammals have also demonstrated magnetoreception indicating radical-pair mechanisms. Malkemper et al. [134] found that the surface-dwelling wood mouse (*Apodemus sylvaticus*) built nests in the northern and southern sectors of a visually symmetrical, circular arena, using the ambient magnetic field, or in a field rotated by 90°, indicating the animals used magnetic cues. When the mice were also tested in the ambient magnetic field with a superimposed radio frequency magnetic field (100 nT, 0.9 to 5 MHz frequency sweep), they changed preference from north-south to east-west nest building. But unlike birds that have been found sensitive to a constant Larmor frequency exposure at 1.33 MHz, that range had no effect on mice orientation. Individual animal physiology clearly plays a role in how various species respond. Malewski et al. [135] also found that the Earth's magnetic field acts as a common directional indicator in five species of subterranean digging rodents. And for the first time, research also found that human brain waves exhibit a strong response to ecologically-relevant rotations of Earth-strength magnetic fields [136].

We need far better understanding of magnetoreception's neural, cellular, and molecular processes because the ultimate question is, given our constant rising background levels of EMF, is this ambient noise reaching a tipping point beyond which species simply cannot "hear?" Are we artificially overwhelming living species' ability to function with innate natural biological sensors that evolved over eons in a far more "electro-silent" world? The electroreception mechanisms described above — electroreceptors, magnetite, and cryptochrone/radical-pairs — enable living organisms to detect the presence and immediate changes in environmental fields of very low intensity. And thus they can be easily disturbed by the presence of unfamiliar low-intensity man-made fields.

Electrohypersensitivity in humans has also shown instantaneous response to EMF at low intensity [137]. According to Lai [77], one wonders whether the underlying mechanisms of electrohypersensitivity are similar to those described above. Electrohypersensitivity may be a remnant of the evolutionary responses of living organisms to electromagnetic fields — particularly magnetic fields — in the environment. Similarities include responsiveness to very low-field intensity; the response is persistent and built into the physiology of an organism; and the response is immediate and reacts quickly to the fields. Cryptochrome-free radical mechanisms may be involved. Some people are more sensitive than others. Perhaps non-sensitive people can tolerate and compensate for effects, and/or have lost responsiveness to natural magnetic fields and thus have become evolutionarily aberrant. Electrosensitivity is an issue in need of more careful and systematic study and has yet to be broadly highlighted as a health or public welfare concern.

One recent theory by Johnsen et al. [138] postulates that magnetoreception in animal species may be "noisy" — meaning that the magnetic signal is small compared to thermal and other receptor noise, for instance. They speculate that magnetoreception may serve as a redundant "as-needed" source of information, otherwise animal species would use it as their primary source of information. Many species, they note, preferentially exploit non-magnetic cues first if they are available despite the fact that the Earth's geomagnetic field is pervasive and ever-present. They speculate that magnetic receptors may thus be unable to instantaneously attain highly precise magnetic information, and therefore more extensive time-averaging and/or other higher-order neural processing of magnetic information is required. This may render "…the magnetic sense inefficient relative to alternative cues that can be detected faster and with less effort." Magnetoreception may have been maintained, however, they said by natural selection because the geomagnetic field may sometimes be the only available source of directional and/or positional information.

We already know that some species use various mechanisms to detect EMFs as noted throughout this paper. With new environmental factors from anthropogenic causes, such as artificial light-at-night, air/water pollution, climate change impacting visibility as environmental cues, and rising background RFR — all of which can obscure natural information — magnetoreception may, in fact, become *more* necessary as an evolutionary survival tool as time goes on, not less.

Other mechanisms of biological significance: DNA — direct and indirect effects (See Part 2, Supplements 1 and 2, for tables of ELF and RFR genetics studies)

A significant biological effect in any toxicology research involves the basic genetics of an exposed organism. Genetic effects consist mainly of gene expression, chromatin conformational changes, and genotoxicity. All such effects can influence normal physiological functions. Relevant to this paper is the fact that genetic effects are found at EMF levels similar to those in ambient environments, far below levels from communication devices and infrastructure (see Part 1, Supplement 1).

DNA, the fundamental building block of all life, is a molecular double helix that is coiled, twisted and folded within the nucleus of each living cell. It is essentially identical among species with variations only in number and specific genes along chromosomes on DNA's twisted chains that distinguish various species and their characteristics from one another. DNA damage repeatedly seen in one species can therefore be extrapolated to other species, although not all species react the same to external stimuli.

Many factors, both endogenous and exogenous, damage DNA which is then normally repaired by DNA enzymes. But an absence of adequate repair can result in the accumulation of damaged DNA, which will eventually lead to aging, cell death (apoptosis) and/or cancer. DNA breaks occur as both single and double strand events; double strand breaks are difficult to repair correctly and can lead to mutations. DNA damage from endogenous factors can include free radical formation from mitochondrial respiration and metabolism; exogenous factors include chemicals, ionizing and nonionizing radiation, and ultra violet light among others [139]

In several early studies, Lai and Singh [140, 141] found both double and single strand DNA breaks in the brain cells of rats exposed to RFR for 2 h at 2,450 MHz, and whole body SAR levels of 0.6 and 1.2 W/kg. The effects were interestingly blocked by antioxidants [142] suggesting free radical involvement, which could indicate an indirect cause for DNA damage (see below). The low-intensity genetic effects listed in Part 2 Supplements 1 and 2 are at 0.1 W/kg and less. Therefore, the Lai and Singh [140, 141] RFR studies are not included in those Supplements. Very similar effects have also been found by Lai and Singh [143, 144] with 60-Hz magnetic field exposure.

There has also been much study of ELF genetic effects. As discussed in Phillips et al. [139], numerous studies found that ELF-EMF leads to DNA damage [143–158]. Two studies [159, 160] showed that ELF also affects DNA repair mechanisms. Sarimov et al. [161] found chromatin conformational changes in human lymphocytes exposed to a 50-Hz magnetic field at 5–20 μT. EMF-induced changes in cellular free radicals are also well studied [77, 162].

Others investigated DNA damage early on but without the availability of today's more sensitive assays. Sarkar et al. [163] exposed mice to 2,450-MHz microwaves at a power density of 1 mW/cm^2 for 2 h/day over 120, 150, and 200 days. They found DNA rearrangement in the testis and brain of exposed animals that suggested DNA strand breakage. Phillips et al. [164] were the first to use the comet assay to study two different forms of cell phone signals — multi-frequency time division multiple access (TDMA) and integrated digital enhanced network (iDEN) — on DNA damage in Molt-4 human lymphoblastoid cells using relatively low intensities of 2.4–26 W/g for 2–21 h. The authors reported seeming conflicting increases *and* decreases in DNA damage, depending on the type of signal studied, as well as the intensity and duration of exposure. They speculated the fields could affect DNA repair mechanisms in cells, accounting for the conflicting results.

In a recent literature review of EMF genetic effects by Lai [165], analysis found more research papers reporting effects than no effects. For RFR, 224 studies (65%) showed genetic effects while 122 publications (35%) found no effects. For ELF and static-EMF studies, 160 studies (77%) found effects while in 43 studies (23%) no effects were seen.

Research now points to the duration, signaling characteristics, and type of exposure as the determining factors in potential damage [164, 166], not the traditional demarcation between ionizing and nonionzing radiation. Long-term, low-level nonionizing radiation exposures common today are thought to be as detrimental to living cells as are short-term, high-intensity exposures from ionizing radiation. Effects may just take longer to manifest [167]. Nonionizing EMF at environmental levels does cause genetic damage. These have also been shown in humans exposed to environmental levels of EMF in both ELF and RFR ranges [168–171]. Conceivably, similar genetic effects could happen in other species living in similar environments.

This body of genetics work goes against the pervasive myth that low-level, low-intensity nonionizing radiation cannot cause detrimental genetic effects. That premise is in fact the bedrock belief upon which vested interests and government agencies rely in support of current exposure standards. But in fact, biological systems are far more complex than physics models can ever predict [6, 8, 172]. A new biological model is needed because today's exposures no longer fit that framework [173] for humans and wildlife. Enough research now indicates a reassessment is needed, perhaps including the very physics model used to back those traditional approaches (see Part 1).

Direct mechanisms: DNA as fractal antennas, cell membranes, ion channels

DNA as fractal antennas

There are several likely mechanisms for DNA damage from nonionizing radiation far below heating thresholds, both direct and indirect, intracellular, intercellular, and extracellular. Such mechanisms potentially apply to all wildlife. One direct mechanism theorizes that DNA itself acts as a fractal antenna for EMF/RFR [174], capable of receiving information from exogenous exposures.

According to Blank and Goodman [174], DNA has interesting electrical characteristics due to its unique structure of intertwined strands connected by rungs of molecules called nucleotides (also called bases), with each rung composed of two nucleotides (one from each strand) in bonded pairs. The nucleotides are held together by hydrogen bonds in close proximity that results in a strong attraction between the two strands. There are electrons on both molecular surfaces making the symmetrical nucleotides capable of conducting electron current along the entire DNA chain, a phenomenon called electron transfer. This makes DNA a most efficient electrical conductor, something not lost on nanotechnology researchers.

DNA may also act as an efficient fractal antenna due to its tightly packed shape within the cell nucleus. Blank and Goodman [174] characterized DNA properties in different frequency ranges, and considered electronic conduction within DNA's compact construction in the nucleus. They concluded that the wide frequency range of observed interactions seen with EMF is the functional characteristic of a fractal antenna, and that DNA itself possesses the two structural characteristics of fractal antennas — electronic conduction and self symmetry. They noted that these properties contribute to greater reactivity of DNA with EMF in the environment, and that direct DNA damage could account for cancer increases, as well as the many other biological effects seen with EMF exposures.

A fractal is a self-repetitive pattern of sometimes geometric shapes, marked by a larger originating design progressing to small identical designs with a potentially unlimited periphery. Each part of the shape looks like the whole shape. Fractal designs are quite common in nature, e.g., in snail/mollusk shells, some deciduous tree leaves and conifer needles, pine cones, many flowering plants, some reptile scales, bird feathers and animal fur patterns, snowflakes, and crystals forming on cold winter glass windows. Minerals — both inert and biological — can also be fractals.

The varying sizes within fractals are what make them inherently multi-frequency. By mimicking nature, repetitive fractal patterns are also designed into mechanical transceiver antennas that radiate in multiband frequencies with more or less efficiency [175]. Cell phones, WiFi, digital TV, and many other transceivers use fractal antennas to operate.

The complex twisted shape and coiled structure of DNA — small coils coiled into larger coils, or *coiled coils*, which Blank and Goodman [174] note that no matter how far you zoom in or out, the shape looks the same — is the exact structure of a fractal that maximizes the length of an antenna within a compact space while boosting multi-frequency signals. As such, DNA may be acting as a hidden intracellular biological fractal capable of interacting with exogenous EMF across a range of frequencies. In fact, one of DNA's fundamental functions may be specifically to interact with exogenous natural energy and as such may be more sensitive to EMF than other larger protein molecules within any living system. Once thought safely tucked away and protected within the nucleus, DNA may be acting as a most efficient electrical conductor at the nexus of all life. This interesting theory, unfortunately, has not been followed up by others to test its biological validity although fractals have been mimicked widely in technology.

Cell membranes/ion channels

Another direct effect from EMF is at the cell membrane itself. While DNA is life's fundamental building block, cells are DNA's complex electron-coherent architectural expression. The cell's membrane is far more than just a boundary. It is rather the most important ordering tool in the biological space between intracellular and extracellular activities, "… a window through which a unitary biological element can sense its chemical and electrical environment" [176]. And it is replete with microcurrent.

The cell's outer surface contains molecules that receive innumerable electrochemical signals from extracellular activities. Specific binding portals on the cell membrane set in motion a sequence leading to phosphorylation of specific enzymes that activate proteins for cellular 'work.' That includes everything from information processing in the central nervous system, mechanical functions such as muscle movements, nutrient metabolism, and the defense work of the immune system, among many others including the production of enzymes, hormones, antibodies, and neurotransmitters [177]. Complex microcurrent signaling pathways exist from the cell's outside to the inside via protein intramembraneous particles in the phospholipid plasma membrane. These convey information on external stimuli to the cell's interior to allow cellular function.

The cell membrane also has electrical properties. Microcurrent constantly moves from the interior to the exterior and vice versa of the cell membrane. According to Adey and Sheppard [176], some of these properties influence proteins that form voltage gated membrane channels, which is one way that cells control ion flow and membrane electromagnetic potential essential to life. There are specific windows that react according to frequency, amplitude, and duration differences, indicating a nonlinear and non-equilibrium character to exogenous exposures on cells [177–185].

Some pulsed fields are more biologically active than non-pulsed fields and different forms of pulsing also create different effects. As far back as 1983, Goodman et al. [186] found pulsed weak electromagnetic fields modified biological processes via DNA transcription when a repetitive single pulse and the repetitive pulse train were used. The single pulse increased the specific activity of messenger RNA after 15 and 45 min while the pulse train increased specific activity only after 45 min of exposure. Digital technology simulates pulsing and is the most common form of environmental exposure today.

Cellular calcium ion channels have long been of interest and may be particularly sensitive targets for EMFs due to possible increased calcium flux through the channels which can lead to secondary responses mediated through Ca^{2+}/calmodulin stimulation of nitric oxide synthesis, calcium signaling, elevated nitric oxide (NO), NO signaling, peroxynitrite, free radical formation, and oxidative stress — many with implications to DNA as hypothesized by Pall [187]. Calcium is essential to signal transduction between cells and is significant to everything from metabolism, bone/cell/blood regeneration, hormone production and neurotransmissions among many others. These cellular calcium responses to EMF indicate an artificial change in the signaling processes at the cell membrane — considered a switchboard for information between the exterior environment and intracellular activities that guide cell differentiation and control growth [188].

Pall [187] cited 23 studies of effects to voltage gated calcium channels (VGCC) and noted nonthermal mechanisms were the most likely since many studies showed effects were blocked by calcium channel blockers (widely prescribed for heart irregularities having nothing to do with thermal issues). Pall [189] noted that many other studies showed EMF changes in calcium fluxes and intracellular calcium signaling. He hypothesized that alterations in intracellular calcium activity may explain some of the myriad biological effects seen with EMF exposure, including oxidative stress, DNA breaks, some cancers, infertility, hormonal alterations, cardiac irregularities, and diverse neuropsychiatric effects. These end points need further study and verification.

There is much to be learned about calcium effects as studies are contradictory. Changes in free radicals (see below) also affect calcium metabolism. There are more studies showing EMF effects on free radicals than calcium changes. Calcium activates the nitric oxide free radical pathway but there are only a few studies of this pathway following EMF exposure — less than 5% of EMF-oxidative change studies are on nitric oxide mechanisms. Also of interest is the fact that power density and frequency windows were seen in early research at rising harmonic increments along the electromagnetic spectrum beginning in the ELF bands [190–195]. Observed effects were quite dramatic in what researchers described as calcium efflux or 'dumping' from cells. The most dramatic effects were seen at 180 Hz in the ELF range. This appears to contradict Pall's work [189] cited above as increased calcium efflux is the opposite of what Pall's hypothesis would predict, e.g., calcium *influx*. With more research both calcium influx and efflux effects may be found to be caused by different variables and/or EMF exposures.

In addition, exogenous signaling characteristics are also important to how cells react to both ELF and RFR ranges. Building on the work that demonstrated carrier waves of 50 and 147 MHz, when sinusoidally amplitude modulated at 16 Hz ELF in *in vitro* chick brain tissue [190, 191] and in live awake cat brain models [196] that created frequency windows for calcium efflux, Blackman et al. [194] additionally found that signaling *characteristics* were also significant. Research showed that calcium efflux occurred only when tissue samples are exposed to specific intensity ranges of an ELF-modulated carrier wave; unmodulated carrier waves did not affect ion efflux. Blackman et al. [194] further wrote that cells may be capable of demodulating signals. The authors reported that 16-Hz sinusoidal fields, in the absence of a carrier wave, altered the efflux rate of calcium ions and showed a frequency-dependent, field-induced enhancement of calcium-ion efflux within the ranges 5–7.5 V/m and 35–50 V/m (peak-to-peak incident field in air) with no enhancement within the ranges 1–2, 10–30, and 60–70 V/m. This body of work indicates that living cells interact with, and are capable of taking direction from, exogenous fields in far more complex ways than ever imagined, at intensities barely above background levels. This work may be particularly important to new technology that turns previously wired ELF frequencies into wireless applications, such as "wireless electricity" to charge electric cars.

Blackman et al. [197] found for the first time a link between the ELF/EMF being studied and the density of the natural local geomagnetic field (LGF) in the production of a biological response. Calcium efflux changes could be manipulated by controlling the LGF along with ELF and RF-EMF exposures. In a local geomagnetic field at a density of 38 μT, 15- and 45-Hz electromagnetic signals had been shown to induce calcium ion efflux from the exposed tissues, whereas 1- and- 30-Hz signals did not. Bawin and

Adey [190] found a reduction in efflux when using an electric field; Blackman et al. [194] found an increase when using an electromagnetic field, thus identifying/isolating for the first time the significance of the magnetic field component in exposure parameters. Building on the window ranges noted above, Blackman et al. [197] demonstrated that the enhanced calcium efflux field-induced 15-Hz signal could be rendered ineffective when the LGF is reduced to 19 μT with Helmholtz coils. In addition, the ineffective 30-Hz signal became effective when the LGF was altered to k25.3 μT or to +76 μT. *The results demonstrated that the net intensity of the local geomagnetic field is an important cofactor in biological response and a potentially hidden variable in research.* The results, they noted, appear to describe a resonance-like relationship in which the frequency of the electromagnetic field can induce a change in calcium efflux proportional to LGF density (see Liboff [198, 199] below for more detail).

The bottom line is that changes of this magnitude at the cellular level — be it directly to DNA within the nucleus or via voltage gated channels at the cell's membrane — can lead to direct effects on DNA within and across species. The evidence cited above illustrates the degree, likelihood, and variety of impacts from EMF directly on cellular physiology that are capable of affecting DNA in all living systems in myriad ways.

Indirect mechanisms: free radicals, stress proteins, resonance, Earth's geomagnetic fields

Free radicals

An indirect, or secondary, mechanism for DNA damage would be through free radical formation within cells, which is the most consistently reported with both ELF and RFR exposures under many different conditions in biological systems. According to Phillips et al. [139], free radicals may also interact with metals like iron [142, 151, 152, 158] and play a role in genotoxic effects from something called the Fenton effect — a process "…catalyzed by iron in which hydrogen peroxide, a product of oxidative respiration in the mitochondria, is converted into hydroxyl free radicals, which are very potent and cytotoxic molecules" [139].

The significance of free radical processes may eventually answer some questions regarding how EMF interacts with biological systems. There are about 200–300 papers showing EMF effects on free radicals [77, 168, 200]. Free radicals are important compounds involved in numerous biological functions that affect many species. Increases in free radicals explain effects from damage to macromolecules such as DNA, protein, and membrane lipids; increased heat shock proteins; neurodegenerative diseases; and many more.

Yakymenko et al. [168] published a review on oxidative stress from low-level RFR and found induced molecular effects in living cells, including significant activation of key pathways generating reactive oxygen species (ROS), activation of peroxidation, oxidative damage in DNA, and changes in the activity of antioxidant enzymes. In 100 peer-reviewed studies, 93 confirmed that RFR induced oxidative effects in biological systems and that their involvement in cell signaling pathways could explain a high pathogenic range of biological/health effects. They concluded that low-intensity RFR should be recognized as one of the primary mechanisms of biological activity of nonionizing radiation. In a follow-up study, Yakymenko et al. [200] investigated the oxidative and mutagenic effects of low intensity GSM 1,800 MHz RFR on developing quail embryos exposed *in ovo* (0.32 $\mu W/cm^2$, 48 s On, 12 s Off) during 5 days before and 14 days through the incubation period. They found statistically significant oxidative effects in embryonic cells that included a 2-fold increase in superoxide generation rate, an 85% increase in nitrogen oxide generation, and oxidative damage to DNA up to twice the increased levels of 8-oxo-dG in cells of 1-day old chicks. RFR exposure almost doubled embryo mortality and was statistically significant. They concluded that such exposures should be recognized as a risk factor for living cells, including embryonic integrity.

Lai [77] focused a review on static magnetic field ELF-EMF and found that changes in free radical activities are one of the most consistent effects. Such changes can affect numerous physiological functions including DNA damage, immune system and inflammatory response, cell proliferation and differentiation, wound healing, neural electrical activities, and behavior. Given that many species have proven sensitive to natural static geomagnetic fields and use such information in critical survival skills, some wildlife species may also be adversely affected via free radical alterations from anthropogenic exposures. But Lai [77] noted the inherent contradictions from EMF-induced changes in free radicals, particularly on cell proliferation and differentiation since those processes can affect cancer development as well as growth and development. Induced free-radical changes may therefore have therapeutic applications in killing cancer cells via the generation of the highly cytotoxic hydroxyl free radical by the Fenton Reaction (noted above), thereby creating a non-invasive low-side-effect cancer therapy.

Stress proteins

Another potentially indirect effect to DNA is via protein synthesis required by all cells to function. A living animal converts animal and plant proteins that it ingests into other proteins needed for life's activities — antibodies, for instance, are a self-manufactured protein. DNA is critical to protein synthesis and can create in humans about 25,000 different kinds of proteins with which the body can then create 2,000,000 types in order to fully function.

There are many different classes of proteins. These include stress proteins stimulated by potentially harmful environmental factors to help cells cope and repair damage due to factors like acute temperatures, changes in oxygen levels, chemicals/heavy metals exposure, viral/bacterial infections, ultraviolet light and other ionizing and nonionizing radiation exposures [124].

The presence of stress proteins indicates healthy repair action by an organism and is considered beneficial up to a point as a protective mechanism. According to Blank and Goodman [201], "The 20 different stress protein families are evolutionarily conserved and act as 'chaperones' in the cell when they 'help' repair and refold damaged proteins and transport them across cell membranes. Induction of the stress response involves activation of DNA." Stress proteins are also considered a yardstick to determine what living cells experience as stress that requires remediation in the first place — something not always obvious, especially with subtle environmental exposures like low-level EMF barely above natural background levels.

Whether an effect is thermal or nonthermal, adverse or simply observed biologically, has been subject to fierce debate for decades; thus tissue-heating DNA pathways are also central to this paper. Heat as a cellular stressor was first observed in the 1960s by Italian researcher Ferruccio Ritossa in fruit flies (*D. melanogaster*) when experimental temperatures were accidentally raised by a few degrees and he observed enlarged chromosomes at particular sites. (*Drosophilae* are often used in research because they only have four pairs of chromosomes, are relatively easy to work with, have a fast breeding cycle, and lay numerous eggs.) As cited in Blank [124], as Ritossa's observation became better understood, with effects subsequently seen over decades in animals, plants and yeast cells, it came to be called the "heat shock response." Extensive research established that the heat shock response lead to the formation of a unique protein class — heat shock proteins (HSP) that repair other proteins from potentially fatal temperature damage, as well as assist cells to be more thermo-tolerant. Research has gone on to prove that cells produce other similar proteins to various stressors, now generally called stress proteins but most are still categorized as "HSP" from the original demarcation.

Goodman and Blank [202, 203] found that EMF is a cellular stressor even at low intensities in the absence of elevated temperatures. They found the protein distribution patterns synthesized in response to ELF-EMF resembled those of heat shock with the same sequence of changes even though the energy of the two stimuli differed by many orders of magnitude. Their results indicated that ELF-EMF stimulates a similar gene expression pathway as that of thermal shock and is itself a cellular stressor. Of particular significance is the fact that over-expression of stress genes is found in a number of human tumors and is characteristic of a variety of neoplasia [202]. Increased stress proteins are seen in numerous animal model studies pertinent to wildlife.

Blank and Goodman [201] further noted that both ELF and RFR activate the cellular stress response despite the large energy difference between them; that the same cellular pathways respond in both frequency ranges; and that models suggest that EMF can interact directly with electrons in DNA. They note that low energy EMF interacts with DNA to induce the stress response while the increased energy in RFR can lead to DNA strand breaks. *As such, this makes the stress response a frequency-dependent direct and indirect cause of DNA damage — a significant finding.* They concluded that exposure standards should not be based on exposure intensity alone but on biological responses long before thermal thresholds are met or crossed.

Resonance and geomagnetic fields

There are other important direct and indirect ways that EMFs interact with and effect biological systems, including various forms of resonance — cyclotron, electron paramagnetic, nuclear, and stochastic — as well as through inherently produced biological materials such as magnetite found in bird brains and many other species (see below).

Resonance is the phenomenon that occurs when a certain aspect of a force (like a frequency wave) matches a physical characteristic (like a cell or whole living organism) and the power inherent in the force is transferred to the physical object causing it to resonate or vibrate. Within the object, the resonance is self-perpetuating. The classic example is of an opera singer hitting high C in the presence of a crystal goblet for a sustained period until it shatters.

Following the work of Blackman et al. [197] who found the Earth's local geomagnetic fields (LGF) could influence calcium ions moving through membrane channels (see above), Liboff [198, 199] proposed that cyclotron resonance was a plausible mechanism for coupling interactions between the LGM and living cells. Liboff found cyclotron resonance consistent with other indications that showed many membrane channels have helical configurations; that the model could apply to other circulating charged components within the cell; and that cyclotron resonance could lead to direct resonant electromagnetic energy transfer to selected cell compartments.

All resonance is based on a *relationship*. Cyclotron resonance is based on the relationship between a constant magnetic field and an oscillating (time-varying) electric or magnetic field that can affect the motion of charged particles such as ions, some molecules, electrons, atomic nuclei, or DNA in living tissue. Living systems are filled with charged particles necessary for life, including calcium, sodium, lithium, and potassium ions that all pass through the cell membrane and are capable of affecting DNA. Cyclotron resonance occurs when an ion is exposed to a steady magnetic field (such as the Earth's) which causes the ion to move in a circular orbit at a right angle to the field. The speed of the orbit is determined by the charge and mass of the ion and the strength of the magnetic field. If an electric field is added that oscillates at exactly the same frequency and that is also at a right angle to the magnetic field, energy will be transferred from the electric field to the ion causing it to move faster. The same effect can be created by applying an additional magnetic field parallel to the constant magnetic field. This is important because it provides a plausible mechanism for how living cells interact with both natural and artificial fields, and explains how vanishingly low levels of EMFs can create major biological activity when concentrated on ion particles. It also points to living systems' ability to demodulate — or take direction from — certain aspects of electromagnetic information from both natural and artificial exposures [7]. Resonance should not be underestimated. It applies to all frequencies and is not based on power density alone.

Another subtle energy relationship in biology is called stochastic resonance that has been determined to be significant in how various species interact with their natural environments, in some instances for their survival. Stochastic resonance is a phenomenon where a signal below normal sensing can be boosted by adding wide-spectrum white noise signals. The frequencies in the white noise that match the original signal's frequencies will resonate with each other and amplify the original signal while not amplifying the rest of the white noise. This increase in what is called the signal-to-noise ratio makes the original signal more prominent. Some fish, for instance, can "hear" predators better in the noise of running water than in still water due to stochastic resonance (see "Fish" below.).

The signal-to-noise ratio has been a prominent aspect of EMF research with some scientists long holding that energy exposures below the body's natural signal-to-noise ratio could not possibly damage living tissue. But the most recent research that finds effects to DNA from low intensity EMF indicates that many variables affect biological processes, often in nonlinear patterns far below the signal-to-noise ratio. Some of the most cutting edge research — with an eye toward treating human *in utero* birth defects and adult limb regeneration — is being done by manipulating the electric charge across cell membranes (called membrane potential) via intentional manipulation of genes that form ion channels. Pai et al. [204] found that by putting ion channels into cells to raise the voltage up or down, they could control the size and location of the brain in embryonic African clawed frogs (*Xenopus laevis*), thus demonstrating the importance of microcurrents on membrane potential in growth and development. The research group also studied endogenous bioelectricity on clawed frog brain patterning during embryogenesis, noting that early frog embryos exhibit a characteristic hyperpolarization of cells lining the neural tube. Disruption of this spatial gradient of the transmembrane potential (V_{mem}) diminished or eliminated the expression of early brain markers in frogs, causing anatomical mispatterning, including absent or malformed regions of the brain. This effect was mediated by voltage-gated calcium signaling and gap-junctional communication. The authors hypothesized that voltage modulation is a tractable strategy for intervention in certain classes of birth defects in humans but they did not make the leap to potential environmental damage to other species from such ambient exposures.

In general, whether direct, indirect, or synergistic, to understand ambient effects to wildlife, one also needs to know if effects are cumulative, what compensatory mechanisms a species may have, and when or if homeostasis will deteriorate to the point of no return [205]. In looking at environmental contaminants, we have historically focused on chemicals for both direct and indirect effects such as endocrine disruption. But primary biological manifestation is more physical than chemical since the only thing that distinguishes one chemical from another on the Periodic Table is the amount of electrons being traded up and down on the scale. Chemicals are actually secondary manifestations of initial atomic principles, not the other way around. Plus, the synergistic effects of the Earth's natural fields can no longer be dismissed as an interesting artifact that is not biologically active or relevant. All living systems are first and foremost expressions of biological energy in various states of relationship.

For a Table of more low-level effects studies on DNA, see Part 2, Supplements 1 and 2.

What the studies show

The literature is voluminous on EMF effects to nonhuman species, going back at least to the 1930s using modern methods of inquiry. We have, after all, been using animal, plant, and microbial models in experiments for decades. We may in fact know *less* about effects to humans than to other species.

In this paper, we focused on exposures common in today's environment. In Part 1, Rising Background Levels, we defined low level RFR as power density of 0.001 mW/cm^2 (1 μW/cm^2), or a SAR of 0.001 W/kg. Part 2 Supplements 3 and 4 contain extensive tables with pertinent studies that apply to fauna and flora, respectively. The sections that follow in Part 2 on individual species include selected studies of particular interest to how EMF couples with, and potentially affects, wildlife. In most studies, as illustrated in Part 2, Supplement 3, the intensity of the incident EMF was provided in μW/cm^2 or V/m. To be consistent throughout the paper, we converted intensity in the studies to μW/cm^2. However, such conversion (i.e. V/m to μW/cm^2) tends to overestimate the exposure level and does not represent the full picture. Therefore where studies provided the amount of energy absorbed, e.g., the specific absorption rate (SAR), they were also included in Supplement 3 (in W/kg). Very low levels of energy absorption have shown effects in all living organisms studied.

Levitt and Lai [167] reported numerous biological effects from RFR at very low intensities and SARs comparable to far-field exposures within 197–492 ft (60–150 m) from cell towers. Included were *in vivo* and *in vitro* low-intensity RFR studies. Effects included genetic, growth and reproductive changes; increased permeability of the blood brain barrier; changes in stress proteins; behavioral responses; and molecular, cellular, genetic, and metabolic alterations. All are applicable to migratory birds, mammals, reptiles, and other wildlife and to plant communities, and to far-field exposures in general. (An update of that table appears in Part 2 Supplement 3.) It is apparent that environmental levels of RFR can elicit biological/health effects in living organisms. Although there are not enough data on low-intensity effects of static ELF-EMF to formulate a separate table, some effects of low-intensity static ELF-EMF are also described throughout this paper. ELF genotoxic effects can be found in Part 2, Supplement 2 and ELF in flora are also listed separately in Part 2, Supplement 4.

Effects, however, do not easily translate from the laboratory to the field. Cucurachi et al. [31] reported on 113 studies with a limited number of ecological studies. The majority were conducted in laboratory settings using bird embryos or eggs, small rodents, and plants. In 65% of the studies, effects from EMF (50% of the animal studies and about 75% of the plant studies) were found at both high and low intensities, indicating broad potential effects. But lack of standardization among the studies and limited sampling size made generalizing results from organism to ecosystem difficult. The researchers concluded that due to the number of variables, no clear dose–response relationship could be determined. Nevertheless, effects from some studies were well documented and can serve as predictors for effects to wild migratory birds and other wildlife.

As noted elsewhere throughout this paper, living organisms can sense and react to very low-intensity electromagnetic fields necessary for their survival as seen, for instance, in studies by Nicholls and Racey [206, 207] on bats and many others. Bats are already in serious trouble in North America from white-nosed syndrome and commercial wind turbine blade collisions. Due to the increased use of tracking radars for bird and bat studies, impacts will likely only increase [22, 23]. Presence of low levels of RFR from tracking radars could adversely affect bat foraging activity, which in turn could affect the composition of insect populations in the vicinity. Many insects, including honey bees (*Apis mellifera* var) and butterflies also depend on the Earth's electromagnetic fields for orientation and foraging. Presence of exogenous RFR can disturb these functions. This is particularly relevant for pollinator insects, such as bees and butterflies. Pollinators are essential in producing commercial crops for human consumption, including almonds, apples, pears, cherries, numerous berry crops, citrus fruits, melons, tomatoes, sunflowers, soybeans, and much more. The strongest disruptive effect to insect pollinators occurs at 1.2 MHz known as the Larmor frequency [208] which is related to radical pair resonance and superoxide radical formation. This is an important indication that effects from RFR are frequency-dependent.

Lai [77], citing Shepherd et al. [209], noted that EMF can disrupt the directional sense in insects. The fact that many animals are able to differentiate the north and south poles of a magnetic field known as the polarity compass [68, 73, 134, 210, 211] indicates they are susceptible to having that important sense impaired. These polarity compass traits confer survival competitiveness to organisms but are of particular concern since directional cues can be easily disturbed by man-made EMF [69, 134, 212].

Bird migration also depends on proper sensing and orientation to natural electromagnetic fields. A study by Engels et al. [213] showed that magnetic noise at 2 kHz–9 MHz (within the range of AM radio transmission) could disrupt magnetic compass orientation in migratory European Robins (*Erithacus rubecula*). The disruption can occur at a vanishingly low level of 0.01 V/m, or 0.0000265 μW/cm^2. Similar effects of RFR interference on magnetoreception have also been reported in a night-migratory songbird [214] and the European Robin [126]. Migration is already a taxing and dangerous activity for birds; adding another potential negative impact to bird survival is troubling.

Lai [77] also noted that another consideration is the "natal homing behavior" exhibited in some animals that return to their natal birth places to reproduce. These include sea turtles [89] eels [90]; and salmon [91]. Newborns of these animals are imprinted with the memory of the intensity and the inclination angle of the local geomagnetic field, later used to locate their place of birth when they return to breed. There are indications that man-made EMF can distort this imprinting memory to locate the site (see "Fish" and "Turtles"below). This has important consequences to the survival of particular species since it interrupts their reproductive processes.

It is clear that biological effects can occur at levels of man-made RFR in our present environment, thereby conceivably altering delicate ecosystems from a largely unrecognized danger.

Mammals

The majority of EMF laboratory research, some going back to the 1800s, has been conducted on a variety of mammal species using mice, rats, rabbits, monkeys, pigs, dogs, and others. (The second and third most used models are on insects and yeast respectively.) Thus, with varying degrees of confidence, we know a significant amount about how energy couples with, and affects, laboratory mammalian species across a range of frequencies. However, this evidence does not automatically transfer at the same confidence level regarding how this vast body of research applies to wildlife, including mammalian species.

There is unfortunately a dearth of field research on EMF effects to wildlife. Referenced below, however, are many potential indicator studies. The effects seen include reproductive, behavioral, mating, growth, hormonal, cellular, and others.

Rodents

Rodents are the most frequently used mammalian species in laboratory research across a range of frequencies and intensities. While studies are inconsistent, there are enough troubling indications regarding potential EMF implications for wildlife.

In the RFR range, there have been several reviews of fertility and other issues in rodent models with citations too numerous to mention here — see La Vignera e al. [215] and Merhi [216] — but some stand out as potentially pertinent to wildlife.

Magras and Xenos [217] investigated effects of RFR on prenatal development in mice, using RFR measurements and *in vivo* experiments at several locations near an "antenna park," with measured RFR power densities between 0.168 and 1.053 μW/cm^2. Divided into two groups were 12 pairs of mice, placed in locations of different power densities, and mated five times. One hundred eighteen newborns were collected, measured, weighed, and examined macro- and microscopically. With each generation, researchers found a progressive decrease in the number of newborns per dam ending in irreversible infertility. However, the crown-rump length, body weight, and number of lumbar, sacral, and coccygeal vertebrae, was improved in prenatal development of some newborns. RFR was below exposure standards and comparable to far-field exposures that mice could experience in the wild.

Aldad et al. [218], in a laboratory setting, investigated cell phone RFR (800–1,900 MHz, SAR of 1.6 W/kg) exposures in *in-utero* mouse models and effects on neurodevelopment and behavior. They found significant adult behavioral effects in prenatally exposed mice vs. controls. Mice exposed *in-utero* were hyperactive, had decreased memory and anxiety, and altered neuronal developmental programming. Exposed mice had dose-response impaired glutamatergic synaptic transmission onto layer V pyramidal neurons of the prefrontal cortex. This was the first evidence of neuropathology in mice from *in-utero* RFR at cell phone frequencies, now the most prevalent in the environment. Effects persisted into adulthood and were transmissible to next generations. Such changes can affect survival in wild populations.

Meral et al. [219] looked at effects in guinea pigs (*Cavia parcels*) from 900 MHz cell phone frequency exposures on brain tissue and blood malondialdehyde (MDA), glutathione (GSH), retinol (vitamin A), vitamin D(3) and tocopherol (vitamin E) levels, as well as catalase (CAT) enzyme activity. Fourteen male guinea pigs were randomly divided into control and RFR-exposed groups containing seven animals each. Animals were exposed to 890- to-915 MHz RFR (217 Hz pulse rate, 2 W maximum peak power, SAR 0.95 W/kg) from a cellular phone for 12 h/day (11 h 45 min stand-by and 15 min spiking mode) for 30 days. Controls were housed in a separate room without cell phone radiation. Blood samples were collected through cardiac puncture; biochemical analysis of brain tissue was done after decapitation at the end of the 30-day period. Results found MDA levels increased ($p<0.05$), and GSH levels and CAT enzyme activity decreased, while vitamins A, E and D(3) levels did not change significantly in the brain tissue of exposed animals. In blood samples of the exposed group, MDA, vitamins A, D(3) and E levels, and CAT enzyme activity increased ($p<0.05$), while GSH levels decreased ($p<0.05$). They concluded that cell phone radiation could cause oxidative stress in brain tissue of guinea pigs but more studies were needed to determine if effects are harmful and/or affect neural functions.

Lai et al. [220] found that Sprague-Dawley rats exposed to RFR during water maze testing showed spatial working memory deficits compared to controls. But similar studies [221–223] did not find performance effects in spatial tasks or alterations in brain development after similar exposures. However, subsequent studies in the last two decades have shown memory and learning effects in animals and humans after RFR exposure [224].

Several studies also investigated RFR behavioral effects in rodent models on learning, memory, mood disturbances, and anxiety behaviors with contradictory results. Daniels et al. [225] found decreased locomotor activity, increased grooming and increased basal corticosterone levels in rats exposed to RFR for 3 h per day at 840 MHz, but no significant differences were seen between controls and test animals in spatial memory testing or morphological brain assessment. The researchers concluded that RFR exposure may lead to abnormal brain functioning.

Lee et al. [226, 227] looked specifically at effects on pregnant mice and rat testicular function from combined RFR mobile network signal characteristics used in wideband code division multiple access (W-CDMA) or CDMA used in 3G mobile communications. Experiments showed no observable adverse effects on development, reproduction, or mutation in tested subjects. And no significant effects were seen by Poulletier de Gannes et al. [228] in *in-utero* and post-natal development of rats with wireless fidelity (WiFi) at 2,450 MHz. Also, Imai et al. [229] found no testicular toxicity from 1.95 GHz W-CDMA.

One extremely high frequency (EHF) study comparable to 5G on a mouse model by Kolomytseva et al. [230] looked at leukocyte numbers and the functional activity of peripheral blood neutrophils. In healthy mice, under whole-body exposures to low-intensity extremely-high-frequency electromagnetic radiation (EHF, 42.0 GHz, 0.15 mW/cm^2, 20 min daily) found that the phagocytic activity of peripheral blood neutrophils was suppressed by about 50% ($p<0.01$ as compared with the sham-exposed control) in 2–3 h after the single exposure. Effects persisted for 1 day and thereafter returned to normal within 3 days. But a significant modification of the leukocyte blood profile was observed in mice exposed to EHF for 5 days after exposure cessation. Leukocytes increased by 44% ($p<0.05$ as compared with sham-exposed animals). They concluded that EHF effects can be mediated via metabolic systems and further said results indicated whole-body low-intenstiy EHF exposure of healthy mice had a profound effect on the indices of nonspecific immunity. These low levels will be common near 5G infrastructure.

In well-designed non-rodent mammal field studies, Nicholls and Racey [206, 207], found that foraging bats showed aversive behavioral responses near large air traffic control and weather radars. Four civil air traffic control (ATC) radar stations, three military ATC radars and three weather radars were selected, each surrounded by heterogeneous habitat. Three sampling points were carefully selected for matched habitats, type, structure, altitude and surrounding land class at increasing distances from each station. Radar field strengths were taken at three distances from the source: close proximity (<656 ft/200 m) with a high EMF strength >2 V/m (1.06 μW/cm^2), an intermediate line-of sight point (656–1,312 ft/200–400 m) with EMF strength <2 V/m, and a control location out of radar sight (>1,312 ft/400 m) registering 0 V/m. Bat activity was recorded three times for a total of 90 samples, 30 within each field strength category. Measured from sunset to sunrise, they found that bat activity was significantly reduced in habitats exposed to an EMF greater than 2 V/m compared to 0 EMF sites, but such reduced activity was not significantly different at lower EMF levels within 400 m of the radar. They concluded that the reduced bat activity was likely due to thermal induction and an increased risk of hyperthermia. This was a large field study near commercial radar installations with mostly high intensity exposures but low-level effects cannot be excluded given known magneto-sensitivity in bats.

In another field study using a small portable marine radar unit significantly less powerful than their earlier measured field study, Nicholls and Racey [207] found the smaller signal could also deter bats' foraging behaviors. First, in summer 2007, bat activity was compared at 20 foraging sites in northeast Scotland during experimental trials with radar switched on, and in controls with no radar signal. After sunset, bat activity was recorded for a period of 30 min with the order of the trials alternating between nights. Then in summer 2008, aerial insects were sampled at 16 of the sites using two small light-suction traps, one with a radar signal, the other a control. Bat activity and foraging were found significantly reduced when the radar signal was unidirectional, creating a maximized exposure of 17.67–26.24 V/m (83–183 μW/cm^2). The radar had no significant effect on the abundance of insects captured by the traps despite reduced bat activity.

Balmori [231] also noted significantly reduced bat activity in a free-tailed bat colony (*Tadarida teniotis*) where the number of bats decreased when several cell towers were placed 262 ft (80 m) from the colony.

In the ELF range, Janać et al. [232] investigated ELF/MF effects — comparable to powerline and stray voltage ground current — on motor behavior patterns in Mongolian gerbils (*Meriones unguiculatus)* and found age-dependent changes in locomotion, stereotypy, and immobility in 3- and 10-month-old males. Animals were continuously exposed to ELF-MF (50 Hz; 0.1, 0.25 and 0.5 mT) for seven days with behavior monitored for 60 min in the open field after the 1st, 2nd, 4th, and 7th day (to capture immediate effects), as well as three days after exposure (to capture delayed effects). They found that exposure to 3-month-old gerbils increased motor behavior (locomotion and stereotypy), and therefore decreased immobility. In the 3-month old gerbils, ELF/MF also showed a delayed effect (except at 0.25 mT) on stereotypy and immobility. In 10-month-old gerbils, ELF/MF of 0.1, 0.25 and 0.5 mT induced decreased locomotion, a slight increase in stereotypy, and pronounced stimulation of motor behavior. Increased motor behavior was observed three days after exposure, indicating long lasting effects. Researchers concluded that in 3- and 10-month-old gerbils, specific temporal patterns of motor behavior changes were induced by ELF/MF due to age-dependent morpho-functional differences in brain areas that control motor behavior.

The above is a very small sample of rodent studies. See Part 2 Supplements 1 and 2 for more genetic effects to rodents, and Supplement 3 for additional studies.

Bovines

Due to domestication and easy accessibility, there are numerous studies of dairy cows (*Bos taurus*) which appear particularly sensitive to both natural and man-made EMFs. Fedrowitz [71] published a thorough review with citations too numerous to mention here. Noted in the review is the fact that bovines, although easily accessible, are difficult to study with precision due to their size, which creates handling and dosimetric complexities. Also noted are that bovines today are at their milk- and beef-production physiological limits, and that the addition of even a weak stressor may be capable of altering a fragile bovine physiological balance. It is clear in the Fedrowitz review that cows respond to environmental exposures from a broad range of frequencies and properties, even as some studies lack good exposure assessment. RFR exposure created avoidance behavior, reduced ruminating and lying times, and alterations in oxidative stress enzymes among other problems, while ELF-EMF found contradictory evidence affecting milk production, fat content, hormone imbalances and important changes in other physiological parameters. Cows have also been found sensitive to stray voltage and transient harmonics with problematic milk production, health, reproduction and behavioral effects.

The question is how much of this body of work could translate to other ruminants and large mammals on-field or in the wild such as deer/cervids — behaviorally, reproductively, and physiologically. Stray voltage and ELF-EMF near powerlines, and rural area RFR from both ground-based and satellite transmitters, for instance, may affect wild migratory herds and large ungulates in remote areas that go undetected.

Bovines and RFR

Loscher and Kas [233] observed abnormal behavior in a dairy herd kept in close proximity to a TV and radio transmitter. They found reduction in milk yield, health problems, and behavioral abnormalities. After evaluating other factors, they concluded the high levels of RFR were possibly responsible. They removed one cow with abnormal behavior to another stable 20 km away from the antenna, resulting in normalization of behavior within five days. Symptoms reappeared when the cow was returned to the stable near the antennas. In a later survey, Loscher [234] also found effects of RFR on the production, health and behavior of farm animals, including avoidance behavior, alterations in oxidative stress parameters, and ruminating duration.

Balode [59] obtained blood samples from female brown cows from a farm close to, and in front of, the Skrunda Radar – located in Latvia at an early warning radar system operating in the 156–162 MHz frequency range — and samples from cows in a control area. They found micronuclei in peripheral erythrocytes were significantly higher in the exposed cows, indicating DNA damage.

Stärk et al. [235] investigated short-wave (3–30 MHz) RFR on salivary melatonin levels in dairy cattle, with one herd at a farm located at 1,640 ft/500 m (considered higher exposure) and a second control herd located 13,123 ft/4,000 m from the transmitter (considered unexposed). The average nightly magnetic field strength readings were 21-fold greater on the exposed farm (1.59 mA/m) than on the control farm (0.076 mA/m). At both farms, after initially monitoring five cows' salivary melatonin concentrations at 2-h intervals during night dark phase for 10 consecutive days, and with the short-wave transmitter switched off during three of the 10 days (off phase), samples were analyzed using a radioimmunoassay. They reported that mean values of the two initial nights did not show a statistically significant difference between exposed and unexposed cows and concluded that chronic melatonin reduction was unlikely. But on the first night of re-exposure after the transmitter had been off for three days, the difference in salivary melatonin concentration between the two farms (3.89 pg/ml, CI: 2.04, 7.41) was statistically significant, indicating a two-to-seven-fold increase of melatonin concentration. They concluded that a delayed acute effect of EMF on melatonin concentration could not be excluded and called for further trials to confirm results.

Hässig et al. [95] conducted a cohort study to evaluate the prevalence of nuclear cataracts in veal calves near mobile phone base stations with follow-up of each dam and its calf from conception through fetal development and up to slaughter. Particular emphasis was focused on the first trimester of gestation (organogenesis). Selected protective antioxidants (superoxide dismutase, catalase, glutathione peroxidase [GPx]) were assessed in the aqueous humor of the eye to evaluate redox status. They found that of 253 calves, 79 (32%) had various degrees of nuclear cataracts, but only 9 (3.6%) of calves had severe nuclear cataracts. They concluded that a relationship between the location of veal calves with nuclear cataracts in the first trimester of gestation and the strength of antennas was demonstrated. The number of antennas within 328–653 ft (100–199 m) was associated with oxidative stress and there was an association between oxidative stress and the distance to the nearest base station. Oxidative stress was increased in eyes with cataract (OR per kilometer: 0.80, confidence interval 95 % 0.62, 0.93). But the researchers further concluded that it had not been shown that the antennas actually affected stress. Hosmer-Lemeshow statistics showed an accuracy of 100% in negative cases with low radiation, and only 11.11% accuracy in positive cases with high radiation. This reflected, in their opinion, that there are a lot of other likely causes for nuclear cataracts beside base stations and called for additional studies on EMF during embryonic development.

Hässig et al. [96] further examined a dairy farm in Switzerland where a large number of calves were born with nuclear cataracts after a mobile phone base station was erected near the barn. Calves showed a 3.5 times higher risk for heavy cataracts if born there compared to the Swiss average. All usual causes for cataracts could be excluded but they nevertheless concluded that the incidence remained unknown.

Bovines and swine: ELF-EMF, stray electric current

Bovines appear unusually sensitive to ELF-EMF from stray current caused by both normal industrial and faulty grounding methods near high tension transmission lines close to dairy farms. Stray current can cover large areas and occurs when current flows between the grounded circuit conductor (neutral) of a farm and the Earth through dairy housing equipment like metal grates. It typically involves small, steady power frequency currents [99], not high transient shocks, although that also can sometimes occur under wet weather conditions. According to Hultgren [236], dairy cattle can perceive alternating currents exceeding 1 mA between the mouth and all four hooves with behavioral effects in cows usually occurring above 3 mA. Stray current can act as a major physical stressor in cows and other animals [237]. This may also be happening in wild migratory species moving through such areas.

At the request of dairymen, veterinarians, and county extension agents in Michigan, U.S., Kirk et al. [238] investigated stray current on 59 Michigan dairy farms. On 32 farms, stray current sources were detected. Where voltage exceeded 1 V alternating current, increased numbers of dairy cows showed abnormal behavior in the milking facility and increased prevalence of clinical mastitis. Recovery from the stray current-induced abnormalities was related to the type of abnormality and the magnitude of the exposure voltage.

Burchard et al. [239] in a small but well-controlled alternating exposure study of non-pregnant lactating Holstein cows found a longer estrous cycle in cows exposed to a vertical electric field of 10 kV/m and a uniform horizontal magnetic field of 30 μT at 60 Hz, compared to when they were not exposed. Rodriguez et al. [240] also found that exposure to EMF may increase the duration of the bovine estrous cycle. Burchard et al. [241] evaluated effects on milk production in Holsteins exposed to a vertical electric field of 10 kV/m and a uniform horizontal MF of 30 μT at 60 Hz and found an average decrease of 4.97, 13.78, and 16.39% in milk yield, fat corrected milk yield, and milk fat, respectively in exposed groups, and an increase of 4.75% in dry matter food intake. And Buchard et al. [242] in two experiments investigated blood thyroxine (T4) levels in lactating pregnant and non-lactating non-pregnant Holstein cows exposed to 10 kV/m, 30 μT EMF and found a significant change depending on the time of blood sampling in exposed groups. They concluded that exposure of dairy cattle to ELF-EMF could moderately affect the blood levels of thyroxine.

Hillman et al. [93, 94] reported that harmonic distortion and power quality itself could be another variable in bovine sensitivity to stray current. They found behavior, health, and milk production were adversely affected by transients at the 3rd, 5th, 7th, and triplen harmonic currents on utility power lines after a cell tower was found charging the ground neutral with 10+ V, causing the distortion. After installing a shielded neutral isolation transformer between the utility and the dairy, the distortion was reduced to near zero. Animal behavior improved immediately and milk production, which had been suppressed for three years, gradually returned to normal within 18 months.

Swine (*Sus scrofa domesticus*) — like rats and mice — have demonstrated aversive behavior to ELF-EMF electric fields. Hjeresen et al. [243] found miniature pigs, exposed to 60-Hz electric fields (30 kV/m for 20 h/day, 7 days/week up to 6 months) preferred an absence of the field during a 23.5-h period by spending more time out of the electric field than in it during sleep periods. And Sikov et al. [244], as part of a broad study of Hanford Miniature swine on reproductive and developmental toxicology (including teratology) over three breeding cycles found a strong association between chronic exposure to a vertical uniform electric field (60-Hz, 30-kV/m, for 20 h/day, 7 days/week) and adverse developmental effects vs. control. They concluded that an association exists between chronic exposure to strong electric fields and adverse developmental effects in swine (75% malformations in exposed vs. 29% sham) in first generation with consistent results in two subsequent generations.

Avian

Birds are important indicators of ecosystem well-being and overall condition. Even subtle effects can be apparent due to their frequent presence in RFR areas. Their hollow feathers have dielectric and piezoelectric properties, meaning they are conductive and capable of acting as a waveguide directing external RFR energy directly and deeply into avian body cavities [245–249]. Their thin skulls have both magnetite and radical pair receptors (see "Mechanisms" above) and they are highly mobile — often traveling across great migratory distances of tens to as much as a hundred thousand kilometers round-trip per year, resulting in potential multi-frequency cumulative effects from chronic near, middle, and far-field exposures. Avian populations are declining worldwide, especially among migratory species. This means that birds may be uniquely sensitive to adverse effects from environmental RFR since their natural habitat is air and they often fly at lateral levels with infrastructure emissions, bringing them that much closer to generating sources.

Tower and building construction, as direct obstacles, are known hazards to birds. One tower at 150 feet (46 m) above ground level is thought to account for as many as 3,000 songbird deaths per month in migratory pathways during peak migration [250] and communication tower collisions have been documented to kill more than 10,000 migratory birds in one night at a TV tower in Wisconsin [251, 252]. It has been known for years that the songbird populations of North America and Europe are plummeting. Only recently were towers considered a significant factor. But is the problem solely due to obstacles in direct migratory pathways or is something else involved?

RFR from towers may be acting as an attractant to birds due to their singular physiology. Avian eyes and beaks are uniquely magnetoreceptive with both magnetite and cryptchrome radical pair receptors. One definitive study by Beason and Semm [253] demonstrated that the common cell phone frequency (900-MHz carrier frequency, modulated at 217 Hz) at nonthermal intensities, produced firing in several types of nervous system neurons in Zebra Finches (*Taeniopygia guttate*). Brain neurons of irradiated anesthetized birds showed changes in neural activity in 76% of responding cells, which increased their firing rates by an average 3.5-fold vs. controls. Other responding cells exhibited a decrease in rates of spontaneous activity. The Beason and Semm study [253] could explain why birds may be attracted to cell towers, a theoretical premise they previously observed with Bobolinks (*Dolichonyx oryzivorus*; [254]).

RFR may also act as an avian stressor/irritant. Early work by Wasserman et al. [255] in field studies on 12 flocks of migratory birds subjected to various combinations of microwave power density and duration under winter conditions at Monomet, MA, using birds from two additional flocks as controls, showed increased levels of aggression in some of the irradiated birds.

Other research indicated a range of effects capable of broad adverse environmental outcomes. Laboratory studies by Di Carlo et al. [256] found decreases in heat shock protein production in chick embryos. The researchers used 915-MHz RFR on domestic chicken embryos and found that exposure typical of some cell phone emissions reduced heat shock proteins (HSP-70) and caused heart attacks and death in some embryos. Controls were unaffected. In replicated experiments, similar results were found by Grigor'ev [257] and Xenos and Magras [258]. Batellier et al. [259] found significantly elevated embryo mortality in exposed vs. sham groups of eggs incubated with a nearby cell phone repeatedly calling a 10-digit number at 3-min intervals over the entire incubation period. Heat shock proteins help maintain the conformation of cellular proteins during periods of stress. A decrease in their production diminishes cellular protection, possibly leading to cancer, other diseases, heart failure, and reduction in protection against hypoxia and ultraviolet light.

Not all results are adverse. Tysbulin et al. [260, 261] investigated both short and prolonged GSM 900 MHz cell phone signal exposure on embryo development in Quail (*Coturnix coturnix japonica),* irradiating fresh fertilized eggs during the first 38 h and 14 days of incubation using a cell phone in connecting mode continuously activated through a computer system. Maximum intensity of incident radiation on the egg's surface was 0.2 mW/cm^2. Results found a significant ($p<0.001$) increase in differentiated somites in 38-h exposed embryos and a significant ($p<0.05$) increase in total survival of embryos in eggs after 14 days exposure. They also found the level of thiobarbituric acid (TBA) reactive substances was significantly (p 0.05–0.001) higher in the brains and livers of hatchlings from exposed embryos and hypothesized that a facilitating effect exists due to enhanced metabolism in exposed embryos via peroxidation mechanisms. They concluded low-level nonthermal effects from GSM 900 MHz to quail embryogenesis is possible and that effects can be explained via a hormesis effect induced by reactive oxygen species (ROS).

Signaling characteristics such as pulsing vs. continuous wave are also important. Berman et al. [262], in a multi-lab study of pulsed ELF magnetic fields found a highly significant incidence of abnormalities in exposed chick eggs vs. controls. And Ubeda et al. [263] found irreversible damage to chick embryos from weak pulsed ELF-EMF magnetic fields that are common in the environment today. Initial studies on freshly fertilized chicken eggs were exposed during the first 48 h of post-laying incubation to pulsed magnetic fields (PMFs) with 100 Hz repetition rate, 1.0 μT peak-to-peak amplitude, and 500 μs pulse duration. Two different pulse waveforms were used, with rise and fall times of 85 μs or 2.1 μs. A two-day exposure found significant increased developmental abnormalities. In follow-up research, after exposure, eggs were incubated for an additional nine days without PMFs. Embryos removed from eggs showed an excess of developmental anomalies in the PMF-exposed groups compared with the sham-exposed samples. There was a high rate of embryonic death in the 2.1 μs rise/fall time. Results indicate PMFs can cause irreversible developmental changes, confirming that a pulse waveform can determine embryonic response to ELF magnetic fields common today.

Between 1999 and 2005, Fernie et al. for the first time investigated various potential reproductive effects on a captive raptor species — the American Kestrel (*Falco sparverius*) — from ELF-EMF equivalent to that of wild nesting pairs on power transmission lines. In a series of studies, captive pairs were typically bred under control or EMF exposure over 1–3 breeding cycles. In 1999, Fernie et al. [264] investigated photo phasic plasma melatonin in reproducing adult and fledgling kestrels, finding that EMFs affected plasma melatonin in adult male kestrels, suppressing it midway through, but elevating it at the end of the breeding season. In long-term, but not short-term EMF exposure of adults, plasma melatonin was supressed in their fledglings too which could affect migratory success. Molt happened earlier in adult EMF-exposed males than in controls. EMF exposure had no effect on plasma melatonin in adult females. In avian species, melatonin is involved in body temperature regulation, seasonal metabolism, locomotor activity, feeding patterns, migration, and plumage color changes important for mate selection. Melatonin also plays a key role in the growth and development of young birds. The researchers concluded it is likely that the results are relevant to wild raptors nesting within EMF exposures.

In 2000 Fernie et al. [265] focused on reproductive success in captive American Kestrels exposed to ELF-EMF, again equivalent to that experienced by wild reproducing kestrels. Kestrels were bred one season per year for two years under EMF or controlled conditions. In some years but not others, EMF-exposed birds showed a weak association with reduced egg laying, higher fertility, larger eggs with more yolk, albumen, and water, but thinner egg shells than control eggs. Hatching success was lower in EMF pairs than control pairs but fledging success was higher than control pairs in one year. They concluded that EMF exposure such as what kestrels would experience in the wild was biologically active in a number of ways leading to reduced hatching success.

Also in 2000, Fernie et al. [266] further investigated behavioral changes in American Kestrels to ELF-EMF, again in captive birds comparable to nesting pairs that commonly use electrical transmission structures for nesting, perching, hunting, and roosting. The amount of EMF exposure time of wild reproducing American Kestrels was first determined at between 25 and 75% of the observed time. On a 24-h basis, estimated EMF exposure in wild species ranged from 71% during courtship, to 90% during incubation. Then effects of EMFs on the behavior of captive reproducing kestrels were examined at comparable exposures of 88% of a 24-h period. Additionally, captive kestrels were exposed to EMF levels experienced by wild kestrels nesting under 735-kV power lines. There appeared to be a stimulatory/stress effect. Captive EMF females were more active, more alert, and perched on the pen roof more frequently than control females during courtship. EMF females preened and rested less often during brood rearing. EMF-exposed male kestrels were more active than control males during courtship and more alert during incubation. The researchers concluded that the increased activity of kestrels during courtship may be linked to changes in corticosterone, but not to melatonin as found in earlier work [264], but said the behavioral changes observed were unlikely to result in previously reported effects in EMF-exposed birds as noted above. They added that behavioral changes of captive EMF-exposed kestrels may also be observed in wild kestrels, with uncertain results.

In 2001 Fernie and Bird [267] looked at ELF-EMF oxidative stress levels in captive American Kestrels using the same test parameters described above to see if ELF-EMF exposure elicited an immune system response. In captive male kestrels bred under control or EMF conditions equivalent to those experienced by wild kestrels, short-term EMF exposure (one breeding season) suppressed plasma total proteins, hematocrits, and carotenoids in the first half of the breeding season. It also suppressed erythrocyte cells and lymphocyte proportions, but elevated granulosa proportions at the end of the breeding season. Long-term EMF exposure (two breeding seasons) also suppressed hematocrits in the first half of the reproductive period. But results found that only short-term EMF-exposed birds experienced an immune response, particularly during the early half of the breeding season. The elevation of granulocytes and the suppression of carotenoids, total proteins, and melatonin [264] in the same kestrel species indicated that the short-term EMF-exposed male kestrels had higher levels of oxidative stress due to an immune response and/or EMF exposure. The researchers noted that long-term EMF exposure may be linked to higher levels of oxidative stress solely through EMF exposure. Oxidative stress contributes to cancer, neurodegenerative diseases, and immune disorders. And in 2005, Fernie and Reynolds [268] noted most studies of birds and EMF indicate changes on behavior, reproductive success, growth and development, physiology and endocrinology, and oxidative stress — with effects not always consistent or in the same direction under EMF conditions. The entire body of work by this research group has implications for all wild species that encounter a wide range of EMFs on a regular basis.

In field studies on wild birds in Spain, Balmori [269] found strong negative correlations between low levels of microwave radiation and bird breeding, nesting, roosting and survival in the vicinity of communication towers. He documented nest and site abandonment, plumage deterioration, locomotion problems, and death in Wood Storks (*Mycteria americana*), House Sparrows (*Passer domesticus*), Rock Doves (*Columba livia*), Magpies (*Pica pica*), Collared Doves (*Streptopelia decaocto)*, and other species. While these species had historically been documented to roost and nest in these areas, Balmori [269] did not observe these symptoms prior to construction and operation of the cell phone towers. Results were most strongly negatively correlated with proximity to antennas and Stork nesting and survival. Twelve nests (40% of his study sample) were located within 656 ft (200 m) of the antennas and never successfully raised any chicks, while only one nest (3.3%), located further than 984 ft (300 m) never had chicks. Strange behaviors were observed at Stork nesting sites within 328 ft (100 m) of one or several cell tower antennas. Birds impacted directly by the main transmission lobe (i.e., electric field intensity > 2 V/m) included young that died from unknown causes. Within 100 m, paired adults frequently fought over nest construction sticks and failed to advance nest construction (sticks fell to the ground). Balmori further reported that some nests were never completed and that Storks remained passively in front of cell site antennas. The electric field intensity was higher on nests within 200 m (2.36 ± 0.82 V/m; 1.48 μW/cm^2) than on nests further than 300 m (0.53 ± 0.82 V/m, 0.074 μW/cm^2). RF-EMF levels, including for nests <100 m from the antennas, were not intense enough to be classified as thermal exposures. Power densities need to be at least 10 mW/cm^2 to produce tissue heating of even 0.5 °C [270]. Balmori's results indicated that RFR could potentially affect one or more reproductive stages, including nest construction, number of eggs produced, embryonic development, hatching and mortality of chicks and young in first-growth stages.

Balmori and Hallberg [271] and Everaert and Bauwens [272] found similar strong negative correlations among male House Sparrows (*Passer domestics)* throughout multiple sites in Spain and Belgium associated with ambient RFR between 1 MHz and 3 GHz at various proximities to GSM cell base stations. House Sparrow declines in Europe have been gradual but cumulative for this species once historically well adapted to urban environments. The sharpest bird density declines were in male House Sparrows in relatively high electric fields near base stations, indicating that long-term exposure at higher RFR levels negatively affected both abundance and/or behavior of wild House Sparrows. In another review, Balmori [25] reported health effects to birds that were continuously irradiated. They suffered long-term effects that included reduced territorial defense posturing, deterioration of bird health, problems with reproduction, and reduction of useful territories due to habitat deterioration.

Birds have been observed avoiding areas with high and low-intensity EMF, in daylight as well as nocturnally. An early study by Southern in 1975 [273] observed that gull chicks reacted to the U.S. military's Project Sanguin ELF transmitter. Tested on clear days in the normal geomagnetic field, birds showed significant clustering with predicted bearing corresponding with migration direction, but when the large antenna was energized they dispersed randomly. He concluded that magnetic fields associated with such conductors were sufficient to disorient birds. Larkin and Sutherland [274] observed that radar tracking of individual nocturnal migrating birds flying over a large alternating-current antenna system caused birds to turn or change altitude more frequently when the antenna system was operating than when it was not. The results suggested that birds sense low-intensity alternating-current EMF during nocturnal migratory flight.

In a well-designed, multi-year avian study of magneto-disruption, Engels et al. [213] investigated environmental broadband electromagnetic 'noise' emitted everywhere humans use electronics, including devices and infrastructure. They found migratory birds were unable to use their magnetic compass in the presence of a typical urban environment today. European Robins (*E. rubecula),* exposed to the background electromagnetic 'noise' present in unscreened wooden huts at the University of Oldenburg campus, could not orient using their magnetic compass. But when placed in electrically grounded aluminum-screened huts, creating Faraday cages that attenuated electromagnetic 'noise' by approximately two orders of magnitude, their magnetic orientation returned. The researchers were able to determine the frequency range from 50 kHz to 5 MHz was the most disruptive. When grounding was removed, or additional broadband electromagnetic 'noise' was deliberately generated inside the screened and grounded huts, birds again lost magnetic orientation abilities. They concluded that RFR's magneto-disruption effects are not confined to a narrow frequency band. Birds tested far from sources of EMFs required no screening to orient with their magnetic compass. This work documented a reproducible effect of anthropogenic electromagnetic ambient 'noise' on the behavior of an intact vertebrate. The magnetic compass is integral to bird movement and migration. The findings clearly demonstrated a nonthermal effect on European Robins and serves as a predictor for effects to other migratory birds, especially those flying over urban areas. Such fields are much weaker than minimum levels expected to produce any effects and far below any exposure standards.

Intensity windows in different species have also been found where effects can be more extreme at lower intensities than at higher ones due to compensatory mechanisms such as cell apotosis. Panagopoulos and Margaritas [34] found an unexpected intensity window at thermal levels around 10 mW/cm^2 RFR — not uncommon near cell towers — where effects were more severe than at intensities higher than 200 mW/cm^2. This window appeared at a distance of 8–12 in (20–30 cm) from a cell phone antenna, corresponding to a distance of about 66–98 ft (20–30 m) from a base station antenna. This could be considered a classic nonlinear effect and would apply to far-field exposures. Since cell base station antennas are frequently located within residential areas where birds nest, often at distances 20–30 m from such antennas, migratory birds, non-migratory avifauna, and other wildlife may be exposed up to 24-h per day.

Concerns also apply to impacts from commercial radio signals on migratory birds. The human anatomy is resonant with the FM bands so exposure standards are most stringent in that range. High intensity (>6,000 W) commercial FM transmitters are typically located on the highest ground available to blanket a wider area. Low powered FM transmitters (<1,000 W) can be placed closer to the human population. High intensity locations, which can be multi-transmitter sites (colloquially called "antenna farms") for other services, also provide convenient perches and nest sites for migratory birds. FM digital signals, which simulate pulsed waves, pose additional health concerns to migratory birds. This creates a dangerous frequency potential for protected migratory birds such as Bald Eagles with wingspans that extend to about 6 ft (1.83 m) — a resonant match with the length of the FM signal — creating a potential full-body resonant effect for both humans and Bald Eagles. Birds could experience both thermal and non-thermal effects.

All migratory birds are potentially at risk, including Bald Eagles, Golden Eagles, birds of conservation concern [275], federal and/or state-listed bird species, birds nationally or regionally in peril, as well as birds whose populations are stable. Sadly, addressing these concerns — beginning with independent research conducted by scientists with no vested interest in the outcomes — has not been a priority for government agencies or the communications industry.

Insects and arachnids

Insects are the most abundant and diverse of all animal groups, with more than one million described species representing more than half of all known living species, and potentially millions more yet to be discovered and identified. They may represent as much as 90% of all life forms on Earth. Though some are considered pests to farm crops and others as disease vectors, insects remain essential to life and planetary health. Found in nearly all environments, they are the only invertebrates that fly, but adults of most insect species walk, while some swim.

Because of these different environmental adaptations, different species will encounter different EMF exposures in varying degrees. For instance, ground-based walking insects may be more susceptible to effects from 60 Hz stray current while flying insects may be more susceptible to wireless exposures. However, all species tested have been affected across a range of the nonionizing electromagnetic bands.

Most insects have an exoskeleton, three-part body consisting of a head, thorax, and abdomen, three pairs of jointed legs, compound eye structures capable to seeing many more colors, widths, and images than humans, and one pair of antennae capable of sensing subtle meteorological changes and Earth's geomagnetic fields. They live in close harmony with the natural environment for survival and mating purposes. The most diverse insect groups coevolved with flowering plants, many of which would not survive without them. Most insect species are highly sensitive to temperature variations and climate alterations as they do not dissipate heat efficiently.

Nearly all insects hatch from eggs that are laid in myriad ways and habitats. Growth involves a series of molts and stages (called instars) with immature stages greatly differing from mature insects in appearance, behavior, and preferred habitat. Some undergo a four-stage metamorphosis (with a pupal stage) and others a three-stage metamorphosis through a series of nyphal stages.

While most insects are solitary, some — like bees, termites and ants — evolved into social networks, living in "cooperative" organized colonies that can function as one unit as evidenced in swarming behaviors. Some even show maternal care over eggs and young. They communicate through various sounds, pheromones, light signals, and through their antennae such as during the bees' "waggle dance" (see below).

As far back as the 1800s, even though testing methods were primitive by today's standards, researchers were curious about electromagnetism's effect on insect development, particularly teratogenicity [276]. Research on EMF across frequencies and insect populations has been ongoing since at least the 1930s with an eye toward using energy as an insecticide and anti-contaminant in grain, typically at high intensity thermal exposures that would not exist in the natural environment. Mckinley and Charles [277] found that wasps die within seconds of high frequency exposure. But not all early work was strictly high intensity, or all effects observed due to thermal factors.

There were interesting theories introduced by early researchers regarding how energy couples with various insect species. Frings [278] found larval stages are more tolerant to heat than adult insects with appendages that can act as conducting pathways to the body, and that the more specialized the insect species, the more susceptible they appear to microwave exposure. Carpenter and Livingstone [279] studied effects of 10 GHz continuous-wave microwaves at 80 mW/cm^2 for 20 or 30 min, or at 20 mW/cm^2 for 120 min on pupae of mealworm beetles (*Tenebrio molitor*) — clearly within thermal ranges. In control groups, 90% metamorphosed into normal adult beetles whereas only 24% of exposed groups developed normally, 25% died, and 51% developed abnormally. Effects were assumed to be thermally induced abnormalities until they simulated the same temperature exposure using radiant heat and found 80% of pupae developed normally. They concluded that microwaves were capable of inducing abnormal effects other than through thermal damage.

Fruit flies

Insects at all metamorphic stages of development have been studied using RFR including egg, larva, pupa and adult stages. Much work has been done on genetic and other effects with fruit flies (*D. melanogaster*) because of their well-described genetic system, ease of exposure, large brood size, minimal laboratory space needed, and fast reproductive rates. Over several decades Goodman and Blank, using ELF-EMF on *Drosophila* models, found effects to heat shock proteins and several other effects ([201]; and see "Mechanisms" above). It is considered a model comparable to other insects in the wild approximating that size. *D. melanogaster* may be the most lab-studied insect on Earth, although honey and related bee species, due to their devastating losses over the last decade and significance to agriculture, are quickly catching up.

Michaelson and Lin [50] noted that RFR-exposed insects first react by attempting to escape, followed by disturbance of motor coordination, stiffening, immobility and eventually death, depending on duration of exposure and insect type. For example, *D. melanogaster* survived longer than 30 min while certain tropical insects live only a few seconds at the same field intensity. Also noted were concentration changes in many metabolic products and effects to embryogenesis — the period needed for a butterfly to complete metamorphosis — with accelerated gastrulation and larval growth [17]. Michaelson and Lin [50] cited several negative studies with *D. melanogaster* exposed with continuous-wave RFR between 25 and 2,450 MHz on larval growth [280, 281] and mutagenicity [282]. This was after Heller and Mickey [283] found a tenfold rise in sex-linked recessive mutations with pulsed RFR between 30 and 60 MHz. It was among the earliest studies that found pulsing alone to be a biologically active exposure.

As reported in Michaelson and Lin [50], Tell [284] looked at *D. melanogaster*'s physiological absorption properties and found that a group of 6-day old male wild-type flies, exposed to 2,450 MHz for 55 min at an intense field caused a dramatic 65% reduction in body weight. This was thought to be from dehydration. They then sought to calculate the fruit fly's absorption properties in relation to plane electromagnetic waves and found that a fly has only a 1/1,000th effective area of its geometric cross section and thus is an inefficient test species for absorbed microwave radiation. However, they concluded that fruit flies were responsive to absorbed energy at thermal levels as a black body resonator at a power density of 1.044×10^4 mW/cm^2, corresponding to a thermal flux density of 0.562×10^{-3} cal. These are levels found in close proximity to broadcast facilities and cell phone towers today.

More recent investigations of RFR by Weisbrot et al. [285] using GSM multiband mobile phones (900/1,900 MHz; SAR approximately 1.4 W/kg) on *D. melanogaster* during the 10-day developmental period from egg laying through pupation found that non-thermal radiation increased numbers of offspring, elevated heat shock protein-70 levels, increased serum response element (SRE) DNA-binding and induced the phosphorylation of the nuclear transcription factor, ELK-1. Within minutes, there was a rapid increase of hsp70, which was apparently not a thermal effect. Taken together with the identified components of signal transduction pathways, the researchers concluded the study provided sensitive and reliable biomarkers for realistic RFR safety guidelines.

Panagopoulos et al. [286] found severe effects in early and mid-stage oogenesis in *D. melanogaster* when flies were exposed *in vivo* to either GSM 900-MHz or DCS 1,800-MHz radiation from a common digital cell phone, at non-thermal levels, for a few minutes per day during the first 6 days of adult life. Results suggested that the decrease in oviposition previously reported [287–289] was due to degeneration of large numbers of egg chambers after DNA fragmentation of their constituent cells which was induced by both types of mobile phone radiation. Induced cell death was recorded for the first time in all types of cells constituting an egg chamber (follicle cells, nurse cells and the oocyte) and in all stages of early and mid-oogenesis, from germarium to stage 10, during which programmed cell death does not physiologically occur. Germarium and stages 7–8 were found to also be the most sensitive developmental stages in response to electromagnetic stress induced by the GSM and DCS fields. Germarium was also found to be more sensitive than stages 7–8. These papers, taken collectively, indicate serious potential effects to all insect species of similar size to fruit flies from cell phone technology, including from infrastructure and transmitting devices.

Fruit flies have also been found sensitive to ELF-EMF. Gonet et al. [290] found 50 Hz ELF-EMF exposure affected all developmental stages of oviposition and development of *D. melanogaster* females, and weakened oviposition in subsequent generations.

Savić et al. [291] found static magnetic fields influenced both development and viability in two species of *Drosophila* (*D. melanogaster and D. hydei*). Both species completed development (egg-to-adult), in and out of the static magnetic field induced by a double horseshoe magnet. Treated vials with eggs were placed in the gap between magnetic poles (47 mm) and exposed to the average magnetic induction of 60 mT, while control groups were kept far from the magnetic field source. They found that exposure to the static magnetic field reduced development time in both species, but only results for *D. hydei* were statistically significant. In addition, the average viability of both species was significantly weaker compared to controls. They concluded a 60 mT static magnetic field could be a potential stressor, influencing on different levels both embryonic and post-embryonic fruit fly development.

Beetles

Other insect species also react to both ELF-EMF and RF-EMF. Newland et al. [292] found behavioral avoidance in cockroaches (*Periplaneta americana*) to static electric fields pervasive in the environment from both natural and man-made sources. Such fields could exist near powerlines or where utilities ground neutral lines into the Earth. They found insect behavioral changes in response to electric fields as tested with a Y-choice chamber with an electric field generated in one arm of the chamber. Locomotor behavior and avoidance were affected by the magnitude of the electric fields with up to 85% of individuals avoiding the charged arm when the static e-field at the entrance to the arm was above 8–10 kV/m. Seeking to determine mechanisms of perception and interaction, they then surgically ablated the antennae and cockroaches were unable to avoid electric fields. They concluded that antennae are crucial in cockroach detection of electric fields that thereby helps them avoid such fields. They also noted that cockroach ability to detect e-fields is due to long antennae which are easily charged and displaced by such fields, not because of a specialized detection system. This leads to the possibility that other insects may also respond to electric fields via antennae alone.

Vácha et al. [208] found that cockroaches (*P. americana*) were sensitive to weak RFR fields and that the Larmor frequency at 1.2 MHz in particular had a "deafening effect" on magnetoreception. The parameter they studied was the increase in locomotor activity of cockroaches induced by periodic changes in geomagnetic North positions by 60°. The onset of the disruptive effect of a 1.2 MHz field was found between 12 and 18 nT whereas the threshold of a field twice the frequency (2.4 MHz) fell between 18 and 44 nT. A 7 MHz field showed no significant effect even at maximal of 44 nT. The results suggested resonance effects and that insects may be equipped with the same magnetoreception system as birds.

Prolić et al. [293] investigated changes in behavior via the nervous system of cerambycid beetles (*Morimus funereus*) in an open field before and after exposure to a 50 Hz ELF-MF at 2 mT. Experimental groups were divided into several activity categories. Results showed activity increased in the groups with medium and low motor activity, but decreased in highly active individuals. High individual variability was found in the experimental groups, as well as differences in motor activities between the sexes both before and after exposure to ELF-MF. They assumed activity changes in both sexes were due to exposure to ELF-MF. Only a detailed analysis of the locomotor activity at 1-min intervals showed some statistically significant differences in behavior between the sexes.

Ants

Ants are another taxa found sensitive to EMF. Ants comprise between 15 and 25% of the terrestrial animal biomass and thrive in most ecosystems on almost every landmass on Earth. By comparison, the total estimated biomass (weight) of all ants worldwide equates to the total estimated biomass of all humans. Their complex social organization in colonies, with problem-solving abilities, division of labor, and both individual and whole colony communication via complex behavioral and pheromone signaling may account for their success in so many environments. Some ant species (e.g., *Formica rufa*-group) are known to build colonies on active earthquake faults and have been found to change behavior hours in advance of earthquakes [294], thus demonstrating predictive possibilities. Ants can modify habitats, influence broad nutrient cycling, spread seeds, tap resources, and defend themselves. Ants co-evolved with other species which led to many different kinds of mutual beneficial and antagonistic relationships.

Ants (e.g., *Solenopsis invictus*) are long known to be sensitive to magnetic fields both natural and manmade [295]. Ants (e.g., *Atta colombica*), like birds, have been found to be sensitive to the Earth's natural fields and to use both a solar compass on sunny days as well as a magnetic compass when there is cloud cover [296]. Jander and Jander [297] similarly found that the weaver ant (*Oecophylla* spp*)* had a more efficient light compass orientation with a much less efficient magnetic compass orientation, suggesting that they switch from the former to the latter when visual celestial compass cues become unavailable. There is evidence from Esquivel et al. [298] that such magnetoreception is due to the presence of varying sized magnetite particles and paramagnetic resonance in fire ants (*Solenopsis* spp). But Riveros and Srygley [299] found a more complex relationship toward a magnetic compass rather than the presence of magnetite alone when leafcutter ants (*Atta columbica)* were subjected to a brief but strong magnetic pulse which caused complete disorientation regarding nest-finding. They found external exposures could interfere with ants' natural magnetic compass in home path integration, which indicated evidence of a compass based on multi-domain and/or super-paramagnetic particles rather than on single-domain particles like magnetite.

Acosta-Avalos et al. [300] found that fire ants are sensitive to 60 Hz alternating magnetic fields as well as constant magnetic fields, changing their magnetic orientation and magnetosensitivity depending on the relation between both types of magnetic fields. Alternating current had the ability to disrupt ant orientation, raising the question of effects to wild species from underground wiring and the common practice of powerline utility companies using the Earth as a neutral return pathway to substations, creating stray current along the way [99].

Camelitepe et al. [301] tested black-meadow ants' (*Formica pratensis*) response under both natural geomagnetic and artificial earth-strength static EMFs (24.5 μT). They found that under the natural geomagnetic field, when all other orientational cues were eliminated, there was significant heterogeneity of ant distribution with the majority seeking geomagnetic north in darkness while under light conditions ants did not discriminate geomagnetic north. Under artificial EMF exposure, however, ant orientation was predominantly on the artificial magnetic N/S axis with significant preference for artificial north in both light and dark conditions. This indicated EMF abilities to alter ant orientation.

Ants are also shown to react to RFR [302, 303]. Cammaerts et al. [304] found that exposures to GSM 900 MHz at 0.0795 $\mu W/cm^2$ significantly inhibited memory and association between food sites and visual and olfactory cues in ants (*Myrmica sabuleti*) and eventually wiped out memory altogether. Subsequent exposure, after a brief recovery period, accelerated memory/olfactory loss within a few hours vs. a few days, indicating a cumulative effect even at very low intensity. The overall state of the exposed ant colonies eventually appeared similar to that exhibited by honey bee (*Apis mellifera*) colony collapse disorder. Although the impact of GSM 900 MHz radiation was greater on the visual memory than on the olfactory memory, the researchers concluded that such exposures — common to cell phones/towers — were capable of a disastrous impact on a wide range of insects using olfactory and/or visual memory, including bees. Many ant species (e.g., *Lasius neglectus, Nylanderia fulva, Camponotus* spp, *Hymenoptera formicidae, Solenopsis invicta,* among others*)* are attracted to electricity, electronic devices, and powerlines, thereby causing short circuits and fires. One hypothesis [305] is that the accumulation of ants in electrical equipment may be due to a few foraging "worker ants" seeking warmth and finding their way into small spaces, completing electrical contacts which then causes a release of alarm exocrine gland pheromones that attract other ants, which then go through the same cycle. In their study, they found that workers subjected to a 120 V alternating-current released venom alkaloids, alarm pheromones and recruitment pheromones that elicited both attraction and orientation in ants as well as some other unknown behavior-modifying substances. But given how ants are affected by EMFs in general it is likely that an attractant factor is also involved, not just warmth and small spaces.

There is evidence that ants use their antennae as "antennas" in two-way electrochemical communications. Over 100 hundred years ago, Swiss researcher Auguste Forel [306] removed the antennae of different species of ants and put them together in one place. What would have normally evoked aggressive behaviors among the different species did not occur and they got along as if belonging to the same colony. To Forel this indicated an ability of ant antennae to help different ant species identify each other.

Two mechanisms in ants have long been known for chemical receptivity as well as electromagnetic sensitivity. Recently Wang et al. [307] found evidence that chemical signals located specific to antennae vs. other body areas drew more attention from non-nest mates. When cuticular hydrocarbons (CHCs) were removed by a solvent from antennae, non-nest mates responded less aggressively than to other areas of the body, indicating that antennae reveal nest-mate identity, conveying and receiving social signals. Regarding magnetoreception, magnetic measurements [308–310] found the presence of biogenic magnetite was concentrated in antennae and other body parts of the ant *Pachycondyla marginata*. De Oliveira et al. [311] also found evidence of magnetite and other magnetic materials imbedded in various locations of antennae tissue in *P. marginata* indicating that antennae function as magnetoreceptors. The amount of magnetic material appeared sufficient to produce a magnetic-field-modulated mechanosensory output and therefore demonstrated a magnetoreception/transduction sense in migratory ants.

Ticks

Ticks are members of the order Arachnida, shared with scorpions and spiders. Recent papers in a tick species (*Dermacentor reticulates*) mirrors an attraction to some frequencies but not others. Vargová et al. [312, 313] found that exposure to RFR may be a potential factor altering both presence and distribution of ticks in the environment. Studies were conducted to determine potential affinity of ticks for RFR using radiation-shielded tubes (RST) under controlled conditions in an electromagnetic compatibility laboratory in an anechoic chamber. Ticks were irradiated using a Double-Ridged Waveguide Horn Antenna to RF-EMF at 900 and 5,000 MHz; 0 MHz served as control. Results found that 900 MHz RFR induced a higher concentration of ticks on the irradiated arm of RST whereas at 5,000 MHz ticks escaped to the shielded arm. In addition, 900 MHz RFR had been shown to cause unusual specific sudden tick movements during exposure manifested as body or leg jerking [312]. These studies are the first experimental evidence of RFR preference and behavioral changes in *D. reticulates* with implications for RFR introduced into the natural environment by devices and infrastructure. In a further study, Frątczak et al. [314] reported that *Ixodes ricinus* ticks were attracted to 900 MHz RFR at 0.1 $\mu W/cm^2$, particularly those infected with Rickettsia (spotted fever).

RFR may be a new factor in tick distribution, along with known factors like humidity, temperature and host presence, causing concentrated non-homogenous or mosaic tick distribution in natural habitats. Tick preference for 900 MHz frequencies common to most cell phones has possibly important ecological and epidemiological consequences. Increasing exposures from use of personal devices and infrastructure in natural habitats where ticks occur may increase both tick infestation and disease transmission. Further studies need to investigate this work, given the ubiquity of ticks today, their northward spread due to climate change in the Northern Hemisphere, and the increasing and sometimes life-threatening illnesses they transmit to humans, pets, and wildlife alike.

Monarch butterflies

The American Monarch butterfly (*D. plexippus)* has fascinated researchers for over 100 years as it is the only insect known to migrate in multi-generational stages [315–319], with the ability to find their exact birthplace on specific milkweed plants (*Asclepias* spp.) at great distances across land and oceans.

Monarchs (*D. plexippus*), found across Southern Canada, the United States, and South America, are generally divided by the Rocky Mountains into eastern and western migratory groups. Their population has precipitously declined by 99.4% since the 1980s (85% of that since 2017) and by 90% in the past two decades in both western and eastern populations [13, 15]. These steep declines are from numerous anthropogenic causes and may have already crossed extinction thresholds, thereby leaving us bereft not only of their beauty and inspiration, but also the perfect model for long-distance animal migration study in general.

Monarch butterflies are among North America's most beloved invertebrates. They have for centuries navigated thousands of miles/kilometers in an iconic fall migration from southern Canada and the mid- and northeastern U.S. to a small area of about 800 square miles (2,072 square kilometers) in Central Mexico where they once wintered over in the millions in small remote oyamel fir forests. By the time they reach their final destination, some will have traveled distances exceeded only by some migratory seabird species. The monarch is the only insect known to migrate annually over 3,000 miles (4,828 km) at ~ 250 miles (402 km) per day in the fall from the Canadian border to Mexico, and in the springtime back again. Similar to some bird species, it is the only butterfly known to have a two-way migration pattern. Monarchs are only followed by army cutworm moths (*Euxoa auxiliaris*) which may migrate several thousand kilometers to high elevation sites in the Rocky Mountains to escape lowland heat and drought.

But monarchs are more interesting than for this one amazing migrational feat alone. How they do this is a long-standing mystery since their entire lifecycle, including their two-stage spring return migration, is multi-generational indicating genetic factors in directional mapping since the final return fall migration south cannot be considered "learned." Several multifaceted mechanisms must come into play, as well as little understood complexities in how those mechanisms cooperate and trade off with each other under different environmental circumstances. Monarchs also go from solitary insects during early developmental stages confined to specific locations, then exhibit social insect behaviors after the third generation has reached northern latitudes and turned south during the final fall migration. And all of this happens in a brain the size of a grain of sand.

Reppert et al. [320] published an excellent review in 2010 on the complexities of monarch migration, noting "… recent studies of the fall migration have illuminated the mechanisms behind the navigation south, using a time-compensated sun compass. Skylight cues, such as the sun itself and polarized light, are processed through both eyes and likely integrated in the brain's central complex, the presumed site of the sun compass. Time compensation is provided by circadian clocks that have a distinctive molecular mechanism and that reside in the antennae. Monarchs may also use a magnetic compass, because they possess two cryptochromes that have the molecular capability for light-dependent magnetoreception. Multiple genomic approaches are being utilized to ultimately identify navigation genes. Monarch butterflies are thus emerging as an excellent model organism to study the molecular and neural basis of long-distance migration." Reppert and de Roode [321] updated that information in 2018.

Although it has been known for some time that monarchs use a circadian rhythm time-compensated directional sun compass [316, 322–338], many questions remain about its dynamics and concerns regarding effects from radiation.

Monarch antennae are known to contain magnetite [339, 340] and cryptochromes [335, 336, 341, 342] — both understood to play a role in magnetoreception (see "Mechanisms"above). One early study by Jones and MacFadden [343] found magnetic materials located primarily in the head and thorax areas of dissected monarchs. More recently, Guerra et al. [16] found convincing evidence that monarchs use a magnetic compass to aid their longest fall migration back to Mexico. Those researchers used flight simulator studies to show that migrants possess an inclination magnetic compass to assist fall migration toward the equator. They found this inclination compass is light-dependent, utilizing ultraviolet-A/blue light between 380 and 420 nm and noted that the significance of light (<420 nm) for an inclination compass function had not been considered in previous monarch studies. They also noted that antennae are important for an inclination compass since they contain light-sensitive magnetosensors. Like some migratory birds, the presence of an inclination compass would serve as an orientation mechanism when directional daylight cues are impeded by cloudy or inclement weather or during nighttime flight. It may also augment time-compensated sun compass orientation for appropriate directionality throughout migration. The inclination compass was found to function at earth-strength magnetic fields, an important metric.

The question remains: Can the magnetic compass in monarchs be disrupted by anthropogenic EMF like it does with geomagnetic orientation in migratory birds [213]. There is some indication this is possible. Perez et al. [330] found monarchs completely disorient after exposure to a strong magnetic field (0.4-T MF for 10 s, or approximately 15,000 times the Earth's magnetic field) immediately before release vs. controls. This is a high exposure but within range of man-made exposures today very close to powerlines.

Bees, wasps, and others

Pollinators, bees in particular, are keystone species without which adverse effects would occur throughout food webs and the Earth's entire biome were pollinators to disappear. Because of their central role and accessibility for research, bee studies have created a wealth of information, including regarding anthropogenic EMFs.

Bees — especially honey and bumble bees — are another iconic insect species beloved for their role in pollination; honey, propolis, royal jelly and beeswax production; their critical importance to our food supply; and their crucial role in global ecological health and stability. Found on every continent except Anarctica wherever there are flowering plants requiring insect pollination, there are over 16,000 known species of bees in seven different biological families, consisting of four main branches. Some species live socially in colonies while others are solitary. The western honey bee (*Apis mellifera*) is the best known and most studied due in part to its central role in agriculture. Bees feed on nectar for energy and pollen for protein/nutrients, and have co-evolved with many plant species in astoundingly complex ways. They are also highly sensitive to both natural and anthropogenic EMFs. Beeswax itself has electrical properties [50].

Human apiculture has been practiced since the time of ancient Egyptian and Greek cultures and bees have been closely studied since the 1800s. Almost all bee species, including commercially raised and wild species, are under decades-long multiple assaults. These include from pesticides, herbicides, climate change, various bacterial/viral diseases, infestations from parasitic mite species — particularly *Apis cerana*, *Varroa destructor* and *Varroa jacobsoni* beginning in the mid-1980s — and predation from introduced species that attack bees directly (e.g., the invasive giant bee-eating hornet *Vespa mandarinia*), as well as alter plant ecology over time to adversely affect bee food supply. Some have suggested that vanishing bees may also have to do with premature aging due to environmentally caused shortened telomeres [344].

Whole colony collapse disorder (CCD) is the most dramatic manifestation of domesticated bee demise in which worker bees abruptly disappear from a hive without a trace, resulting in an empty hive with perhaps a remaining queen and a few worker bees despite ample resources left behind. Few, if any, dead bees are ever found near the hive. CCD was first described in the U.S. in 2006 in Florida in commercial western honey bee colonies. Van Englesdorp et al. [345] quantified bee losses across all beekeeping operations and estimated that between 0.75 and 1.00 million honey bee colonies died in the United States over the winter of 2007–2008. Up until that survey, estimates of honey bee population decline had not included losses occurring during the wintering period, thus underestimating actual colony mortality.

The same phenomenon had been described by beekeepers in France in 1994 [346] — later attributed to the timing of sunflower blooming and the use of imidacloprid (IMD), a chlorinated nicotine-based insecticide or "neonicotinoid" being applied to sunflowers for the first time there [347]. Similar to DDT but considered safer for mammals including humans, neonicotinoids are a slow-release class of neurotoxins that block insect nervous systems via acetylcholine receptors, interfering with neuronal signaling across synapses. Sublethal doses can interfere with bee navigation.

Since then similar phenomena have been seen throughout Europe [348] and some Asian countries. Causal hypotheses included all of the above factors with varying foci on pesticide classes like neonicotinoids and genetically modified crops, but no single agent adequately explains CCD. Bromenshenk et al. [349] however, identified pathogen pairing/co-infection with two previously unreported RNA viruses — *V. destructor*-1, and Kakugo viruses, and a new irridescent virus (IIV) (*Iridoviridae*) along with *Nosema ceranae* — in North American honey bees that were associated with all sampled CCD colonies. The pathogen pairing was not seen in non-CCD colonies. Later cage trials with IIV type-6 and *N. ceranae* confirmed that co-infection with those two pathogens was more lethal to bees than either pathogen alone. Still many questions remain.

There are two national surveying groups in the U.S. — the U.S. Department of Agriculture (USDA) which began surveying managed bee populations in 2015 but funding was cut in late 2019; and the Bee Informed Partnership (BIP), a non-profit that coordinates with research facilities and universities. Prior to USDA's funding cuts, managed colonies decreased from CCD by 40% [350] with an additional 26% over the same quarter in 2019 [351]. BIP's survey period for April 1, 2018 through April 1, 2019 found U.S. beekeepers lost an estimated 40.7% of their managed honey bee colonies. The previous year had similar annual losses of 40.1%. The average annual rate of loss reported by beekeepers since 2010–11 was 37.8% [352].

Also in the U.S., for the first time in 2016, seven species of Hawaiian yellow-faced bees (*Hylaeus anthracinus*, *Hylaeus longiceps*, *Hylaeus assimulans*, *Hylaeus facilis*, *Hylaeus hilaris*, *Hylaeus kuakea*, and *Hylaeus mana*) were added to the federal endangered species list, as well as the rusty patched bumble bee (*Bombus affinis*) which, prior to the late 1990s, had been widely dispersed across 31 U.S. states [353]. Mathiasson and Rehan [354] examined 119 species in museum specimens in New Hampshire going back 125 years and concluded that 14 species found across New England were on the decline by as much as 90%, including the lesser studied leafcutter and mining bees that nest in the ground, unlike honeybees that nest in commercial hives or in trees, shrubs, and rock crevices in the wild.

Worldwide, many bee and other pollinator populations have also declined over the last two decades. Managed honey bee (*Apis mellifera*) colonies decreased by 25% over 20 years in Europe and 59% over 58 years in North America, with many wild bumble bee populations in Europe and North America having gone locally extinct [355–358]. But while dramatic range contractions have been seen, not all bees in all places are declining; some populations are growing depending on opportunistic and species-adaptability factors. For many species data are still insufficient, of poor quality, or nonexistent [359]. In addition, bee declines can affect flora survival. Miller-Struttmann et al. [360] recorded flower declines of 60% with 40 years of climate warming in alpine meadows — areas largely protected from land-use changes. Insects are highly sensitive to temperature changes.

A comprehensive UK survey of pollinator species [361] found that of 353 wild bee and hoverfly species across Britain from 1980 to 2013, 25% had disappeared from the places they had inhabited in 1980. Further estimates found a net loss of over 2.7 million in 0.6 mi (1 km) grid cells across all species. Declining pollinator evenness suggested losses were concentrated in rare species. Losses linked to specific habitats were also identified, with a 55% decline among wild upland species while dominant crop pollinators increased by 12%, possibly due to agricultural business interventions. The general declines found a fundamental deterioration in both wider biodiversity and non-crop pollination services.

There is no question that the huge diversity of pollinator species across the planet is suffering and that losses could be catastrophic with an estimated 90% of wild plants and 30% of world crops in jeopardy [362].

There is a likelihood that rising EMF background levels play a role. Bees have been known for decades to have an astute sense of the Earth's DC magnetic fields [363, 364] and rely on that perception for survival. For centuries beekeepers had noticed curious movements in bee hives but Austrian ethologist Karl von Frisch finally interpreted that activity in the 1940s, winning the Nobel Prize in 1973 for what came to be known as the honey bee "waggle dance." Through complex circles and waggle patterns, bees communicate the location of food sources to other members of the hive, using the orientation of the sun and the Earth's magnetic fields as a gravity vector, "dancing" out a map for hive members to follow like nature's own imbedded GPS. Bees also detect the sun's direction through polarized light and on overcast days use the Earth's magnetic fields, likely through the presence of magnetite in their abdominal area, and employ complex associative learning and memory [365].

Building on the earlier work of Gould et al. [119], Kobayashi and Kirschvink [52] noted that biogenic magnetite in honey bees is located primarily in the anterior dorsal abdomen. When small magnetized bits of wire were glued over those areas, it interfered with bees' ability to learn to discriminate magnetic anomalies in conditioning experiments, while nonmagnetized wire used in controls did not interfere [366]. Kirschvink and Kobayashi [367] found that when pulse-remagnetization techniques were used on bees trained to exit from a T-maze, that north-exiting bees could be converted to a south-exiting direction similar to what was observed in magnetobacteria and artificial reorientation by Blakemore [113]. Honeybees could also be trained to respond to very small changes in the geomagnetic field intensity [368]. Valkova and Vacha [369] discussed the possibility that honey bees use a combination of both radical pair/cryptochromes and magnetite to detect the geomagnetic field and use it for direction like many birds.

Given these sensitivities, bees may be reacting negatively through muti-sensory mechanisms to numerous sources of anthropogenic multi-frequency interference. Bumble bees (*Bombus terrestris*), a solitary species, and honey bees (*Apis mellifera*), a social hive species, are known to detect weak electric fields in different behavioral contexts, using different sensory mechanisms. Bumble bee e-field detection is likely through mechanosensory hairs [370–372] while honey bees reportedly use their antennae [373] that are electro-mechanically coupled to the surrounding e-field, taking place in the antennal Johnston's organ. Greggers et al. [373] found that honey bee antennae oscillate under electric field stimulation that can then stimulate activity in the antennal nerve. The latter occurs due to bees being electrically charged, and thus subject to electrostatic forces. Erickson [374] found different surface potentials in bees when leaving or entering hives, and Colin et al. [375] found seasonal variability between positive and negative charges in resting bees. It has also been shown that honey bees with removed or fixed antennae are less able to associate food reward with electric field stimuli and that bees emanate modulated electric fields when moving their wings (at about 230 Hz) and body (at about 16.5 Hz) during the waggle dance [373].

Electro-ecological interplay between flowers and pollinators has also been known since the 1960s and is critical to pollen transfer from flowers to bees [376–378]. It is known that as bees fly through the air, they accumulate a positive charge. Flowers, on the other hand, which are electrically grounded through their root systems, tend to have a negative charge in their petals created by surrounding air that carries around 100 V for every meter above ground. The accumulating positive charge around the flower induces a negative charge in its petals which then interacts with the positive charge in bees. In fact, bees do not even need to land on flowers for pollen transfer to occur; pollen can "jump" from the flower to the bee as the bee approaches due to charge differentials between the two. Thus, it appears that bees and flowers have been "communicating" via electric fields all along [379]. Bees can also learn color discrimination tasks faster when color cues are paired with artificial electric field cues similar to those surrounding natural flowers, but did not learn as readily in an electrically neutral environment [370].

This evidence points to floral e-fields being used in a co-evolutionary symbiotic relationship with bees. Clarke et al. [370, 371] even found that bumblebees can distinguish between flowers that give off different electric fields as floral cues to attract pollinators. Like visual cues, floral electric fields exhibit complex variations in pattern and structure that bumblebees can distinguish, contributing to the myriad complex cues that create a pollinator's memory of floral food sources. And because floral electric fields can — and do — change within seconds of being visited by pollinators, this sensory ability likely facilitates rapid and dynamic "information exchange" between flowers and their pollinators. Bumblebees can even amazingly use electric field information to discriminate between nectar-rewarding and unrewarding flowers [370].

Bees, locusts: ELF-EMF

Bees are also known to be sensitive to anthropogenic ELF-EMF. In 1973,Wellenstein [380] found that high tension powerlines adversely affected honey bees in wooden hives. This in part prompted the Bonneville Power Administration, an American federal agency operating in the Pacific Northwest under the U.S. Department of Energy (U.S. DOE), to investigate in 1974 [381–384] the effects of transmission lines on people, plants, and animals, including honey bees. The industry group, Electric Power Research Institute, also followed up on bee research [385, 386]. Both of those studies confirmed that transmission line electric fields can affect honey bees inside wooden hives as wood is a poor insulator and current can be induced when hives are placed in electric fields whether metal is present or not. The strength of the current inside the hive was influenced by the electric field strength, hive height, and moisture conditions with effects noticeable when induced current exceeded 0.02–0.04 mA. Depending on hive height, this occurred in field strengths between 2 and 4 kV/m. Effects included increased motor activity with transient increase in hive temperature, excessive propolis production (a resinous material used by bees as a hive sealer), decreased colony weight gains, increased irritability and mortality, abnormal production of queen cells, queen loss, decreased seal brood, and poor over-winter colony survival [387]. Impacts were most likely caused by electric shocks inside the hives [386, 388]. Effects were mitigated with grounded metal screen/shielding of hives [385]; however, bees appeared unaffected by magnetic fields which permeate metal shielding. The authors concluded that the shielding results indicated that bees were unaffected by flying through an external electric field up to 11 kV/m but noted that the study design could not reveal if subtle effects were occurring.

A more recent study of electric fields by Migdał [389] focused on honey bee behavioral effects on walking, grooming, flight, stillness, contact between individuals, and wing movement. They found that the selected frequency, intensity, and duration of exposure effects bees' behavioral patterns. Bees were exposed for 1, 3 and 6 h to E-fields at 5.0 kV/m, 11.5 kV/m, 23.0 kV/m, or 34.5 kV/m (with controls under E-field <2.0 kV/m). Within the exposed groups, results showed that exposure for 3 h caused decreased time that bees spent on select behaviors as well as the frequency of behaviors, whereas after both 1 and 6 h, the behavioral parameters increased within the groups. The researchers concluded that a barrier allowing behavioral patterns to normalize for some periods was indicated although none of the exposed groups returned to reference values in controls which adhered to normal behavioral patterns. Bees may have compensatory windows that appear to be both time and intensity dependent for E-fields. The significance of this study is that bees must accomplish certain activities — like flight frequency and the honey bee 'waggle dance' noted above — that are critical for life expectancy and survival. Even slight sequential disturbances may have cascading effects.

In an early-1988 study, Korall et al. [390] also found effects to bees from magnetic fields (MF). Bursts comparable to some of today's pulsed exposures of artificial MF at 250 Hz — the frequency of buzzing during the waggle dance — were applied parallel to natural EMF field lines and induced unequivocal 'jumps' of misdirection by up to +10° in bees during the waggle dance. This alone could cause directional confusion in hives. Continuous fields of 250 Hz with bursts perpendicular to the static MF however caused no effects. They concluded that a resonance relationship other than classic resonance models was indicated (see "Mechanisms" above). This early work has implications for subsequent digital pulsing and all wireless broadband technology.

More recent work on honey bees and ELF-EMF by Shepherd et al. [209] in 2018 found that acute exposure to 50 Hz fields at levels from 20–100 μT (at ground level underneath powerline conductors), to 1,000–7,000 μT (within 1 m of the conductors), reduced olfactory learning, foraging flight success toward food sources and feeding, as well as altered flight dynamics. Their results indicated that 50 Hz ELF-EMFs from powerlines is an important environmental honey bee stressor with potential impacts on cognitive and motor abilities.

Some wasp species have also been found sensitive to ELF-EMF. Pereira-Bomfim et al. [391] investigated the magnetic sensitivity of the social paper wasp (*Polybia paulista*) by analyzing wasp behavior in normal geomagnetic fields and in the presence of external magnetic fields altered by either permanent magnets (DC fields) or by Helmholtz coils (AC fields). They evaluated the change in foraging rhythm and colony behavior, as well as the frequency of departing/homeward flights and the behavioral responses of worker wasps located on the outer nest surface. They found that the altered magnetic field from the DC permanent magnet produced an increase in the frequency of departing foraging flights, and also that wasps grouped together on the nest surface in front of the magnet with their heads and antennae pointing toward the perturbation source, possibly indicating a response to a potential threat as a defense strategy. Controls showed no such grouping behavior. The AC fields created by the Helmholtz coils also increased foraging flights, but individuals did not show grouping behavior. The AC fields, however, induced wasp workers to perform "learning flights." They concluded that for the first time, *P. paulista* demonstrated sensitivity to an artificial modification of the local geomagnetic field and that mechanisms may be due to both cryptochrone/radical pairs and magnetite.

Another flying insect model — desert locust (*Schistocerca gregaria*) — was found susceptible to entrainment by ELF-EMF. In a complex study, Shepherd et al. [392] analyzed acute exposure to sinusoidal AC 50 Hz EMF (field strength range: 10 to 10,000 μT) vs. controls on flights of individual locusts tethered between copper wire coils generating EMFs at various frequencies and recorded on high-speed video. Results found that acute exposure to 50 Hz EMFs significantly increased absolute change in wingbeats in a field-strength-dependent manner. Applying a range of ELF-EMF close to normal wingbeat occurance, they found that locusts entrained to the exact frequency of the applied EMF. They concluded that ELF exposure can lead to small but significant changes in locust wingbeats, likely due to direct acute effects on insect physiology (vs. cryptochrome or magnetite-based magnetoreception) and/or behavioral avoidance responses to molecular/physiological stress. Wyszkowska et al. [393] also found effects on locusts — exposure to ELF-EMF above 4 mT led to dramatic effects on behaviour, physiology and increased Hsp70 protein expression. Such higher exposures may be found near high tension lines.

Bees: RF-EMF

The effects of RF-EMF on bees is of increasing interest since that is the fastest rising EMF environmental exposure of the past 30 years [369]. Beginning in the early 2000s, studies of cell phones placed in the bottom of hives began to appear. Honey bees showed disturbed behavior when returning to hives after foraging and under various RFR exposures [394–396]. Early methodologies, however, were not well designed or controlled. For instance, Favre [397] found increased piping — a distress signal that honey bees give off to alert hive mates of threats and/or to announce the swarming process. Both active and inactive mobile phone handsets were placed in close proximity to honey bees with sounds recorded and analyzed. Audiograms and spectrograms showed that active phone handsets had a dramatic effect on bee behavior in induced worker piping. This study was criticized by Darney et al. [398] for using music in the active RFR exposure which may have introduced a variable capable of affecting bee piping in response to the added sound alone.

In a complex study, Darney et al. [398] tested high frequency (HF) and ultra high frequency (UHF) used in RFID technology in order to develop a method to automatically record honey bees going in and out of hives. They glued RFID tags onto individual bee dorsal surfaces that were detected at the hive entrance by readers emitting HF radio waves. They then looked for possible HF adverse effects on honey bees' survival. Eight-day-old honey bees were exposed to HF 13.56 MHz or UHF 868 MHz RFR for 2 h split into ON and OFF periods of different durations. Dead bees were counted daily with cumulative mortality rates of exposed and non-exposed honey bees compared seven days after exposure. Two out of five experimental conditions found increased mortality, once after HF and once after UHF exposure, with OFF duration of 5 min or more, after which they recommended limiting honey bee exposure to RFR to less than 2 h per day. They also curiously concluded that the RFID parameters they used for monitoring hive activity presented no adverse effects but the multifrequency peak exposures and RFID attachments need further study in light of other works on RFID effects (see Part 1 for discussion of RFID.)

In another study using an active cell phone attached to hive frames, Odemer and Odemer [399] investigated RFR effects on honey bee queen development and mating success. Control hives had an inactive cell phone attached. After exposing honey bee queen larvae to GSM 900 MHz RFR during all stages of pre-adult development (including pupation), hatching of adult queens was assessed 14 days after exposure and mating success after an additional 11 days. They found that chronic RFR exposure significantly reduced honey bee queen hatching; that mortalities occurred during pupation but not at the larval stages; that mating success was not adversely affected by the irradiation; and that after exposure, surviving queens were able to establish intact colonies. They therefore determined that mobile phone radiation had significantly reduced the hatching ratio but not mating success if queens survived, and if treated queens successfully mated, colony development was not adversely affected. Even though they found strong evidence of mobile phone RFR damage to pupal development, they cautioned its interpretation, noting that the study's worst-case exposure scenario was the equivalent of a cell phone held to a user's head, not at a level found in typical urban or rural hive settings. They concluded that while no acute negative effects on bee health were seen in the mid-term, they also could not rule out effects on bee health at lower chronic doses such as found in ambient environments, and urgently called for long term research on sublethal exposures present in major city environments.

Sharma and Kumar [400] found similar abnormalities in honey bee behavior when they compared the performance of honey bees in RFR exposed and unexposed colonies. Two of four test colonies were designated and each equipped with two functional cell phones — a high exposure — placed on two different hive side walls in call mode at GSM 900 MHz. The average RFR power density was measured at 8.549 $\mu W/cm^2$ (56.8 V/m, electric field). One control colony had a dummy phone; the other had no phone. Exposure was delivered in 15 min intervals, twice per day during the period of peak bee activity. The experiment was performed twice a week during February to April. It covered two brood cycles with all aspects of hive behavior observed, including brood area comprising eggs, larvae and sealed brood; queen proficiency in egg-laying rate; foraging, flight behavior, returning ability; colony strength including pollen storage; and other variables. Results included a significant decline in colony strength and egg laying and reduced foraging to the point where there was no pollen, honey, brood, or bees by the end of the experiment. One notable difference in this study was that the number of bees leaving the hive decreased following exposure. There was no immediate exodus of bees as a result of exposure — instead bees became quiet, still, and/or confused "…as if unable to decide what to do…" the researchers said. Such a response had not been reported before. The authors concluded that colony collapse disorder is related to cell phone radiation exposures.

Vilić et al. [401] investigated RFR and oxidative stress and genotoxicity in honey bees, specifically on the activity of catalase, superoxide dismutase, glutathione *S*-transferase, lipid peroxidation levels and DNA damage. Larvae were exposed to 900 MHz RFR at field levels of 10, 23, 41 and 120 V m^{-1} for 2 h. At a field level of 23 V m^{-1} the effect of 80% AM 1 kHz sinusoidal and 217 Hz modulation were also investigated. They found that catalase activity and the lipid peroxidation levels significantly decreased in larvae exposed to the unmodulated field at 10 V m^{-1} (27 $\mu W/cm^2$) compared to the control. Superoxide dismutase and glutathione *S*-transferase activity in honey bee larvae exposed to unmodulated fields were not statistically different compared to the control. DNA damage increased significantly in larvae exposed to modulated (80% AM at 1 kHz) field at 23 V m^{-1} (140 $\mu W/cm^2$) compared to control and all other exposure groups. Their results suggested that RFR effects in honey bee larvae manifested only after certain EMF exposure conditions. Interestingly, they found that increased field levels did not cause a linear dose-response in any of the measured parameters, while modulated RFR produced more negative effects than the corresponding unmodulated field. They concluded that while honey bees in natural environments would not be exposed to the high exposures in their experiments, the results indicated additional intensive research is needed in all stages of honey bee development since the cellular effects seen could affect critical aspects of bee health and survival.

Kumar et al. [402] also found biochemical changes in worker honey bees exposed to RFR. A wooden box was designed with glass on the front and back and wire gauze for ventilation on two sides for both exposed bees and controls. Cell phones (same make, model, and network connection) were kept in listen-talk mode for 40 min. At intervals of 10, 20 and 40 min, 10 exposed and 10 control bees were collected at the same times. Hemolymph was then extracted from the inter-segmental region of bee abdomens and analyzed. Results included increased concentration of total carbohydrates in exposed bees in the 10 min exposure period compared to unexposed bees. Increasing the exposure time to 20 min resulted in a further increase in the concentration, but exposure at 40 min had a reverse effect with declines in carbohydrate concentration although it was still higher than controls. Hemolymph glycogen and glucose content also showed the same exposure pattern — increase in content up to 20 min after which a slight decline that was still higher than controls. Changes in total lipids/cholesterol — the major energy reserves in insects — can affect numerous biological processes. Some lipids are crucial membrane structure components while others act as raw materials in hormones and pheromones. Changes in these parameters are significant to every biological activity, including reproduction. Also of interest in this study was that as exposure time increased, the bees appeared to have identified the source of disturbance. There was a large scale movement of workers toward the talk-mode (with higher RFR exposure during transmission function) but not the listening mode. Bees also showed slight aggression and agitation with wing beating. The researchers hypothesized that this increased activity could be responsible for increased energy use thereby accounting for the decrease in concentration of carbohydrates and lipids in the 40 min exposed sample. The researchers concluded that cell phone radiation influences honey bee behavior and physiology. Sharma [403] had also reported increased glycogen and glucose levels in exposed honey bee pupa.

It must be pointed out that the cell phone emission conditions used in some experiments are questionable, in particular where there was no detail regarding how the phones were activated to achieve emission.

Not all studies demonstrated adverse effects. Mall and Kumar [404] found no apparent RFR effects on brood rearing, honey production or foraging behavior in honey bees in hives with cell phones inside or near a cell tower; and Mixon et al. [405] also found no effects of GSM-signal RFR on increased honey bee aggression. They concluded that RFR did not impact foraging behavior or honey bee navigation and therefore was unlikely to impact colony health.

Although there are several anectodal reports of insect losses near communication towers, there are only a handful of ambient RFR field studies conducted on invertebrates thus far. In the first large survey of wild pollinating species at varying distances from cell towers, Lázaro et al. [406] found both positive and negative effects from RFR in a broad range of insects on two islands (Lesvos and Limnos) in the northeastern Aegean Sea near Greece. Measured ambient RFR levels included all frequency ranges used in cell communications; broadcast RFR is absent on the islands. RFR values did not significantly differ between islands (Lesvos: 0.27 ± 0.05 V/m; Limnos: 0.21 ± 0.04 V/m; v3 2 = 0.08, p=0.779) and did not decrease with the distance to the antenna, possibly, they hypothesized, because some sampling points near the antenna may have been outside or at the edge of the emission lobes. They measured RFR at four distances of 50, 100, 200 and 400 m (164, 328, 656, and 1,312 ft, respectively) from 10 antennas (5 on Lesvos Island and 5 on Limnos Island) and correlated RFR values with insect abundance (numbers of insects) and richness (general health and vitality) — the latter only for wild bees and hoverflies. The researchers conducted careful flowering plant/tree- and- insect inventories in several low-lying grassland areas, including for wild bees, hoverflies, bee flies, other remaining flies, beetles, butterflies, and of various types. Honey bees were not included in this study as they are a managed species subject to beekeeper decisions and therefore not a wild species. On Lesvos 11,547 insects were collected and on Limnos 5,544. Varied colored pan traps for both nocturnal and diurnal samples were used. Results found all pollinator groups except butterflies were affected by RFR (both positively and negatively) and for most pollinator groups effects were consistent on both islands. Abundance for beetles, wasps, and hoverflies significantly decreased with RFR but overall abundance of wild bees and bee flies significantly increased with exposure. Further analysis showed that only abundance of underground-nesting wild bees was positively related to RFR while wild bees nesting above ground were not affected. RFR effects between islands differed only on abundance of remaining flies. On species richness, RFR tended to only have a negative effect on hoverflies in Limnos. Regarding the absence of effects seen in butterflies, they hypothesized that the pan trap collection method is not efficient for collecting butterflies (butterflies accounted for only 1.3 % of total specimens), and that a different sampling method might produce a different result. They concluded that with RFR's negative effects on insect abundance in several groups leading to an altered composition of wild pollinators in natural habitats, it was possible this could affect wild plant diversity and crop production. They further said the negative relationship between RFR on the abundance of wasps, beetles and hoverflies could indicate higher sensitivity of these insects to EMFs. Potentially more EMF-tolerant pollinators, such as underground-nesting wild bees and bee flies, may fill the vacant niches left by less tolerant species, thus resulting in their population increases. Another possible explanation is that EMFs may have particularly detrimental effects on more sensitive larval stages, and if so, larvae developing above ground (many beetles, wasps, hoverflies) may be more vulnerable than those developing underground since the former could be exposed to higher radiation levels.

In another field study, Taye et al. [407] placed five hives from December to May at varying distances of 1,000, 500, 300, 200 and 100 m (3,280, 1,640, 984, 656 and 328 ft, respectively) from a cell tower in India to measure flight activity, returning ability, and pollen foraging efficiency in honey bees (*Apis cerana* F). They found most effects closest to towers with the least returning bees at 100 m distance from the tower. Maximum foraging and return ability to the colonies was seen at 500 m, followed by 1,000 m and in descending order at 300 and 200 m, with the fewest returning bees at 100 m from the tower. The study also found that if bees returned, the pollen load per minute was not significantly affected.

Vijver et al. [408] however challenged the accuracy of distance from towers that is often used as a proxy for EMF gradients such as the study above. In a field study in The Netherlands, the researchers tested exposure to RFR from a cell base station (GSM 900 MHz) on the reproductive capacity of small virgin invertebrates during the most sensitive developmental periods spanning preadolescent to mating stages when reproductive effects would most likely be seen. Careful RFR field measurements were taken to determine null points in order to see if distance from emitters is a reliable RFR exposure model in field studies. They exposed four different invertebrate hexapod species. Springtails (*Folsomia candida*), predatory 'bugs' (*Orius laevigatus)*, parasitic wasps (*Asobara japonica)*, and fruitflies (*D. melanogaster*) were placed in covered pedestal containers within the radius of approximately 150 m of a 900 MHz mobile phone base station for a 48-h period. Six control groups were placed within 6.6 ft (2 m) of the treatment groups and covered in Farady cages. After exposure, all groups were brought to the laboratory to facilitate reproduction with resulting fecundity and number of offspring then analyzed. Results showed that distance was not an adequate proxy to explain dose-response regressions. After complex data synthesis, no significant impact from the exposure conditions, measures of central tendency, or temporal variability of EMF on reproductive endpoints were found although there was some variability between insect groups. As seen in other studies, distance is often used to create a gradient in energy exposures in studies but this study found the intensity of the transmitter and the direction of transmission to be more relevant, as did Bolte and Eikelboom [409, 410]. The direction and tilt of the transmitter determines whether the location of interest in field studies is in the main beam. In some instances, the closer promixity to the transmitter provided lower readings than further away, which they found between two locations. They also noted that the organisms selected in the study were small in size; springtails have a body length on average of 2 mm; wasps are about 3 mm, insect sizes from 1.4 to 2.4 mm, with the largest organisms tested being female fruit flies at about 2.5 mm length and males slightly smaller. Due to size, limited absorption and little energy uptake capacity, none of these insects are efficient whole-body receptors for 900 MHz waves with a wavelength of approximately 13 in (33 cm). But they further noted that this was a linear regression study and that biological effects are often non-linear. However, finding no distinct effects did not exclude physiological changes. They concluded that because of RFR exposure's increasing ubiquity, urgent attention to potential effects on biodiversity is needed.

The issue of insect size, nonlinearity, and antenna tilt/direction are factors of critical importance with 5G radiation which will create extremely complex near- and- far-field ambient exposures to species in urban and rural environments alike, not only from a densification of small cell antennas close to the ground but also from increased satellite networks circling in low Earth orbits (see Part 1). The range of frequencies used for wireless telecommunication systems will increase from below 6 GHz (2G, 3G, 4G, and WiFi) to frequencies up to 120 GHz for 5G which, due to smaller wavelengths, is therefore a better resonant match for small insects. An alarming study by Thielens et al. [411], drawing on numerous robust studies of RFR's decades-long use as a thermal insecticide, modeled absorbed RFR in four different types of insects as a function of frequency alone from 2 to 120 GHz. A set of insect models was obtained using novel Micro-CT (computer tomography) imaging and used for the first time in finite-difference time-domain electromagnetic simulations. All insects showed frequency-dependent absorbed power and a general increase in absorbed RFR at and above 6 GHz, in comparison to the absorbed RFR power below 6 GHz. Their simulations showed that a shift of 10% of the incident power density to frequencies above 6 GHz would lead to an increase in absorbed power between 3–370% — a large differential of serious potential consequence to numerous insect species.

Using a similar approach, Thielens et al. [412] focused on the western honey bee (*Apis mellifera*) with RF-EMF, using a combination of *in-situ* exposure measurements near bee hives in Belgium and numerical simulations. Around five honey bee models were exposed to plane waves at frequencies from 0.6 to 120 GHz — frequencies carved out for 5G. Simulations quantified whole-body averaged RFR absorbed as a function of frequency and found that the average increased by factors of 16–121 (depending on the specimen) when frequency increased from 0.6 to 6 GHz for a fixed incident electric field strength. A relatively small decrease in absorption was observed for all studied honey bees between 12 and 120 GHz due to interior attenuation. RFR measurements were taken at 10 bee hive sites near five different locations. Results found average total incident RFR field strength of 0.06 V/m; those values were then used to assess absorption and a realistic rate was estimated between 0.1 and 0.7 nW. They concluded that with an assumed 10% incident power density shift to frequencies higher than 3 GHz, this would lead to an RFR absorption increase in honey bees between 390 and 570% — a frequency shift expected with the buildout of 5G.

The two previous studies alone should give pause regarding environmental effects to invertebrates in these higher 5G frequency ranges.

Kumar [413] noted that RFR should be included as causal agents of bee CCD and that test protocols need to be standardized and established. Standardization is critical since many studies conducted with cell phones in hives are of very uneven quality and only indicative of potential effects. Placing cell phones in hives and assuming that RFR is the only exposure is inaccurate and misleading. ELF-EMFs are always present in all telecommunications technology, using pulsed and modulated signals [414]. All of these characteristics have been found to be highly biologically active apart from frequency alone. Such studies are likely capturing ELF effects without identifying them. All aspects of transmission, including transmission engineering itself from towers, need to be considered to determine accurate exposures and delineate causative agents. Vibration and heat must also be considered — cell phones in transmission mode could raise hive temperature quickly and bees are highly temperature sensitive. Due to "waggle dance" specifics in creating foraging "roadmaps," bees should not be artificially relocated from hives to determine return ability after EMF exposure. They may be confused by relocation alone, adversely affecting their return abilities. Such tests also involve only one stressor when there are multiple stressors on insect species today. Understanding such cofactors is critical in determining accurate data and outcomes [415, 416]. Translating laboratory studies to field relevance has always been problematic but understanding EMF effects to insects has become urgent with ever increasing low-level ambient exposure from devices and infrastructure, especially in light of the new 5G networks being built. There are numerous variables that studies have yet to factor in. All of the above indicates a critical need to standardize experimental protocols and to take electroecology far more seriously, especially regarding aerial species in light of 5G.

Aquatic environments

There are fundamental electrical differences in conductivity (how well a material allows electric current to flow) and resistivity (how strongly a material opposes the flow of electric current) between air and water. Through water, EMF propagation is very different than through air because water has higher permittivity (ability to form dipoles) and electrical conductivity. Plane wave attenuation (dissipation) is higher in water than air, and increases rapidly with frequency. This is one reason that RFR has not traditionally been used in underwater communication while ELF has been. Conductivity of seawater is typically around 4 S/m, while fresh water varies but typically is in the mS/m range, thus making attenuation significantly lower in fresh water than in seawater. Fresh water, however, has similar permittivity as sea water. There is little direct effect on the magnetic field component in water mediums; propagation loss is mostly caused by conduction on the electric field component. Energy propagation continually cycles between electric and magnetic fields and higher conduction leads to strong attenuation/dissipation of EMF [98].

Because of these essential medium differences, electroreceptor mechanisms in aquatic species may be very different than those previously described in aerial species since air is a less conductive and resistive medium with less attenuation. That is why RFR travels more easily and directly through air. In aquatic species electroreception may be a result of transmission via water directly to the nervous system through unique receptor channels called Ampullae of Lorenzini [371]. In frogs, amphibians, fish, some worm species and others, receptor channels may be through the skin as well as via mechanisms more common in aerial species such as in the presence of magnetite (see "Mechanisms" above). There can be great variation in electroreceptive sensitivities in species inhabiting the two fundamentally different environments. Some amphibian species, however, have physical characteristics that span both mediums and therefore varied magnetoreception mechanisms.

Amphibians: frogs, salamanders, reptiles: regeneration abilities

Amphibians are the class of animals that include frogs, toads, salamanders, newts, some reptiles, and caecilians. The common term 'frog' is used to describe thousands of tailless amphibian species in the Order *Anura*. There are over 6,300 anuran species recorded thus far, with many more likely disappearing today due to climate change and other factors before we even knew they existed. Informal distinctions are made between frogs (thin-skinned species) and toads (thick, warty skins) but such distinctions are not used for taxonomic reasons. While the greatest concentration of diverse frog species is in tropical rainforests, they are widely found all over the world from the tropics to subarctic regions. Most adult frogs live in fresh water and/or on dry land while some species have adapted to living in trees or underground. Their skin varies in all manner of colors and patterns, from gray/green and brown/black to bright reds/yellows.

Frog skin is smooth and glandular — something of concern given nascent 5G technology (see Part 1) — and can secrete toxins to ward off predators. Frog skin is also semi-permeable which makes them highly susceptible to dehydration and pollutants. With radical weather shifts due to climate change and unpredictable swings between abnormal droughts followed by flooding in previously weather-stable regions, environmentally sensitive amphibians like frogs are considered bell-weather species. Frequently, time may be insufficient for some local/regional species to regenerate in between radical weather cycles, leading to population collapse.

Since the 1950s, there has been a significant decline in frog populations with more than one third of species today considered threatened with extinction while over 120 species are already believed to have gone extinct since the 1980s [10, 417, 418]. This amphibian decline is considered part of an ongoing global mass extinction, with population crashes as well as local extinctions creating grave implications for planetary biodiversity [419]. Amphibian extinction results are from climate change [420–422]; habitat loss/destruction [423, 424]; introduced species [425]; pollution [426], parasites [423, 427]; pesticides, herbicides and fungicides [428–430]; disease [431–435]; and increased ultraviolet-B radiation [436–439] among others. Anthropogenic sound pollution may also affect amphibian call rates and therefore impact reproduction [440] and artificial night lights affect male green frog (*Rana clamitaus melanota*) breeding [441]. Nonionizing electromagnetic fields may also play a role [442].

McCallum [443] calculated that the current extinction rate of amphibians could be 211 times greater than their pre-anthropogenic natural "background extinction" rate with the estimate rising 25,000–45,000 times if endangered species are also included in the computation. Today, declining amphibian populations are seen in thousands of species across numerous ecosystems, including pristine forested areas [418] and declines are now recognized among the most severe impacts of the anthropocene era [417, 442].

In addition, the number of frogs with severe malformations often incompatible with survival has risen sharply. Deformities are a complex issue related to physiology, anatomy, reproduction, development, water quality, changing environmental conditions, and ecology in general. Any time deformities are observed in large segments of wildlife populations there are indications of serious environmental problems [442]. Amphibian malformations are presumed due to an aggressive infectious fungal disease called Chytridiomycosisy, caused by the chytrid fungi *Batrachochytrium dendrobatodis* and *Batrachochytrium salamandrivorans* [432–435], and by parasites like *Ribeiroia ondatrae* [427]. Chytridiomycosis has been linked to dramatic amphibian declines and extinctions in North, Central, and South America, across sections of Australia and Africa and on Caribbean islands like Dominica and Montserrat. First identified in the 1970s in Colorado, U.S., it continues to spread globally at an alarming rate. Some populations witness sporadic deaths while others experience 100% mortality. There is no effective measure to control the disease in wild populations. Herbicides like glyphosate used in Roundup™ and atrazine, an endocrine disruptor, have also been found to cause severe malformations in both aquatic and land amphibian species from farmland pesticide/herbicide/fungicide runoff [428–430].

Frogs are known to be highly sensitive to natural and manmade EMF. Much research into the electrophysiology of frogs has been conducted because they are good lab models for human nervous system research, readily available, and easily handled. As far back as 1780, the Italian physicist Luigi Galvani discovered what we now understand to be the electrical basis of nerve impulses while studying static electricity (the only kind then known) when he accidentally made frog leg muscles contract while connected to the spinal cord by two different metal wires [444]. Galvani thought he had discovered "animal magnetism" but had actually discovered direct current and what later became known as a natural "current of injury"—the process by which an injured limb, for instance, produces a negative charge at the injury site that will later turn to a positive charge at the same site in some species as discovered in the 1960s by Robert O. Becker [444–451]. The earliest curiosity about natural current continued throughout the 1800s on various aspects of EMF and later throughout the 1920s to 1940s in pioneering researchers Elmer J. Lund [452–454] and Harold Saxon Burr [455–457] who worked to establish the first unified electrodynamic field theory of life, using hydra, frog, and salamander models among several others because of their morphogenic properties [458]. While frogs do not regenerate limbs the way salamanders do, both are so similar in taxonomy that curiosity was high in the early pioneers cited above throughout the 1960s to 1990s about what fundamentally allowed limb regeneration in one species, by not the other. Much was learned in the process about amphibian electrophysiology and cellular microcurrent in wound healing, as well as the electrophysiological properties of cellular differentiation, and eventually dedifferentiation pertinent to all contemporary stem cell research. Today the implications of this early work have gained new interest and targeted research regarding endogenous microcurrent and limb regeneration potential in humans, as well as dediffentiation/stem cell/morphogenesis in general for cancer treatment and other healing modalities. For a thorough review of studies on morphogenesis see Levin [459].

Ubiquitous low-level ambient EMFs today match some of the natural low-level microcurrent found critical to the fundamental processes of amphibian growth, reproduction, morphogenesis, and regeneration, lending new meaning to the early research that defined amphibian electrophysiology. We just need to make far better use of it to understand what role, if any, today's ambient exposures may be contributing to amphibian losses. (To compare tables between rising ambient EMF levels and low level effects in wildlife, see Part 1, Supplement 1; and Part 2, Supplement 3.)

Amphibian and reptile magnetoreception

How amphibians perceive natural and manmade EMF is similar to other species reviewed above and for amphibian mechanism reviews see Phillips et al. [460, 461]. Like many bird and insect species, evidence indicates that amphibians perceive the Earth's geomagnetic fields by at least two different biophysical magnetoreception mechanisms: naturally occurring ferromagnetic crystals (magnetite), and light-induced reactions via specialized photo-receptor cells (cryptochromes) that form spin-correlated radical pairs. Like birds, both mechanisms are present in some amphibians. Cryptochromes provide a directional 'compass' and the non-light-dependent magnetite provides the geographical 'map.'

In a thorough discussion of many magnetoreception studies in anura and urodela species, Diego-Rasilla et al. [462] found evidence that Iberian green frog tadpoles (*Pelophylax perezi*) had a light-dependent magnetic compass, and Diego-Rasilla et al. [463] also found that tadpoles of the European common frog (*Rana temporaria*) are capable of using the Earth's magnetic field for orienting along a learned y-axis. In these studies, they investigated if this orientation is accomplished using a light-dependent magnetic compass similar to that found in the earlier experiments with other species of frogs and newts [460, 462–470] or from some other factor. They concluded that the magnetic compass provided a reliable source of directional information under a wide range of natural lighting conditions. They also compared their findings to studies [470] that showed the pineal organ of newts to be the site of the light-dependent magnetic compass, as well as to recent neurophysiological evidence showing magnetic field sensitivity located in the frog frontal organ which is an outgrowth of the pineal gland. They hypothesized this work could indicate a common ancestor as long ago as 294 million years.

To determine if orientation using Earth's magnetic fields changed according to seasonal migration patterns, Shakhparonov and Ogurtsov [471] tested marsh frogs (*Pelophylax ridibundus*) in the laboratory to see if frogs could determine migratory direction between the breeding pond and their wintering site according to magnetic cues. Adult frogs (n=32) were tested individually in a T-maze 127 cm long inside a three-axis Helmholtz coil system (diameter 3 m). Maze arms were positioned parallel to the natural migratory route and measured in accordance with the magnetic field. Frogs were tested in the breeding migratory state and the wintering state, mediated by a temperature/light regime. Frog choice in a T-maze was evident when analyzed according to the magnetic field direction. They moved along the migratory route to the breeding pond and followed the reversion of the horizontal component of the magnetic field. The preference was seen in both sexes but only during the breeding migratory state. They concluded that adult frogs obtained directional information from the Earth's magnetic field.

Diego-Rasilla et al. [472] found similar evidence in two species of lacertid lizards (*Podarcismuralis and Podarcis lilfordi*) that exhibited spontaneous longitudinal body axis alignment relative to the Earth's magnetic field during sun basking periods. Both species exhibited a highly significant bimodal orientation along the north-northeast and south-southwest magnetic axis. Lizard orientations were significantly correlated over a five-year period with geomagnetic field values at the time of each observation. This suggested the behavior provides lizards with a constant directional reference, possibly creating a spacial mental map to facilitate escape. This was the first study to provide spontaneous magnetic alignment behavior in free-living reptiles although studies of terrapins have also found such spontaneous magnetic alignment [92, 323, 473]. Nishimura et al. [474, 475] also found sensitivity to ELF-EMF (sinusoidal 6 and 8 Hz, peak magnetic field 2.6 μT, peak electric field (10 V/m) in a lizard species (*Pogona vitticeps*) as demonstrated by significant increased tail lifting — a reproductive behavior. Interestingly, this tail-lifting response to ELF-EMF disappeared when the parietal eye was covered, suggesting that the parietal eye contributes to light-dependent magnetoreception and that exposure to ELF-EMFs may increase magnetic-field sensitivity in the lizards. A further experiment [476] showed that light at a wavelength lower than 580 nm was needed to activate the light-dependent magnetoreception of the parietal eye.

Amphibians: RF-EMF

Most frogs spend significant time on land but lay eggs in water where they hatch into tadpoles with tails and internal gills. However, some species bypass the tadpole stage and/or deposit eggs on land. Frogs are thus subject to exposures from both land-based and aquatic environments. A frog's life cycle is complete when metamorphosis into an adult form occurs. Many adverse effects do not appear until after metamorphosis is completed but problems have been found throughout the entire life cycle after exposures to both ELF-EMF and RFR.

Most early research on frogs (other than the Becker et al. regeneration inquiries noted above) was conducted at high thermal levels rarely encountered in the environment but some are included here because they helped delineate amphibian electrophysiology with effects later supported in low-level research. Some early work did use frog models to investigate cardiac effects with lower intensity exposures. Levitina [477] found that intact frog whole-body exposure caused a decrease in heart rate, while irradiation of just the head caused an increase. Using VHF frequency RFR at a power density of 60 μW/cm^2, A=12.5 cm, Levitina attributed the cardiac changes to peripheral nervous system effects but according to Frey and Siefert [478], because of the wavelengths used in that study, little energetic body penetration would be expected. They said a skin receptor hypothesis was therefore reasonable.

Following on Levitina's work, Frey and Seifert [478] — using isolated frog hearts, UHF frequencies that penetrate tissue more efficiently and low intensity pulse modulation — found that pulsed microwaves at 1,425 GHz could alter frog heart rates depending on the timing of exposure between the phase of heart action and the moment of pulse action. Twenty-two isolated frog hearts were irradiated with pulses synchronized with the P-wave of the ECGs; pulses were of 10 s duration triggered at the peak of the P-wave. Two control groups were used without RFR exposures with no effects noted. They found heart rate acceleration occurred with pulsing at about 200 ms after the P-wave. But if the pulse occurred simultaneously with the P-wave, no increases were induced. Arrhythmias occurred in half the samples, some resulting in cardiac cessation. Clearly from this study, RFR affected frog heart rhythm and could cause death.

A more recent work by Miura and Okada [479] found severe vasodilation in frog foot webs from RFR. In a series of three experiments using 44 anesthetized frogs (*X. laevis*) at thermal and non-thermal intensities, researchers exposed foot webs to pulsed RFR in three parameters with the monitor coil set at 1 V peak-to-peak: 100 kHz 582-3 mG and 174.76 V cm^{-1}; 10 MHz 7.3 mG and 2.19 V cm^{-1}; 1 MHz 539 mG and 16.11 V cm^{-1}. They found not only dilated arterioles of the web which had already been re-constricted with noradrenaline, but also dilated arterioles under non-stimulated conditions. Vasodilatation increased slowly and reached a plateau 60 min after radiation's onset. After radiation ceased, vasodilation remained for 10–20 min before slowly subsiding. Vasodilation was optimum when pulsation was applied 50% of the total time at a 10 kHz burst rate at 10 MHz. Effects were non-thermal. The pattern of vasodilation induced by warm Ringer solution was different from the vasodilatory effect of weak RFR, involving the level of intracellular Ca^{2+}. They hypothesized that since Ca^{2+} ATPase is activated by cyclic GMP which is produced by the enzymatic action of guanylate cyclase, RF-EMF may activate guanylate cyclase to facilitate cyclic GMP production. They concluded the study indicates for the first time that RFR dilates peripheral resistance vessels by neither pharmacological vasodilator agents nor physical thermal radiation, but that the precise mechanisms of activation of guanylate cyclase by RFR at the molecular level required further study. Vasodilation and constriction affects every part of the body and can affect all organ systems.

Prior to this, Schwartz et al. [480] found changes in calcium ions in frog hearts in response to a weak VHF field that was modulated at 16 Hz. This would be an exposure common in the environment. Calcium ions are critical to heart function.

Balmori [24–30, 442] and Balmori and Hallberg [271] have focused widely on EMF effects to wildlife, with two papers on amphibians. Balmori [442], in a review, noted that RFR in the microwave range is a possible cause for deformations and decline of some amphibian populations, and Balmori [481] in 2010 found increased mortality in tadpoles exposed to RFR in an urban environment. In the 2010 study, tadpoles of the common frog (*Rana temporaria*) were exposed to RFR from several mobile phone towers at a distance of 459 ft (140 m). Two month exposures lasted through egg phase to advanced tadpole growth prior to metamorphosis. RF and MW field intensity between 1.8 and 3.5 V/m (0.86–3.2 μW/cm^2) were measured with three different devices. Results determined that the exposed group (n=70) had low coordination of movements and asynchronous growth that resulted in both large and small tadpoles, as well as a disturbing 90% high mortality rate. In the control group (n=70) a Faraday cage was used under the same conditions. Controls found movement coordination to be normal and development synchronous with mortality rate at a low 4.2%. These results indicated that RFR from cell towers in a field situation could affect both development and mortality of tadpoles. Prior to this study, Grefner et al. [482] also found increased death in tadpoles (*Rana temporaria* L.) exposed to EMF, as well as higher mortality rates, and slower less synchronous development.

Mortazavi et al. [483] found changes in muscle contractions in frogs exposed to 900-MHz cell phone radiation for 30 min; gastrocnemimus muscles were then isolated and exposed to a switched on/off mobile phone radiation for three 10-min intervals. The authors reported RFR-induced effects on pulse height and latency period of muscle contractions. SARs of the nerve-muscle preparation were calculated to be 0.66 (muscle) and 0.407 (nerve) W/kg.

Rafati et al. [484] investigated the effects of RFR on frogs from mobile phone jamming equipment emitting RFR in the same frequencies as mobile phones. (Although illegal in many countries, jammers are nevertheless used to interfere with signals and stop communication.) The study sought to follow up on reports of non-thermal effects of RFR on amphibians regarding alterations of muscle contraction patterns. They focused on three parameters: the pulse height of leg muscle contractions, the time interval between two subsequent contractions, and the latency period of frog's isolated gastrocnemius muscle after stimulation with single square pulses of 1 V (1 Hz). Animals in the jammer group were exposed to RFR at a distance of 1 m from the jammer's antenna for 2 h while the control frogs were sham exposed. All were then sacrificed and isolated gastrocnemius muscles were exposed to on/off jammer radiation for three subsequent 10 min intervals (SAR for nerve and muscle of the different forms of jammer radiation was between 0.01 and 0.052 W/kg). Results showed that neither the pulse height of muscle contractions nor the time interval between two subsequent contractions were affected, but the latency period (time interval between stimulus and response) was statistically significantly altered in the RFR-exposed samples. They concluded the results supported earlier reports of non-thermal effects of EMF on amphibians including the effects on the pattern of muscle contractions. Control sham exposed samples showed no effects.

Amphibians, reptiles: ELF-EMF

Amphibians are highly sensitive to ELF-EMF. An early-1969 study by Levengood [485] using a magnetic field probe found increased high rates of teratogenesis in frogs (*Rana sylvatica*) and salamanders *(Ambystoma maculatum*). Two identical probes using different field strengths were employed — both operated in the kilogauss region with high field gradients. Amphibian eggs and embryos were exposed at various stages of development with gross abnormalities found in developing larvae vs. control. At the hatching stage severe abnormalities were noted in both anuran and urodele larvae from probe-treated eggs. Hatching abnormalities included microcephaly, altered development, and multiple oedematous growths. In probe-treated frogs there was a delay in the appearance of a high percentage of malformations until the climax stage of metamorphosis. Until that stage, the larvae were of the same appearance as control specimens, thus camouflaging the damage after just a brief treatment of early embryos. The frog abnormalities at metamorphosis differed from those in the hatching tadpoles and consisted mainly of severe subepidermal blistering and leg malformations including formation of multiple deformed limbs incompatible with life. Over 90% of the morphological alterations at metamorphosis climax were also found to be associated with deformed kidneys. The gastrula stages of development appeared to be the most sensitive in the delayed-effects category. While this was a high-field exposure experiment, it is an intensity that is found in some environments today especially near high tension lines and in abnormal ground current situations.

Neurath [486] also found strongly inhibited early embryonic growth of the common leopard frog (*Rana pipiens*) by a high static magnetic field with a high gradient (1T) — an exposure sometimes found in the environment — while Ueno and Iwasaka [487] found abnormal growth and increased incidence of malformations in embryos exposed to magnetic fields up to 8T but exposures that high are typically near industrial sites and rarely found in nature.

Severini et al. [488] specifically addressed whether weak ELF magnetic fields could affect tadpole development and found delayed maturation in tadpoles. Two cohorts of *X. laevis laevis* (Daudin) tadpoles were exposed for 60 days during immaturity to a 50 Hz magnetic field of 63.9–76.4 μT rms (root mean square, average values) magnetic flux density in a solenoid. Controls were two comparable cohorts remotely located away from the solenoid. The experiment was replicated three times. Results showed reduced mean developmental rate of exposed cohorts vs. controls (0.43 vs. 0.48 stages/day, $p< 0.001$) beginning from early larval stages; exposure increased the mean metamorphosis period of tadpoles by 2.4 days vs. controls ($p < 0.001$); and during the maturation period, maturation rates of exposed vs. control tadpoles were altered. No increases in mortality, malformations, or teratogenic effects were seen in exposed groups. The researchers concluded that relatively weak 50 Hz magnetic fields can cause sub-lethal effects in tadpoles via slowed larval development and delays in metamorphosis. Such exposures are found in the environment today in some locations and even though the changes were small, coupled with climate change, such sub-lethal effects may impact some wildlife populations in some environments.

In similar followup work, Severini and Bosco [489] found sensitivity to small variations of magnetic flux density (50 Hz, 22-day continuous exposure, magnetic flux densities between 63.9 and 76.4 μT) in tadpoles exposed to a stronger field vs. controls exposed to a weaker field. A significant delay in development of 2.5 days was found in exposed vs. controls. They concluded the delay was caused by the slightly different magnetic flux densities with results suggesting a field threshold around 70 μT in controlling the tadpole developmental rate.

Schlegel in 1997 found European blind cave salamanders (*Proteus anguinus*) and Pyrenean newts (*Euproctus asper)* to be sensitive to low level electric fields in water [490]. And Schlegel and Bulog [491] in followup work found thresholds of overt avoidance behavior to electric fields as a function of frequency of continuous sine-waves in water. Nine salamanders from different Slovenian populations of the urodele (*P. anguinus)* that included three specimens of its 'black' variety (*P. anguinus parkelj*) showed thresholds between 0.3 mV/cm (ca 100 nA/cm^2) and up to 2 mV/cm (670 nA/cm^2), with the most reactive frequencies around 30 Hz. Sensitivity included a total frequency range below 1 Hz (excluding DC) up to 1–2 kHz with up to 40 dB higher thresholds. These are ranges that may be found in the wild near high tension lines and utility grounding practices near water, by some underwater cabling, and by some RFR transmitters.

Landesman and Douglas in 1990 [492] found some newt species showed accelerated abnormal limb growth when pulsed electromagnetic fields were added to the normal limb regeneration process. While normal limb regeneration found normal regrowth patterns in 72% of specimens, 28% were abnormal. Abnormalities included loss of a digit, fused carpals, and long bone defects which occurred singly or in combination with one another. When exposure to a PEMF was added for the first 30 days post-amputation, followed by a 3–4 month postamputation period, a group of forelimbs with unique gross defects increased by an additional 12%. Defects (singly or in combination) included the loss of two or more digits with associated loss of carpals, absence of the entire hand pattern, and abnormalities associated with the radius and ulna. The researchers offered no explanation. Exposure intensities were similar to those used to facilitate non-juncture fracture healing in humans.

Komazaki and Takano in 2007 [493] found accelerated early development growth rates with 50 Hz, 5–30 mT alternating current exposures in the fertilized eggs of Japanese newts (*Cynops pyrrhogaster*). The period of gastrulation was shortened via EMF-promoted morphogenetic cell movements and increased $[Ca^{2+}]_i$. They said their results indicated that EMF specifically increased the $[Ca^2]_i$ of gastrula cells, thereby accelerating growth. This study only observed through the larval stages and they did not see any malformations under EMF exposures, which they attributed to possible differences in the intensity and mode of EMF.

With amphibians and some reptiles demonstrating high sensitivity to natural background EMF for important breeding and orientation needs, amphibians living in aquatic, terrestrial, and aerial environments (i.e. tree frog species) may be affected from multi-frequency anthropogenic EMF in ways we do not fully understand. There are potential effects — especially from 5G MMW that couple maximally with skin — to all aspects of their development and life cycles, including secondary effects.

Fish, marine mammals, lobsters, and crabs

Aquatic animals are exquisitely sensitive to natural EMF and therefore potentially to anthropogenic disturbance. The Earth's dipole geomagnetic field yields a consistent though varying source of directional information in both land and aquatic species for use in homing behavior, orientation during navigation and migration. This information is used both as a 'map' for positional information as well as a 'compass' for direction [494–497]. Aquatic species are known to be sensitive to static geomagnetic fields, atmospheric changes and sunspot activities [498]. For recent comprehensive reviews on magnetic field sensitivity in fish and effects on behavior, see Tricas and Gill [36] and Krylov et al. [33]. Some biological 'magnetic maps' may be inherited [499]. And for a recent extensive discussion of the Earth's natural fields and magnetoreception in marine animals with a focus on effects from electromagnetic surveys that use localized strong EMFs to map petroleum deposits under seabeds, see Nyqvist et al. [498] and below.

As mentioned above, because of the difference in conductivity of water and other factors, the way some aquatic species sense EMF may rely on unique modes of physiological perception, as well as those employed by terrestrial animals. There may also be sensory combinations not yet understood in some aquatic and semi-aquatic species. For instance, what role does the neural conductivity of whiskers (vibrissae) in seals, sea lions and walrus play other than for food finding? Aquatic species' dense network of whiskers is larger with greater blood flow than terrestrial species and can contain 1,500 nerves per follicle vs. cats at 200 per follicle. Seal whiskers also vary geometrically from terrestrial species and the largest part of the seal brain is linked to whisker function. Seals use whiskers to map the size, shape and external structure of objects and can find prey even when blindfolded. Their whiskers are also sensitive to weak changes in water motion [100]. But are they also using them as a location or directional compass in relation to the geomagnetic field? That has yet to be studied.

Unique sensory differences in aquatic species have long been documented. Joshberger et al. [500] noted that in 1,678 Stefano Lorenzini [501] was the first to describe a network of organs in the torpedo ray that became known as the Ampullae of Lorenzini (AoL). Its purpose was unknown for 300 years until Murray [502] measured AoL's electrical properties in elasmobranch fish — sharks, rays and skates. Later work [101, 503–508] confirmed and greatly added to this knowledge. Researchers now know that AoL is likely the primary mechanism that allows elasmobranch fish to detect and map a potential prey's physiology via the very weak changes in electric fields given off by prey's muscle contractions.

Individual ampullae are skin pores that open to the aquatic environment with a jelly-filled canal leading to an alveolus containing a series of electrosensing cells. Within the alveolus, the electrosensitive cells of the ampullae communicate with neurons and this integration of signals from multiple ampullae is what allows elasmobranch fish to detect electric field changes as small as 5 nV/cm [503, 506, 509, 510]. The AoL jelly has been reported as a semiconductor with temperature-dependence conductivity and thermoelectric behavior [500, 509, 510], as well as a simple ionic conductor with the same electrical properties as the surrounding seawater [503, 506]. Josberger et al. [500] attempted to clarify what AoL's role is in electrosensing by measuring AoL's proton conductivity. They found that room-temperature proton conductivity of AoL jelly is very high at 2 ± 1 mS/cm — only 40-fold lower than some current state-of-the-art manmade proton-conducting polymers. That makes AoL the highest conductive biological material reported thus far. They suggested that the polyglycans contained in the AoL jelly may contribute to its high proton conductivity.

Other aquatic magneto-sensory mechanisms more in harmony with terrestrial animals include the presence of ferromagnetic particles in magnetite — tiny naturally produced magnets that align with the Earth's magnetic field, allowing for species' direction and orientation. Magnetite appears to transmit necessary information through a connection with the central nervous system [340, 497, 511]. A magnetite-based system is plausible for cetaceans [512, 513] as magnetite has been found in the meninges dura mater surrounding the brains of whales and dolphins [514, 515]. There is also evidence that local variations/anomalies in the geomagnetic field in certain underwater topographies may play a role in live cetacean strandings [516, 517] which indicates a magnetic compass based on magnetite. And free-ranging cetaceans have shown evidence of magnetoreception-based navigation, e.g., Fin whale migration routes have been correlated with low geomagnetic intensity [513].

Recently, Granger et al. [518] found correlations in data between 31 years of gray whale (*Eschrichtius robustus*) strandings and sunspot activity, especially with RF 'noise' in the 2,800 MHz range. The 11-year sunspot cycle strongly correlates with the intense releases of high-energy particles known as solar storms which can temporarily modify the geomagnetic field, and in turn may modify orientation in magnetoreceptive species. Solar storms also cause an increase in natural broadband RF 'noise'. They examined changes in both geomagnetic fields and RF 'noise' and found RF to be a determinant. Further, they hypothesized that increased strandings during high solar activity is more likely due to radical pair mechanisms which are more reactive with RFR than magnetite, which appears more reactive to ELF-EMF. Two previous studies also found correlations with cetacean strandings and solar activities [519, 520]. Both mechanisms may come into play under different circumstances or act in synergy.

Kremers et al. [512] investigated the spontaneous magnetoreception response in six captive free-swimming bottlenose dolphins (*Tursiops truncates*) to introduced magnetized and demagnetized devices used as controls. They found a shorter latency in dolphins that approached the device containing a strong magnetized neodymium block compared to a control demagnetized block identical in form and density and therefore indistinguishable with echolocation. They concluded that dolphins can discriminate on the basis of magnetic properties — a prerequisite for magnetoreception-based navigation. Stafne and Manger [521] also observed that captive bottlenose dolphins in the northern hemisphere swim predominantly in a counter-clockwise direction while dolphins in the southern hemisphere swim predominantly in clockwise direction. No speculation was offered for this behavior.

How salmon navigate vast distances — from their hatching grounds in freshwater river bottoms to lakes during juvenile growth, then the open ocean during maturity, and with a final return to their neonatal birthing grounds to spawn and die (for most anadromous salmonids) — has fascinated researchers for decades. Research indicates they may use several magneto-senses to accomplish this, including inherited mechanisms [522], imprinting [499, 522], a magnetic compass [499, 522, 523], and biomagnetic materials. Salmon have been found to have crystal chains of magnetite [524]. One recent study found that strong magnetic pulses were capable of disrupting orientation in salmon models [525], indicating a magnetite-based mechanism. In salmon, the migration process is complicated by the fact that the ability to sense geomagnetic fields can be altered by changes in salinity between fresh and salt water, thus pointing to multi-sensory mechanisms [499].

Speculation that salmon use the geomagnetic field in some capacity for their iconic migration goes back decades [526]. Quinn [527] found evidence that sockeye salmon (*Oncorhynchus nerka*) frey use both a celestial and magnetic compass when migrating from river hatching to lakes. Putman et al. [499], who have written extensively on this subject, focused on how salmon navigate to specific oceanic feeding areas — a challenge since juvenile salmon reach feeding habitats thousands of kilometers from natal locations. The researchers experimentally found that juvenile Chinook salmon (*Oncorhynchus tshawytscha*) responded to magnetic fields similar to latitudes of their extreme ocean range by orienting in directions that would lead toward their marine feeding grounds. They further found that fish use the combination of magnetic intensity and inclination angle to assess their geographic location and concluded that the magnetic map of salmon appears to be inherited since the fish had no prior migratory experience. These results, paired with findings in sea turtles (see below), indicate that magnetic maps are widespread in aquatic species and likely explain the extraordinary navigational abilities seen in long-distance underwater migrants [499].

It is less likely that light-sensing radical pair cryptochromes play much of a role in aquatic species though some hypothesize the possibility [528]. Krylov et al. [33], however, noted that there are no anatomical structures or neurophysiological mechanisms presently known for radical pair receptors in the brains of fish and that since light decreases with water depth and fish are capable of orienting in complete darkness using the geomagnetic field, their opinion was that it is too early to say fish have magnetoreception mechanisms based on free radicals, light-dependent or otherwise.

Fish, lobsters, crabs: ELF-EMF

For several reasons having to do with differences in conductivity in water vs. air (see above), RFR is of far less concern in aquatic environments at present than is ELF. With the ever-increasing number of underwater cables used for everything from transcontinental data/communications to power supplies for islands, marine platforms, underwater observatories, off-shore drilling, wind facilities, tidal and wave turbines among others, many new sources of both AC and DC electric current are being created in sea and freshwater environments alike. According to Ardelean and Minnebo writing in 2015 [529], almost 4,971 mi (8,000 km) of high voltage direct current (HVDC) cables were present on the seabed worldwide, 70% of which were in European waters, and this is only expected to grow dramatically as new sources of renewable energy are built to replace fossil fuels globally.

Curiosity about potential adverse effects from cable-generated ELF-EMF on all phases of fish life has also grown, especially in benthic and demersal species that spend significant time near cables in deeper bottom environments for egg laying, larvae growth, and development for most, if not all, of their adult lives.

Fey et al. [494, 495] and Öhman et al. [530] noted that there are two types of anthropogenic exposures created by cables: high voltage direct current (HVDC) that emits static magnetic fields, and three-phase alternating current (AC power transmission) that emit time-varying electromagnetic fields. The density of electric current near underwater cables on the sea floor can vary significantly depending on the type of cable and whether they are positioned on the sea bottom or buried [36, 530]. Noticeable magnetic field changes can occur within meters but generally not more than several meters from the cable. However, Hutchinson et al. [531], in a robust field study and extensive review, found surprisingly stronger and more complex exposures than anticipated (see below).

Since fish are highly sensitive to static magnetic fields (MF), it is important to delineate static fields from anthropogenic alternating current EMF in aquatic studies. In freshwater species under laboratory conditions, Fey et al. [494] found similar results to those of salmon studies (noted above) in northern pike (*Esox lucius*) exposed to a static magnetic field from DC cables (10 mT) during the embryonic phase and in the first six days of post-hatching. No statistically significant MF effect was seen on hatching success, larvae mortality, larvae size at hatching, and growth rate during the first six days of life. However, significant MF effects were seen on hatching time (one day earlier in a magnetic field than in control), yolk-sac size was smaller, and yolk-sac absorption rate was faster. They interpreted the faster yolk-sac absorption in a magnetic field as an indication of increased metabolic rate but added that even if some negative consequences were expected as a result, that the actual risk for increased northern pike larvae mortality seemed negligible. Though higher than 10 mT magnetic field values are hazardous for fish larvae, they added such values do not occur in the natural environment even along underwater cables.

But in follow-up work of longer duration the same general research group reached a different conclusion. Fey et al. [495] studied effects on eggs and larvae of rainbow trout (*Oncorhynchus mykiss*) exposed to a static magnetic field (MF) of 10 mT and a 50 Hz EMF of 1 mT for 36 days (i.e., from eyed egg stage to approximately 26 days post hatching). They found that while neither the static MF nor the 50-Hz EMF had significant effects on embryonic/larval mortality, hatching time, larval growth, or the time of larvae swim-up from the bottom, both fields did however enhance the yolk-sac absorption rates. While they said this was not directly related to a MF effect, it was shown that larvae with absorbed yolk-sacs by the time of swim-up were less efficient in taking advantage of available food at first feeding and gained less weight. They concluded that these exposures could negatively affect the yolk-sac absorption rate thereby hampering fish in important feeding activities needed for fast weight gain and increased survival. In an additional study, Fey et al. [532] observed that rainbow trout reared in a laboratory for 37 days and exposed to a static MF (10 mT) or a 50-Hz EMF (1 mT) showed defects in otolith of the inner ear which is responsible for hearing and balance in fish. The authors concluded that underwater construction and/or cables that emit a MF of 10 mT or higher can affect living organisms within a few meters distance, especially species like trout in settled life stages on the sediment bottom during early development.

Zebrafish (*Danio rerio*) are often used in EMF research in toxicology and developmental biology investigating effects on humans because the genomes are so similar. Li et al. [533] studied ELF-MF on the development of fertilized zebrafish embryos divided into seven groups. Embryos of experimental groups were continuously exposed to 50-Hz sinusoidal MF with intensities of 30, 100, 200, 400, or 800 μT for 96 h. The sham group was identical but without ELF-MF exposure. Results showed that ELF-MF caused delayed hatching and decreased heart rate at early developmental stages but no significant differences were seen in embryo mortality or abnormality. Acridine orange staining assays showed notable signs of apoptosis in the ventral fin and spinal column and transcription of apoptosis-related genes (caspase-3, caspase-9) was significantly up-regulated in ELF-MF-exposed embryos. They concluded that ELF-EMF demonstrated detrimental effects on zebrafish embryonic development, including on hatching, decreased heart rate, and induced apoptosis, although such effects were not a mortal threat. The lower range exposures of this study are found in some aquatic environments.

Sedigh et al. [534] investigated effects on zebrafish exposed to static magnetic fields. Exposures of 1-week acute and 3-week subacute exposures to different static magnetic fields at 2.5, 5, and 7.5 mT were measured on stress indices (cortisol and glucose), sex steroid hormones (17β-estradiol and 17-α hydroxy progesterone) and fecundity. They found a significant change in cortisol, glucose, 17β-estradiol (E_2) and 17-α hydroxy progesterone (17-OHP) levels with increased intensity and duration of exposure and concluded that static magnetic fields at higher intensities showed harmful effects on the reproductive biology of zebrafish during both acute and subacute exposures.

Recent laboratory research by Hunt et al. [535] used the transparent glass catfish (*Kryptopterus vitreolus*) found in slow moving waters in Southeast Asia as a model to investigate magnetoreception. The study used Y-maze chambers, animal tracking software and artificial intelligence techniques to quantify effects of magnetic fields on the swimming direction of catfish. They placed a permanent Neodymium Rare Earth Magnet (11.5 × 3.18 × 2.2 cm) with a horizontal magnetic flux of 577 mT at the magnet's surface at 10 cm from the end of one of the Y-maze arms and found that catfish consistently swam away from magnetic fields over 20 μT. The catfish also showed adaptability to changing magnetic field direction and location. The magnetic avoidance was not influenced by school behavior. Sham exposures produced no avoidance. Such exposures might be found near some underwater cables.

To further elucidate findings of species reactions near underwater cables and fill in knowledge gaps since the 2011 Tricas and Gill review [36], Hutchinson et al. [531] conducted both field and laboratory modeling studies of both AC and DC fields on the American lobster (*Homarus americanus*) and the little skate (*Leucoraja erinacea*). They noted that in previous studies, while behavioral responses had been seen, findings were unable to determine if significant biological effects (e.g., population changes) occurred. The American lobster was modeled because it is a magnetosensitive species [536] and concern existed that EMF from cables might restrict movements and/or migration. Lobsters may migrate up to 50 mi (80 km) one way from deep waters to shallow breeding grounds. The little skate was used as a model for the most electro-sensitive taxa of the elasmobranchs, which may be attracted by/to the EMF of cables, particularly for benthic species, thereby altering their foraging or movement behavior. Both models were therefore thought indicative of potential EMF impacts. In this robust field study, the researchers found that the American lobster exhibited a statistically significant but subtle change in behavioral activity when exposed to the EMF of the HVDC cable (operated at a constant power of 330 MW at 1,175 Amps). The little skate exhibited a strong behavioral response to EMF from a cable powered for 62.4% of the study with the most frequently transmitted electrical current at 16 Amps (at 0 MW, 37.5% of time), 345 Amps (100 MW, 28.6%) and 1,175 Amps (330 MW, 15.2%). They concluded that for both species, the behavioral changes have biological relevance regarding how they will move around and are distributed in a cable-EMF zone, but they noted that the EMF did not constitute a barrier to movements across the cable for either species.

Of interest in this study were the actual field readings near cables. Unexpected significant AC magnetic and electric fields did not match computer models and were observed to be associated with both of the DC power cables studied. The maximum observed AC values along the cable axis were 0.15 μT and 0.7 mV/m for the magnetic and electric fields respectively for one cable, and 0.04 μT and 0.4 mV/m respectively, for the other cable. Also, the cross section of the EMF peaks exhibited by the DC subsea power cables were broader than anticipated at both studied. The DC and AC magnetic fields reached background levels on either side of the cable on a scale of c.a.5 and 10 m from the peak observed value respectively, whereas the AC electric fields reached background on a scale of 100 m (328 ft) from the peak value. Peak observed values occurred almost directly above the cable axis location; there was an offset of 3.3 ft (<1 m) where the cable was twisted. The researchers noted that this observation of AC fields, with broad areas of EMF distortion being associated with DC cables, increased the complexity of interpreting the studies of EMF's biological effects from DC cables. The AC electric fields associated with the AC sea2shore cable (1–2.5 mV/m) were higher than the unanticipated AC electric fields produced by the DC cables (0.4–0.7 mV/m). The magnetic field produced by the AC sea2shore cable (range of 0.05–0.3 μT) was ~10 times lower than modeled values commissioned by the grid operator, indicating that the three-conductor twisted design achieves significant self-cancellation. This entire aspect of the study indicates the need for accurate field assessment, not just computer modeling, and well-designed systems since anomalies occur.

Nyqvist et al. [498] in a thorough review, focused on marine mammals and the use of underwater electromagnetic surveys that map petroleum deposits in seabeds via strong induced EMFs in varied directional applications. They found that EMFs created during such active surveying were within the detectable ranges of marine animals and the fields can potentially affect behavior in electro-perceptive species, but they noted that effects should be limited to within a few kilometers as the electric and magnetic fields created attenuate rapidly. They added that in migrating marine animals, exposures are of short duration and most are close to naturally occurring levels but cautioned that lack of studies is a concern, especially for the most sensitive elasmobranchs at highest risk for disturbance to electric fields. They also noted that with induced magnetic fields, animals using magnetic cues for migration or local orientation during certain time-windows for migration, orientation, or breeding, could be most affected by this surveying technology.

Taorimina et al. [537] studied both static and time-varying magnetic fields on the behavior of juvenile European lobsters (*Homarus gammarus*). Using two different behavioral assays, day-light conditions to stimulate sheltering behavior and exposures to an artificial magnetic field gradient (maximum intensity of 200 μT), they found that juvenile lobsters did not exhibit any behavioral changes compared to non-exposed lobsters in the ambient magnetic field. No differences were noted on the lobsters' ability to find shelter or modified their exploratory behavior after one week of exposure to anthropogenic magnetic fields (225 ± 5 μT) which remained similar to behavior in controls. They concluded that neither static nor time-varying anthropogenic magnetic fields at those intensities significantly impacted the behavior of juvenile European lobsters in daylight conditions, but they noted that evidence exists showing magnetosensitivity changes during different life stages in lobster species, and that since their modeling was on juveniles, their study was therefore an incomplete picture requiring further study.

Scott et al. [538] focused on ELF-EMF effects on commercially important edible/brown crab species (*Cancer pagurus*) and what they found was startling. In laboratory tanks, they simulated EMF (with Helmholtz coils, 2.8 mT evenly distributed, assessments during 24 h periods) that would be emitted from sub-sea power cables now commonly used at offshore renewable energy facilities. They measured stress related parameters ((L-lactate, D-glucose, haemocyanin and respiration rate) along with behavioral and response parameters (antennal flicking, activity level, attraction/avoidance, shelter preference and time spent resting/roaming). They found that although there was no EMF effect on haemocyanin concentrations, respiration rate, activity level or antennal flicking rate, there were significant changes in haemolymph L-lactate and D-glucose natural circadian rhythms, indicating alterations in hormones. Crabs also showed an unusually high attraction to EMF-exposed shelter areas (69%) compared to control shelter areas (9%) and significantly reduced their time roaming by 21%, with adverse implications for food foraging, mating, and overall health. They noted that EMF clearly altered behavior. Crabs spent less time roaming around the tank and more time in a shelter in direct contact with the EMF source, indicating natural roaming/food-or-mate-seeking behavior had been overridden by attraction to EMF. In fact, crabs consistently chose an EMF-exposed shelter over a non-exposed one and were always drawn to the EMF. The results appear to predict that in benthic areas surrounding EMF-emitting cables, there will be an increase in the abundance of *Cancer pagurus* present. They noted that such potential crab aggregation around benthic cables and the subsequent physiological changes in L-lactate and D-glucose levels caused by EMF exposure, is a concern regarding feeding rates, mating, and especially egg incubation directly in increased EMF environments. They concluded that long term investigations are needed regarding chronic EMF exposure, especially on egg development, hatching success and larval fitness, and added that EMF emitted in marine environments from renewable energy devices must be considered as part of the study of cumulative impacts during the planning stages.

Clearly ELF-EMF can affect myriad aquatic species at intensity levels found in proximity to underwater cables at environmental intensities.

Fish: RF-EMF

As mentioned, RFR is of minimal environmental concern for fish since aquatic environments, while highly conductive mediums, also highly attenuate EMF at higher frequencies. This may change in the near future as new technologies now exist that may surpass these obstacles [98], thereby introducing for the first time novel new RFR exposures underwater. Longer wave wireless ELF with expanded ranges are used in anthropogenic sonar (sound navigation ranging), primarily for military applications. These travel easily through water and are known to adversely affect cetaceans and other species that rely on their natural sonar for communication, migration, reproduction and food finding. But sound waves are not considered “EMF” in the strict sense of the term; since the focus of this paper is EMF, sound waves are tangential here. But acoustic damage, especially to cetaceans from military and commercial applications, is well documented and ELF cables used for underwater military submarine communications can have significant EMF exposures near cables. Just because this paper does not address impacts from sound waves in detail does not mean they are without serious effects.

There are, however, three recent studies of RFR on zebrafish included here because it is plausible that such exposures could exist near shallow aquatic environments under some circumstances. Nirwane et al. [539] studied 900-MHz GSM RFR effects on zebrafish (*D. rerio*) neurobehavioral changes and brain oxidative stress as a model for human exposures to cell phones. Exposures were applied daily for 1 h, 14 days, with SAR 1.34 W/Kg. They found 900-MHz GSM radiation significantly decreased socialization and increased anxiety as demonstrated by significant increased time spent in bottom areas, freezing behaviors, and duration and decreased distance travelled, as well as decreased average velocity and number of entries to the upper half of the tank. Exposed zebrafish spent less time in the novel arm of a Y-Maze indicating significant impaired learning compared to the control group. Exposure also decreased superoxide dismutase (SOD) and catalase (CAT) activities while increased levels of reduced glutathione (GSH) and lipid peroxidation (LPO) were encountered indicating compromised antioxidant defense. Post-exposure treatment with melatonin in the water, however, significantly reversed the induced neurobehavioral and oxidative changes.

Piccinettia et al. [540] investigated *in vivo* effects on embryonic development in zebrafish at 100 MHz thermal and nonthermal intensities via a multidisciplinary protocol. Results found 100 MHz RFR affected embryonic development from 24 to 72 h post fertilization in all the analyzed pathways. Most notably at 48 h post fertilization, reduced growth, increased transcription of oxidative stress genes, onset of apoptotic/autophagic processes and a modification in cholesterol metabolism were seen. EMF affected stress by triggering detoxification mechanisms. At 72 h post fertilization, fish partially recovered and reached hatching time comparable to controls. The researchers concluded that EMF-RFR unequivocally showed *in vivo* effects at non-thermal levels.

Dasgupta et al. [541] used embryonic zebrafish models at 3.5 GHz SAR ≈ 8.27 W/kg and exposed developing zebrafish from 6 to 48 h post fertilization, then measured morphological and behavioral endpoints at 120 h post fertilization. Results found no significant impacts on mortality, morphology or photomotor response but noted a modest inhibition of startle response suggesting some levels of sensorimotor disruptions. They concluded that exposures at low GHz levels are likely benign but nevertheless entailed subtle sensorimotor effects. Such effects can affect fish survival in various ways, including inhibited response time to predators, among others. This study was done with an eye toward potential human bioeffects at frequencies used in 4 and 5G technology. It was also conducted at intensities higher than the focus of this paper.

If new technology overcomes the conductivity/attenuation limitations of aquatic environments and introduces more RFR to aquatic species, studies like those cited above may soon have more environmental relevance, even at higher intensities than explored here.

Turtles

Oceanic sea turtle migration joins that of other renowned long-distance migratory species like salmon and over-land monarch butterfly treks, spanning thousands of kilometers and traversing multiple complex environments throughout their life cycles. Sea turtles have long been known to use geomagnetic fields for orientation [542, 543]. Freshwater species (e.g., *Chelydra serpentina*) have also been shown to have a magnetic sense capable of artificial disruption [92] as do terrestrial box turtles (*Terrapene carolina;* [544]).

Sea turtles demonstrate natal homing behavior — the ability to return over great distances to their exact birth location to reproduce [89] and because of anthropogenic disruptions of nesting grounds along beaches, this reproductive homing drive imperils them today. The underlying mechanism is still imperfectly understood but involves 'imprinting' of the intensity and inclination angle of the geomagnetic field at the birth location [545]. The information is then later used in maturity to return to their place of origin.

Sea turtles are by far the most studied models for turtle magnetoreception, especially by the Lohmann Laboratory at the University of North Carolina, U.S. [323, 546–558].

Irwin and Lohmann [559] discussed the advantages and disadvantages of various research approaches used to investigate magnetic orientation behavior in turtles. These include the use of large magnetic coil systems in laboratory settings to generate relatively uniform fields over large areas [560] which allow the magnetic field to be artificially altered and carefully controlled to determine changes in behavioral orientation. This approach, however, is unsuited for manipulating exposures around animals in natural environments or for studying localized body magnetoreceptors, which in turtles are still a mystery. Another approach is to attach a small magnet or electromagnetic coil to an animal to disrupt magnetic orientation behavior — a far easier approach in hatchlings than in juvenile or mature free-swimming species. They note that if the imposed field from an attached magnet or coil is strong enough to interfere with the Earth's field, behavioral orientation changes [116, 544, 561] and the performance of a conditioned response [367, 562] can be observed. This latter approach has been used in field studies for the purpose of blocking access to normal magnetic information [544, 561, 563–565] and to localize magnetoreceptors by disrupting the field around a specific terrapin body part [562]. This technique's disadvantage, however, is that fields rapidly change with distance from the source, making it difficult to quantify the fields that the animal actually experiences.

Most sea turtle studies have involved large magnetic coil systems but Irwin and Lohmann [559] attached small magnets greater in strength than the Earth's fields to two groups of loggerhead sea turtle hatchlings (*Caretta caretta* L.) under laboratory conditions in which turtles are known to orient magnetically [473, 546, 548–550]. They found that magnetic orientation behavior in hatchling turtles can be disrupted via small magnets attached to the carapace which then create exposures over the entire body. They concluded that such an approach can be used to finally determine local magnetoreceptors by varying the location of the magnet and using smaller, weaker magnets that alter the field only around specific anatomical target sites.

In loggerhead sea turtles, there is evidence of an inclination compass [473, 550] that is functionlly similar to the bird magnetic compass reported in European Robins [566, 567]. Lohmann and Lohmann [550] investigated an inclination compass in sea turtles and found it was a possible mechanism for determining latitude. Also investigated were detection of magnetic intensity [551]; natural regional magnetic fields used as navigational markers for sea turtles [557]; and sea turtle hatchlings' mapping abilities [545]. Sea turtles are also known to have magnetite in their heads [104, 568]. Studies with young sea turtles have shown that a significant portion of their navigational abilities involve magnetoreception following hatching [569] — imprinting with the Earth's magnetic field being one of several cues hatchlings use as they first migrate offshore [546, 554]. The magnetic fields that are unique to different areas at sea eventually serve as navigational markers to guide swimming direction to important migratory routes. As juveniles mature, they form topographical magnetic maps where they live that direct them to specific regions. But it has remained largely unknown if mature turtles, specifically nesting females, use such mechanisms in open-sea homing as this magneto-sense may change over time.

Field studies are notoriously difficult with large species at sea but Papi et al. [564] studied mature green turtles (*Chelonia mydas*) during their post-nesting migration over 1,243 mi (2,000 km) from their nesting grounds on Ascension Island in the middle of the Atlantic Ocean back to their Brazilian feeding grounds. They were investigating whether mature female turtles use an inclination compass and geomagnetic fields for direction, or by inference (once that sense is disturbed) by some other means as yet determined. Papi et al. [564] attached very strong DC magnets — significantly stronger than the Earth's fields — to disturb and overcome natural magnetoreception, and thereby determine if they could still navigate back to Ascension Island. Controls had nonmagnetic brass bars attached and some had transmitters glued to their heads. All had tracking devices that communicated with satellites, thus creating strong multi-frequency static and pulsed RFR exposures. Seven turtles were each fitted with six powerful static magnets that produced variable artificial fields surrounding the whole turtle, making reliance on a geomagnetic map impossible. The study's travel courses were very similar to those of eight turtles without magnets that had been tracked via satellite over the same period in the previous year. No differences between the magnetically exposed test turtles and untreated turtles were found regarding navigational performance and general course direction. They concluded that magnetic cues were not essential to turtles on the return trip and speculated that perhaps other factors such as smell or wave current direction may come into play.

Luschi et al. [563], like Papi et al. [564], also investigated the role of magnetoreception and homing in mature sea turtles but used a different design and found very different results. In a large field study in the Mozambique Channel, 20 mature pre-nesting green turtles were also equipped with both strong magnets and satellite tracking devices. The turtles were gathered at their nesting beach on Mayotte Island before egg-laying and transported to four open-sea sites 62–75 mi (100–120 km, respectively) away. There were five releases of four turtles each with three different treatments: turtles magnetically 'disturbed' only during transportation with magnets removed before release; those treated only during the homing trip with magnets attached just prior to release; and controls with nonmagnetic brass discs attached to their heads. Treated turtles had very strong moveable magnets attached to their heads to induce varying magnetic fields around them either at the nesting beach at the start of the relocation journey or on the boat just prior to release for the homing trip. All groups had satellite transmitters attached to their carapaces, thereby creating in the opinion of the authors of this paper, an additional exposure that was not considered as a variable. The researchers also included ocean currents in their assessments, estimated by using oceanographic remote sensing measurements. All but one turtle eventually returned to Mayotte to complete delayed egg-laying. But treated turtles, whether treated during transportation or homing, took significantly longer to reach the destination vs. controls — a surprising finding. Most homing routes showed very long circuitous curved and looping patterns before reaching their target. Control paths were direct. Both treated turtle groups were clearly impaired by the MF exposure, indicating significant recovery time needed between exposure and correcting positional behavior. The researchers hypothesized the existence of a navigational role for geomagnetic information being gathered by those turtles in the passive transportation group, as well as the possibility that magnetic disturbance during transportation may have persisted for some time after the removal of the magnets in that group, thus rendering the two treated groups functionally equivalent during their homing journeys. They also noted that exposures may have physically altered magnetite particles, thus creating a longer lasting effect but they said that since long-lasting after-effects of magnet application have not been described, this theory could neither be inferred nor dismissed.

Lohmann [323] reviewed both of the above studies and added that in addition to the two causal hypotheses of Luschi et al. [563] regarding their unexpected findings of turtle circuitous migration routes, another explanation would include the positioning of the satellite transmitters in the Papi et al. [564] study on turtle heads vs. on the carapace of the Luschi models. He added that since satellite transmitters also produce magnetic fields capable of disrupting magnetoreception, and since the Papi group also attached satellite transmitters on the heads of several control turtles, that re-analyzing the Papi study using only turtles with satellite transmitters placed on the carapace like the Luschi study could show evidence consistent with the hypothesis that adult turtles exploit magnetic cues in navigation. He concluded that sea turtles, like all other animals studied to date, likely exploit multiple cues for navigation since even with artificial magnetic disturbance causing impaired performance, the magnets in either study did not prevent turtles from eventually reaching their target beaches. This implies that turtles can also rely on other sources of information [570, 571] such as celestial compasses, wave direction [572], or olfactory cues like other species — a significant finding.

The sum total of the studies mentioned above is that sea turtle species are highly sensitive to Earth's fields and are capable of adapting to subtle anthropogenic disruption.

Turtles: RF-EMF

Turtles may also be senstitive to RFR, especially during incubation while on land, and/or initial hatchling stages if they are exposed to anthopogenic RF-EMF that could distort the imprinting memory they use in later life to locate their birthsite beaches again. For example, if a radar or communications base station is installed on or near the beach of a nesting site, could that affect the initial "imprinting" process? Perhaps augment imprinting and make return easier? Or conversely overwhelm the subtle imprinting process at the start and make return impossible? If the latter is valid, such technology could lead to extinction of sensitive species since it interrupts the reproduction process. In the very least, in sensitive species, disorientation might result as discussed above.

To characterize the underlying compass mechanisms in turtles, Landler et al. [92] studied freshwater juvenile snapping turtles' (*Chelydra serpentine*) ability for spontaneous magnetic alignment to the Earth's geomagnetic fields. Using exposure to low-level RFR near the Larmor frequency (1.2 MHz) that is related to free radical pair formation, turtles were first introduced to the testing environment without the presence of RFR ("RF off, RF off") and they were found to consistently align toward magnetic north. But when subsequent magnetic testing conditions were initially free of RFR, then included an introduced signal ("RF off, RF on"), they became disoriented. Thus, introduction of a RFR field could affect the turtles' alignment response to the natural magnetic field. The RFR field used was only 30–52 nT (1.43 MHz). In the following reverse scenario, when the turtles were initially introduced to the testing environment with RFR present but then removed ("RF on, RF off"), they became disoriented when tested *without* RFR. And with RFR on in both cases ("RF on, RF on"), they aligned in the opposite direction toward magnetic south. Clearly test turtles were affected by the exposures. The researchers concluded that the sensitivity of the spontaneous magnetic alignment response of the turtles to RFR was consistent with a radical pair mechanism (see "Mechanisms" above). In addition, they concluded that the effect of RFR appeared to result from a change in the pattern of magnetic input, rather than elimination of magnetic input altogether. Their findings indicated that turtles, when first exposed to a novel environment, form a lasting association between the pattern of magnetic input and their surroundings, and that they may form a larger internal GPS-like mapping ability when they meet any new magnetic reference framework based on natural magnetic cues, from multiple sites and localities.

They also showed that RFR at or near the Larmor frequency (1.2–1.43 MHz) had the ability to disrupt snapping turtle natural orientation, establish its own novel orientation, and completely reverse a natural orientation, leading back to the complex questions asked above regarding imprinting and possible reproductive disruption. Although the Landler et al. study [92] was conducted in a freshwater, non-homing species, snapping turtles are long-lived with a low reproduction success rate. Even small disruptions to this species from anthropogenic sources could have an outsized population effect over time. If this freshwater species is any indication of potential RFR effects, researchers need to further investigate RFR in long-distance migrating turtle species that imprint on land. We simply do not know the full range of possible effects across frequencies with which turtle species come in contact at vulnerable points throughout development and lifetimes.

Nematodes and smaller biota

There are reports of sensitivity to EMF in lesser taxa as well. EMF is known to affect numerous other species including: nematodes (Earth and aquatic worms), mollusks (snails), amoeba (single-celled organisms), molds, algae, protozoans, yeast, fungi, bacteria, and viruses (to a limited extent) — with ramifications for creation of antibiotic resistant bacteria strains. Below are some representative examples of observed effects.

Nematodes

Common soil-based nematode species like *C. elegans* serve as a useful whole-organism model for genetic and multicellular organism investigations. They are routinely used as a research model to investigate key biological processes including aging, neural system functioning, and muscle degeneration, to name a few. This species' genetic and phenotypic traits are extremely well documented and they can thus be used as important proxies for quantitative analyses [573]. Nematodes have a short lifespan, are hermaphrodites, and demonstrate effects quickly. As lab models they are used primarily for information that can be applied to humans but we can also glean important information and extrapolate to environmental exposures under certain circumstances. Healthy soil worm populations are critical to soil health upon which we all depend.

Hung et al. [574] investigated static magnetic field (SMF) effects on life span and premature aging in *C. elegans*. Nematodes were grown in SMFs varying from 0 to 200 mT. They found that SMF's accelerated development and reduced lifespan in wild-type nematodes. They also found increases in heat shock proteins that were selective and dose dependent.

Vidal-Gadea et al. [66] investigated magnetic orientation in *C. elegans* to identify magnetosensory neurons and found that they orient to the Earth's geomagnetic field during vertical burrowing migrations. Well-fed worms migrated up, while starved worms migrated down. Populations isolated from around the world were found to migrate at angles to the magnetic vector that would vertically translate to their native soil, with northern- and southern-hemisphere worms displaying opposite migratory preferences in conjunction with natural geomagnetic fields. They also found that magnetic orientation and vertical migrations required the TAX-4 cyclic nucleotide-gated ion channel in the AFD sensory neuron pair while calcium imaging showed that these neurons respond to magnetic fields even without synaptic input. They hypothesized that *C. elegans* may have adapted magnetic orientation to simplify their vertical burrowing migration by reducing the orientation task from three dimensions to one.

C. elegans have also demonstrated sensitivity to electric fields via electrotaxis (also known as galvanotaxis) which is the directed motion of living cells or organisms guided by an electric field or current and often seen in wound healing. Sukul and Croll [575] found that nematodes exposed to an electrical current (0.02–0.04 mA, potential differences 2–6 V) demonstrated a directional sensorily-mediated orientation toward the current at first, but at 2 mm from the electrode, individual worms increased reversing behaviors which then remained uniform as they moved in a constant direction parallel to the exposure. A few which did not reverse direction died (presumably from electrocution) at 6 V or 0.4 mA. They concluded that adult *C. elegans* move directionally at selected combinations of voltage and potential differences and that electrophoresis could be eliminated.

Gabel et al. [576] also investigated electric field effects on directionality on *C. elegans* with an eye toward better understanding how the nervous system transforms sensory inputs into motor outputs. They used time-varying electric fields modulated at 100 Hz across an agar surface with a defined direction and amplitude up to 25 V/cm. They found that the nematodes deliberately crawl toward the negative pole in an electric field at specific angles to the direction of the electric field in persistent forward movements with the preferred angle proportional to field strength. They also found that the nematodes orient in response to time-varying electric fields by using sudden turns and reversals (normal reorientation maneuvers). They also found that certain mutations or laser ablation that disrupt the structure and function of amphid sensory neurons also disrupted their electrosensory behavior and that specific neurons are sensitive to the direction and strength of electric fields via intracellular calcium dynamics among the amphid sensory neurons. This study showed that electrosensory behavior is crucial to how the *C. elegans* nervous system navigates and can be disrupted at some intensities found in the environment.

Maniere et al. [573] also found *C.elegans* was sensitive to electric fields and that when submitted to a moderate electric field, worms move steadily along straight trajectories. They hypothesized that imposing electric fields in research settings was an inexpensive method to measure worms' crawling velocities and a method to get them to self-sort quickly by taking advantage of their electrotactic skills.

An early RFR study of *C elegans* by Daniells et al. [577] found this species to be a useful model for investigating stress-responses. In the majority of investigations, they used 750 MHz with a nominal power of 27 dBm; controls were shielded and all temperatures were strictly controlled. Stress responses were measured in terms of beta-galactosidase (reporter) induction above control levels. Response to continuous microwave radiation showed significant differences from 25 degrees C in controls at 2 and 16 h, but not at 4 or 8 h. Using a 5×5 multiwell plate array exposed for 2 h, the 25 microwaved samples showed highly significant responses compared with a similar control array. Experiments in which the frequency and/or power settings were varied suggested a greater response at 21 than at 27 dBm, both at 750 and 300 MHz indicating a nonlinear effect, although extremely variable responses were observed at 24 dBm and 750 MHz. Lower power levels tended to induce greater responses — the opposite of simple heating effects. They concluded that microwave radiation causes measurable stress to transgenic nematodes via increased levels of protein damage within cells at nonthermal levels.

Tkalec et al. [578] found oxidative and genotoxic effects in earthworms (*Eisenia fetida*) exposed *in vivo* to RFR at 900 MHz, at 10, 23, 41 and 120 V m(-1) for 2 h using a Gigahertz Transversal Electromagnetic (GTEM) cell. All exposures induced significant effects with modulation increasing such effects. Their results also indicated antioxidant stress response induction with enhanced catalase and glutathione reductase activity, indicating lipid and protein oxidative damage. Antioxidant responses and damage to lipids, proteins and DNA differed depending on EMF level, modulation, and exposure duration.

Aquatic and semi-aquatic worm species also show sensitivity to EMF. Jakubowska et al. [579] investigated behavioral and bioenergetic effects of EMF at 50 Hz, 1 mT fields (comparable to exposures near underwater cables) in polychaete ragworms (*Hediste diversicolor)* that live and burrow in the sand/mud of beaches and estuaries in intertidal areas of the North Atlantic. While they found no attraction or avoidance behavior to EMF, burrowing activity was enhanced with EMF exposure, indicating a stimulatory effect. Food consumption and respiration rates were unaffected but ammonia excretion rate was significantly reduced in EMF-exposed animals compared to control conditions at only geomagnetic fields. The mechanisms remained unclear. The authors said this was the first study to demonstrate effects of environmentally realistic EMF values on the behavior and physiology of marine invertebrates.

Van Huizen et al. [67] investigated effects of weak magnetic fields (WMF) on stem-cells and regeneration in an *in vivo* model using free-swimming flatworms (*Planaria* ssp*)* that are capable of regenerating all tissues including the central nervous system and brain. This regeneration ability is due to the fact that about 25% of all their cells are adult stem cells (ASC). Injury is followed by a systemic proliferative ASC response that initially peaks at ~ 4 h, followed by ASC migration to the wound site over the first 72 h when a second mitotic peak occurs. Like salamander regeneration (see “Amphibians” above) this activity produces a blastema — a group of ASC cell growth that forms the core of new tissues. Full regeneration of damaged planaria tissues or organs occurs through new tissue growth and apototic remodeling/scaling of old tissues within 2–3 weeks. Following amputation above and below the pharynx (feeding tube), they exposed amputation sites to 200 μT WMF. At three days post-amputation, they found that 200 μT exposure produced significantly reduced blastema sizes compared to both untreated and earth-normal 45 μT field strength controls, indicating a WMF interference effect to regeneration. They also found that the 200 μT exposure was required early and had to be maintained throughout blastema formation to affect growth, and that shorter, single-day exposures failed to affect blastema size. In addition, they found weak magnetic fields produced field strength–dependent effects. These included significant reductions of blastema size observed from 100–400 μT, but conversely, a significant increase in outgrowth occurred at 500 μT. They hypothesized that WMF effects were caused by altered reactive oxygen species (ROS) levels, which peak at the wound site around 1-h post-amputation and are required for planarian blastema formation. This study shows that weak anthropogenic magnetic fields can affect stem cell proliferation and subsequent differentiation in a regenerative species, and that field strength can increase or decrease new tissue formation *in vivo*. This is a significant finding for regenerating species of all kinds, and may affect non-regenerating species as well. Sea lamprey eels (*Petromyzon marinus*), a fish species, are also known to regenerate even after multiple amputations [580].

Mollusks, amoeba, molds, algae, protozoans

Mollusks (marine versions are called chitons) are long known to manufacture magnetite in their teeth and to use fields weaker than the geomagnetic field for kinetic movement and direction [52, 117, 340, 524]. Lowenstam [118] first discovered that magnetite was the major mineral in the teeth of marine chitons, thought to give teeth their natural hardness. But Ratner [62] discovered chitons use magnetite as a magnetic compass when he found a number of chiton species have radulae (tongues) that are covered by ferro-magnetic (magnetite) denticles. The radulae of *Acompapleura granulata* and *Chiton squamosis* were also found to be ferromagnetic but the shells were not. Live specimens of a chiton (*Chaetopleura apiculata*) that also have ferro-magnetic radulae were found to rotate more and move farther in a magnetic field weaker than in the Earth’s stronger geomagnetic field, indicating a nonlinear directionality. Ratner concluded that chitons are responsive to magnetic fields and demonstrate kinetic movements within them.

Some snails are sensitive to EMFs. Nittby et al. [581] observed analygesic effects in land snails (*Helix pomatia*) caused by GSM-1900 RFRs when snails lost sensitivity to pain on a hot plate test after nonthernal exposure to RFR.

Smaller organisms have also long shown effects from EMF. Goodman et al. [582] found delays in mitotic cell division in slime mold (*Physarum polycephalum*) with ELF-EMF exposures. Friend et al. [583] found perpendicular and parallel elongation of the giant amoeba Chaos chaos (*Chaos carolinensis*) in alternating electric fields over a wide frequency range (1 Hz–10 MHz) with characteristic changes as a function of frequency. Marron et al. [584] found effects on ATP and oxygen levels in another species of slime mold (*P. polycephalum*) after exposures to 60 Hz sinusoidal electric and magnetic fields. Luchien et al. [585] found a stimulating effect on the productivity of the algal biomass (*Chlorella sorokiniana*) for a magnetic field of 50 Hz but an inhibitory effect at 15 Hz in these microalgae.

Protozoans, thought to be more related to animals than microbes, also show sensitivity to EMF. Protozoans, as single-celled eukaryotes, are generally larger than bacteria which are classified as prokaryotes. The two organisms are structurally different: bacterial cells lack a nucleus while protozoa contain organelles such as mitochondria. Bacteria generally absorb nutrients through their cell walls while protozoa feed on bacteria, tissue, and organic matter and can be both infectious and parasitic. These protozoa include human parasites that cause diseases such as amoebic dysentery, malaria, giardiasis, leishmaniasis, trichomoniaisis, toxoplasmosis and others. Animal species are also affected by protozoans which can severely weaken and shorten their lifespans.

Rodriguez-de la Fuente et al. [586] tested ELF-EMF (60 Hz, 2.0 mT for 72 h) on two infectious protozoans, *Trichomonas vaginalis* and *Giardia lamblia*, and found growth alterations in both species which they attributed to alterations in cell cycle progression and cellular stress. Cammaerts et al. [587], used RFR (GSM 900-MHz at 2 W vs. control) on protozoans (*Paramecium caudatum*) and found individuals moved more slowly and sinuously than usual and that their physiology was affected. Paramecia became broader, pulse vesicles had difficulty expelling content to the outside of their cells, cilia moved less efficiently, and trichocysts became more visible — all effects that indicate poor functioning or cell membrane damage. They hypothesized that the first impact of RFR could be to cell membranes.

Clearly there are multiple effects at all levels documented in lower taxa from multi-frequency exposures that are now found in the environment.

Yeast and fungi

Yeast is often used in lab models, especially since 1996 when a complete genomic sequence of *Saccharomyces cerevisiae* was created. In fact it is now considered a "premier model" [588] for eukaryotic cell biology as well as having helped establish whole new fields of inquiry such as "functional genomics" and "systems biology" which focus on the interactions of individual genes and proteins to reveal specific properties of living cells and whole organisms.

EMF research is rich with studies using yeast models too numerous to fully analyze here. However we include a small sample of recent EMF research with potential significance to environmental exposures.

Lin et al. [589] investigated glucose uptake and transcriptional gene response to ELF-EMF (50 Hz) and RFR (2.0 GHz) on several strains of budding yeast (*S. cerevisiae*). Results determined that ELF-EMF and RFR exposure can upregulate the expression of genes involved in glucose transportation and the tricarboxylic acid (TCA) cycle, but not glycolysis pathways, thus showing that such exposures can affect energy metabolism which is closely related with cellular response to environmental stress. Glucose metabolism is fundamental to all living cells' need for energy, with related significance to many disease states including most cancers.

In a magnetic field study by Mercado-Saenz et al. [590], premature aging and cellular instability were found in yeast (*S. cerevisiae*) exposed to low frequency, low intensity sinusoidal magnetic fields (SMF continuous exposure at 2.45 mT, 50 Hz) and pulsed magnetic fields (PMF 1.5 mT, 25 Hz, 8 h/day). Chronological aging was evaluated during 40 days and cellular stability was evaluated by a spontaneous mutation count and the index of respiratory competence (IRC). They found exposure to PMF produced accelerated aging while SMF did not, and decreased mitochondrial mutation during aging was also seen with PMF. No alterations in respiratory competence were observed for either SMF or PMF exposures. They concluded that exposure to PMF accelerated chronological aging and altered the spontaneous frequency of mitochondrial mutation during the aging process, whereas the SMF used had no effect, thus showing abnormal effects on cell activity from pulsed exposures.

Because yeast cells are known to be sensitive to magnetic fields, some industrial and therapeutic applications to human health have been investigated. These investigations serve to illuminate what we know about yeast and fungal reactions to EMF in general, as well as specific uses. For industrial applications, Wang et al. [591] investigated low level static magnetic fields (SMF) on mold (*Aspergillus versicolor*) growth which can have high impacts on metal corrosion in environmental conditions conducive to mold growth. This is especially problematic in fine electronic circuit boards produced today. Using a

10 mT static magnetic field (SMF) perpendicular to the surface of printed circuit boards, they found the magnetic field inhibited mold growth and surface corrosion which were slowed down, unlike control boards without applied magnetic fields where mold formed a spore-centered corrosion pit that then led to macroscopic regional uniform corrosion. This demonstrated changes in cell/spore growth at a low intensity exposure that can be found in the environment.

Also with an eye toward commercial possibilities, Sun et al. [592] found that a polysaccharide of *Irpex lacteus* (a white-rot fungus found widely in the environment which breaks down organic materials but also is commercially used to treat nephritis in humans) was sensitive to low-intensity ELF-EMF as demonstrated by increased biomass and polysaccharide content, as well as induced malformed twists on the sample cell surfaces. Polysaccharides are carbohydrates with a large number of sugar molecules used as energy sources in living cells. They identified varying changes in multiple differentially expressed genes after exposure to alternating current EMF (50 Hz, 3.5 mT, 3 h per day, for 4 days). They found initial sharp increases in growth rates in exposed samples that were then marked by significant declines in EMF's influence over time, although there were also important lasting effects. Global gene expression alterations from EMF indicated pleiotropic effects (capable of affecting multiple proteins or catalyzing multiple reactions) were related to transcription, cell proliferation, cell wall and membrane components, amino acid biosynthesis and metabolism. Polysaccharide biosynthesis and metabolism were also significantly enriched in the EMF-exposed samples. They concluded that EMF significantly increased amino acid contents and was therefore deemed a suitable method for increasing fermentation of microorganisms, presumably for commercial use. However, the significance of this study to environmental exposures relates to the multiple ways that ELF alternating current common to electric power generation changed yeast gene expression. There is at least one clinical case of a different strain of *I. lacteus* taking on a rare infectious and dangerous quality in an immunocompromised human [593]. The question is: can now-ubiquitous ELF-EMF contribute to potentially emerging new forms of yeast contagion?

The same question arises with *Candida albicans* and other pathogenic yeasts that have rapidly developed resistance to antifungal medications. *C. albicans* can live harmlessly in human microflora, but certain lifestyle circumstances or immunosuppression can turn it into an opportunistic pathogen. It can also infect some non-human animals. While chronic mucocutaneous candidiasis can infect the skin, nails, and oral and genital mucosae, under high host immunodeficiency *C. albicans* can enter the bloodstream and induce systemic infections with mortality between 30 and 80% [594]. There has been increasing resistance of *C. albicans* to traditional antifungal agents, such as fluconazole and amphotericin B [595, 596]. Resistance mechanisms include overproduction of membrane drug efflux transporters and/or changes in gene expression [597].

Two investigations in search of new therapeutic strategies were conducted using EMF. Sztafrowski et al. [594] investigated the use of static magnetic fields (SMF, 0.5 T) on *C. albicans* cultures in the presence of two commonly used antifungal medications. Their aim was to assess whether SMF had any impact on general viability of *C. albicans* hyphal transition and its susceptibility to fluconazole and amphotericin B. They found reduction of *C. albicans* hyphal length in EMF-exposed samples. They also found a statistically significant effect on *C albicans* viability when SMF was combined with amphotericin B. They hypothesized that this synergistic effect may be due to the plasma membrane binding effects of amphotericin B and that SMF could influence domain orientation in the plasma membrane. They concluded, with caution, that the use of a SMF in antifungal therapy could be a new supporting option for treating candidas infections.

Novickij et al. [598] also focused on therapeutic possibilities given the multi-drug resistance and side effects to antifungal therapies. Their aim was to optimize the electroporation-mediated induction of apoptosis using pulses of varied duration (separately and in combination with formic acid treatment) and to identify yeast apoptotic phenotypes. They focused on nonthermal nanosecond pulsed electric fields (PEF 3 kV, 100 ns – 1 ms squarewave; and 250, 500, 750 ns duration 30 kV/cm PEF, 50 pulses, 1 kHz) as a therapeutic alternative and/or to enhance effects in combination with conventional treatments. In three yeast models, *S. cerevisiae* (as control) and drug resistant *Candida lusitaniae* and *Candida guilliermondii*, they found that nanosecond PEF induced apoptosis in all three strains. Combining PEF with a weak formic acid solution improved induced apotosis and inactivation efficacy in the majority of the yeast population. Yeast cells showed DNA breaks and other changes. They concluded that PEF could be a useful new non-toxic protocol to treat some fungal diseases and minimize tissue damage.

Choe et al. [599] studied ion transportation and stress response on a yeast strain (K667) to ELF-EMF (60 Hz, 0.1 mT, sinusoidal or square waves), specifically investigating internal ionic homeostasis via the cell membrane involving metal ions and cation transports (cations are ionic species of both atoms and molecules with a positive charge). They found significantly enhanced intracellular cation concentrations as ELF-EMF exposure time increased, as well as other changes. This study has implications for soil health as yeast can be an integral aspect of how healthy organic soil matter is formed. They concluded that EMF and yeast could also play a role in the bioremediation processes in metal-polluted environments.

Lian et al. [600] studied effects of ELF-EMF (50 Hz, 0–7.0 mT) and RFR (2.0 GHz, 20 V/m, temperature at 30 °C, average SAR single cell/0.12 W/kg) on two budding yeast strains (NT64C and SB34) and prion generation/propagation. They found under both EMF exposures that *de novo* generation and propagation of yeast prions (URE3) were elevated in both yeast strains. The prion elevation increased over time and effects were dose-dependent. The transcription and expression levels of heat shock proteins and chaperones were not statistically significantly elevated after exposure but levels of reactive oxygen species (ROS), as well as superoxide dismutase (SOD) and catalase (CAT) activities were significantly elevated after short-term, but not long-term exposure. This work demonstrated for the first time that EMF exposure could elevate the *de novo* generation and propagation of yeast prions, supporting the researcher's hypothesis that ROS may play a role in the effects of EMF on protein misfolding. ROS levels also mediate other broad effects of EMF on cell function. They concluded that effects of EMF exposure on ROS levels and protein folding may initiate a cascade of effects negatively impacting many biological processes.

The effects of EMF on protein folding cannot be overstated. Proteins must fold into proper three-dimensional conformations to carry out their specific functions — intact proteins are critical to the existence of all life. Misfolding not only impairs function but leads to disease. Folding inside of cells does not happen spontaneously but rather depends on molecular helpers called chaperones. Protein misfolding has been implicated in Alzheimer's, Parkinson's, and Huntington's diseases, among others. The devastating Creutzfeldt–Jakob disease is caused by prion misfolding in the brain, which causes abnormal signaling in neurons that eventually leads to paralysis and death. Wildlife can also suffer from prion diseases such as chronic wasting in deer, elk, and other cervids, and cattle can suffer from so-called "mad-cow" disease. The two studies from above [599, 600] have implications for how such diseases are spread through soil with possible links to environmental EMFs.

It is clear from the above that ELF-EMF and RF-EMF, using multiple signaling characteristics, are biologically active in both temporary and permanent ways in yeast/fungi species with wide environmental implications across numerous taxa.

Bacteria

Strains of bacteria are known to be magnetotactic and use geomagnetic fields for direction. Blakemore [63] was the first to suggest in 1973 that bacteria in North American saltwater marsh muds use magnetite as a sensor when he discovered not only that bacteria were highly attracted to an external magnet but they also had magnetite crystals that caused them to align with the lines of the Earth's magnetic fields. This was also discovered to be geolocation specific to the North Pole in northern samples and South Pole-seeking in southern species [52, 63, 511]. The bacteria showed "mud-up" and "mud-down" behavior along magnetic field gradients when mud was disturbed, indicating a magnetic compass. Since that early work, a whole new field called electromicrobiology has developed with discoveries that include some electro-active bacteria being responsible for magnetite formation, with others creating their own electric "wires" in mud flats with implications for new technologies [601].

Among the more troubling EMF effects are bacterial alterations with pressing implications for antibiotic resistance. Since the 1940s [602], nonthermal effects were documented in bacterial, viral, and tissue cultures with applied low-repetition 20-MHz pulses. Most studies spanning the 1940s though the 1980s focused on EMF's ability to kill microbes and fungi in human food sources at high intensity, consequently most research was focused on thermal intensities. That work still continues today as microwaves have been shown to be an efficient means for killing microbes [50]. But microbes also react to much lower nonlethal intensities and recent work finds effects from both ELF and RFR.

The common bacteria *Escherichia coli*, which can live harmlessly in the gut of humans and many other animal species, can also turn virulent and kill through food-borne illnesses. *E. coli* comes in many strains, is well studied, and now considered the most genetically and physiologically characterized bacterium. *E. coli* encounter varied and numerous environmental stressors during growth, survival, and infection, including heat, cold, changes in Ph levels, availability of food/water supplies, and EMF. Along with other bacteria, they respond by activating groups of genes and heat shock proteins (see "Mechanisms" above) which can eventually lead to stress tolerance for survival purposes. But induced stress tolerance can also lead to increased virulence, as well as enhanced tolerance to other stressors that confer cross-protection [603].

Salmen and colleagues [604, 605] published papers of EMF effects on bacterial strains documenting the growing investigation of microbes related to antibiotic resistance with many findings stressing responses to EMF [606–610]. Cellini et al. [611] investigated *E. coli*'s adaptability to environmental stress induced by ELF exposures to 50-Hz magnetic fields at low intensities (0.1, 0.5, 1.0 mT) vs. sham controls. They found exposed samples and controls displayed similar total and culturable counts, but increased cell viability was observed in exposed samples reincubated for 24 h outside of the test solenoid compared to controls. Exposure to 50 Hz EMF (20–120 min) also produced a significant change in *E. coli* morphotype with a presence of coccoid cells aggregated in clusters after reincubation of 24 h outside of the magnetic field-solenoid. Atypically lengthened bacterial forms were also noted, indicating probable alteration during cell division. Some differences in RNA-AFLP analysis were also seen for all intensities evaluated. They concluded that exposure to 50-Hz ELF-EMF is a bacterial stressor as evidenced by its immediate response in modifying morphology (from bacillary to coccoid) and inducing phenotypical and transcriptional changes. Despite this stressor effect, it was also seen that exposed samples significantly increased viability, suggesting the presence of VBNC cells. They concluded that further studies were needed to better understand ELF-EMF in bacterial cell organization. They did not extrapolate to the obvious — that *E. coli* was changed in an abnormal way but nevertheless strengthened in viability — a recipe for antibiotic resistance.

Crabtree et al. [612], in a small human study, investigated the biomic relationship of human bacteria exposed to both static magnetic fields (SMF) and RFR. Using laboratory culture strains and isolates of skin bacteria collected from the hand, cheek, and chin areas of four volunteers who had different (self-reported) cell phone use histories, they found varied growth patterns of *E. coli*, *Pseudomonas aeruginosa*, and *Staphylococcus epidermidis* under static magnetic fields on different bacterial species. Isolates of skin microbiota showed inconsistent growth among the test subjects, likely due to their differing cell phone usage histories (classified as heavy, medium and light) and other variables. The growth of *Staphylococci* was increased under RFR in certain individuals while in others growth was suppressed. This was complicated by the different body areas tested, some with higher chronic exposures such as the hands, as well as other variables when one test subject used an antibacterial face wash. Volunteers in the heavy use category showed less bacterial growth on the hands, possibly due to microbe habituation. Overall, and despite the small sample, they concluded RFR can disrupt the balance in skin microbiota, making it more vulnerable to infection by specific opportunistic and/or other foreign pathogens. They noted that both SMF and RF-EMFs have significant but variable effects on the growth of common human bacteria; that bacterial growth was either unaffected, increased, or suppressed depending on the species of bacteria; and that bacterial responses seemed to be determined by historic exposure to RF-EMF and life style. This study, even with inherent limitations, indicates changes in microbes with EMFs and may prove a novel way to study bacteria with significance for real-life exposures to humans and animals alike.

Salmen et al. [605] also found highly variable results from RFR (900 and 1,800 MHz) effects on DNA, growth rate, and antibiotic susceptibility in *Staphylococcus aureus*, *Staphylococcus epidermidis*, and *P. aeruginosa*. Using an active cell phone handset, they exposed bacteria to 900 and 1,800 MHz for 2 h, then injected samples into a new medium where growth rate and antibiotic susceptibility were evaluated. Regarding DNA, they found no differences in *S. aureus* and *S. epidermidis* when exposed to 900 and 1,800 MHz vs. controls, but *P. aeruginosa* showed changes in DNA band patterns following such exposures. Regarding growth rates, with the exception of a significant decrease after 12 h exposure to 900 MHz, no significant effects on growth of *S. aureus* and *S. epidermidis* were seen. But the growth of *P. aeruginosa* was significantly reduced following exposure for 10 and 12 h to 900 MHz, while no significant reduction in growth followed exposure to 1,800 MHz. Regarding antibiotic susceptibility, in the drugs studied (i.e., amoxicillin 30 mg, azithromycin 15 mg, chloramphenicol 10 mg, and ciprofloxacin 5 mg), with the exception of *S. aureus* treated with amoxicillin (30 mg), EMF-exposure had no significant effect on bacterial sensitivity to antibiotics. This study shows variability among bacterial species not only to different frequencies common in the environment today but also to changes in sensitivity to some antibiotics but not others. There may have been design problems with this study, however.

Several studies investigated WiFi signals on bacterial strains. Taheri et al. [610] assessed exposure to 900-MHz GSM mobile phone radiation and 2.4-GHz RFR from common WiFi routers to see if cultures of *Listeria monocytogenes* and *E. coli* resulted in altered susceptibility to 10 different antibiotics. They found narrow windows in which microbes became more resistant: For L. *monocytogenes* no significant changes in antibacterial activity between exposed and nonexposed samples — except for Tetracycline (Doxycycline) — were noted. For *E. coli*, however, there was a significant change in antimicrobial activities suggesting RFR exposures can influence antibiotic susceptibility of *E. coli* more than in *Listeria*. For window and pronounced effects, they found *L. monocytogenes* exhibited different responses to each antibiotic. For Doxycycline, the window occurred after 6 h exposure to WiFi and mobile phone-RFR. After 9 h of exposure to WiFi for Ciprofloxacin and Sulfonamide (Tremethoprin/sulfamethoxazole), bacteria tended to become more resistant. By contrast, the pattern for Levofloxacin and Penicillin (Cefotaxime/Deftriaxone) showed increased sensitivity. For *E.coli*, the pattern of the response to WiFi and mobile phone RFR was the same: maximum antibiotic resistance was seen between 6 and 9 h of exposure but after 12 h, a stress response lead to a return to preexposure conditions indicating an adaptive reaction. Taheri et al. [609] found similar nonlinear window effects and differences in growth rates in *Klebsiella pneumonia*, while Mortazavi et al. [613] found similar window effects in *E coli*. In addition, they saw significant increased growth rates after radiation exposures in both Gram-negative *E. coli* and Gram-positive *L. monocytogenes*. They concluded that such window effects can be determined by intensity and dose rate; that exposure to RFR within a narrow window can make microorganisms resistant to antibiotics; and that this adaptive phenomenon is a human health threat. The same can be inferred for many non-human species.

Said-Salman et al. [614] evaluated non-thermal effects of WiFi at 2.4 GHz for 24 and 48 h (using a WiFi router as the source) on the pathogenic bacterial strains *E. coli* 0157H7, *S. aureus, and S. epidermis* for antibiotic resistance, motility, metabolic activity and biofilm formation. Results found that WiFi exposure altered motility and antibiotic susceptibility of *E. coli* but there was no effect on *S. aureus and S. epidermis*. However, exposed cells (vs. unexposed controls) showed an increased metabolic activity and biofilm formation ability in *E. coli*, *S. aureus and S. epidermis*. They concluded that WiFi exposure acted as a bacterial stressor by increasing antibiotic resistance and motility of *E. coli*, as well as enhancing biofilm formation in all strains studied. They indicated the findings may have implications for the management of serious bacterial infections.

Movahedi et al. [615] also investigated antibiotic resistance, using short-term exposure to RFR from a mobile phone simulator (900 MHz, 24 h) on *P. aeruginosa* and *S. aureus* against 11 antibiotics. They found significant changes in structural properties and resistance to the numerous antibiotics studied. *P. aeruginosa* was resistant to all antibiotics after 24 h of exposure vs. non-exposed controls while *S. aureus* bacteria were resistant to about 50%. They also found structural changes in all exposed samples and increased cell wall permeability.

In a field study near cell towers, Sharma et al. [616] looked at changes in microbial diversity and antibiotic resistance patterns in soil samples taken near four different base stations with control samples taken >300 m away. *Stenotrophomonas maltophilia, Chryseobacterium gleum,* and *Kocuria rosea* were isolated and identified in soil samples collected near the exposed zones. They found greater antibiotic resistance in microbes from soil near base stations compared to controls, with a statistically significant difference in the pattern of antibiotic resistance found with nalidixic acid and cefixime when used as antimicrobial agents. They concluded that cell tower radiation can significantly alter the vital systems in microbes and make them multi-drug resistant.

Researchers have also investigated ELF-EMF effects on bacterial growth and antibiotic sensitivity. Segatore et al. [608] investigated 2 mT, 50 Hz exposures on *E. coli* ATCC 25922 and *P. aeruginosa* ATCC 27853 and found EMF significantly influenced the growth rate of both strains, notably at 4, 6, and 8 h of incubation. The number of cells was significantly decreased in exposed bacteria vs. controls. And at 24 h incubation, the percentage of cells increased (*P. aeruginosa* ~ 42%; *E. coli* ~ 5%) in treated groups vs. controls which suggested to the researchers a progressive adaptive response. However, they saw no remarkable change in antibiotic sensitivity. Potenza at al. [617] also found effects at high-intensity static magnetic fields at 300 mT on growth and gene expression in *E.coli* but that would be a high environmental exposure.

Viruses

There is a paucity of research on viral species and EMF, likely due to the fact that viruses lack ferromagnetic materials, are difficult to study, and don't make good general lab models other than to investigate their direct impact on specific *in vivo* end points. Virology research thrives in its own specialized niche and has not been used for basic modeling like so many other living life forms as noted throughout this paper. There is long-standing debate on whether viruses are even alive.

However, one wide-ranging discussion by Zaporozhan and Ponomarenko [618] hypothesized a possible complex mechanistic link between influenza pandemics, natural sun spot cycles, and non-thermal effects of weak magnetic fields via cryptochromes/radical pairs, gene expression pathways, and stress-induced host immunological alterations favorable to influenza epidemics. Noting that most — though not all — major influenza epidemics occurred in time intervals starting 2–3 years before and ending 2–3 years after maximum solar activity, they hypothesized that solar cycles are able to both regulate and entrain processes of biological microevolution in viral species (among others), as well as influence human biorhythms in synergistic ways that could lead to influenza epidemics. Although others have also noted links between influenza pandemics and sunspot activity — possibly based on changes in migratory bird patterns as viral vectors [619–621]— and some have linked sun spots with other adverse human health events, these effects remain of interest but are still hypothetical. UV radiation, which is not covered in this paper, is known to suppress cell-mediated immunity and is therefore capable of adversely affecting the course of a viral infection in some mammal species. Ambient EMF in lower frequency ranges may also be reducing immune viability across species which can theoretically foster opportunistic virulence. Far more EMF research needs to be conducted on viruses; one fruitful approach might be synergistic investigations in virus-infected plant species.

The previous studies of microbes show a pattern of sensitivity in microorganisms to EMF with associations that encompass a wide range of critical changes, including consistent stress responses, alterations in growth and viability, cell membrane alterations, and clear patterns of how easily antibiotic resistance forms in microbial life to now ubiquitous EMF levels.

Plants (see Part 2, Supplement 4, for a table of flora studies: ELF, RFR)

Plants have evolved in highly sensitive ways to natural and manmade EMF in all phases of germination, growth and maturation [31]. Magnetoreception, which is well documented in animals such as birds, has also been described in plants [622] and plant species can respond to subtle changes in EMF in the environment, including in whole plant communities [623]. They may even 'communicate' and gather various kinds of 'information' via electrical signals in neuron-like cells in root tips and elsewhere [624]. Some hypothesize [625] that a form of vibrational and acoustic sensitivity around 220 Hz may play a role in plant life, although not everyone agrees [626].

Almost all vegetation is subject to complex multi-frequency fields due to their soil-based root systems and high water content, plus above-ground ambient RFR exposures makes plants uniquely susceptible to effects near transmission towers [623, 627]. Many EMF studies have found both growth stimulation as well as dieback. The presence of numerous RFR-emitters in the German and Swiss Alps is thought to have played a role in the deforestation there [628]. The 'browning' of treetops is often observed near cell towers, especially when water is near tree root bases [25]. Treetops, with their high moisture content and often thick vegetative canopy, are known RFR waveguides. In fact, military applications utilize this capability in treetops for communication signal propagation in remote areas and for guidance of low-flying weapons systems [629].

How flora interacts with EMF is still a mystery but a clear pattern has emerged in researching the database for this paper: static ELF-EMF has largely been found beneficial to plant and seed growth [630] while RFR is detrimental. Plants clearly have magnetoreception in their stationary condition. The normal ground state of magnetic fields for plants is the relatively constant natural geomagnetic field that averages between 25 and 65 μT depending on location and seasonal variations [631]. Atmospheric changes, such as thunderstorms and lightning, can cause intermittent changes in ambient magnetic fields. These activities are also generally associated with rainwater critical to virtually all plant life. Plants can detect these changes and prepare for growth using the upcoming rainfall. Trees are seen extending their branches skyward long before rain actually occurs and such changes match alterations in tree polarities [632].

There are many studies showing an increase in the growth rate in plants, such as studies of seed germination exposed to alternating magnetic fields. Plants also respond similarly to high intensity static magnetic fields. This may mean that the physiological mechanism in plants that causes magnetic field-induced growth is finely tuned to a certain intensity of magnetic flux. Any variation in intensity or shape of the ambient magnetic field could activate or hinder this growth mechanism.

Lightning, for instance, generates fast and intense electromagnetic pulses (EMP). EMP has consistently been shown to cause biological effects [633] with just one pulse. Plants may have mechanisms so sensitive that they can detect the energy of EMP from kilometers away. The pulse causes a transient change in the environmental magnetic field that may be detected by one or more of the mechanisms mentioned in the "Mechanisms" section above, as well as discussed below. EMP has been closely investigated for military applications for its ability at high intensities to disable electronics. While much of the military-supported research finds no biological effects from EMP exposure, non-military supported research does show effects. This parallels the same findings in industry vs. non-industry research patterns [165, 634].

There is a long history on the study of effects of EMF exposure on plant growth, notably, the work of the Indian scientist Sir Jagadish Bose (1858–1937) who proposed the electric nature of plant responses to environmental stimuli and studied effects of microwaves on plant tissues and membrane potentials [635]. Interestingly, Bose investigated the effects of millimeter waves [636] now applicable to 5G technology. Bose, arguably, was a pioneer of wireless communication.

Another early pioneer in EMF effects on plants was Harold Saxon Burr (1889–1973) at Yale University who investigated the electric potential of trees in two tree species (a maple and an elm) located on one property and another maple tree for comparison growing 40 miles (64 km) away. Measurements of numerous parameters were taken using embedded electrodes that recorded hourly from 1953 to 1961 [637]. Simultaneous records of temperature, humidity, barometric pressure, sunlight, moon cycles, sunspot activity, weather conditions, atmospheric-potential gradients, earth-potential gradients, and cosmic rays were correlated with tree potentials. Burr also installed equipment that measured the potential between electrodes in the Earth (about 10 miles apart) and the potential gradient of the air, and found that the air and Earth potentials fluctuated exactly with the phase of the tree potentials although the trees were not always synchronous. Burr ultimately found that the electrical environment correlated closely with tree potentials in a kind of entrainment to diurnal, lunar and annual cycles. Meteorological parameters did not correlate in any immediate way other than when passing thunderstorms elicited anomalous behavior in the trees in direct parallel to measurements with the Earth electrodes. This follows the theory noted above that plants can sense EMP and take immediate information from it.

There are no other long-term field studies as detailed as Burr's of magnetic field effects on a plant species. However, another field study of RFR in Latvia [638] measured effects directly on trees near the Skrunda Radio Location Station, an early warning radar system that operated from 1971 to 1998. The system operated in the 156–162 MHz frequency range transmitting from four pulsed two-way antennas that had operated continuously for over 20 years by the time of the study. In permanent plots in pine forest stands, at varying distances from the radar station and in control areas, tree growth changes were measured and analyzed using retrospective tree ring data. They found a statistically significant negative correlation between the relative additional increment in tree growth and the intensity of the electric field with the radial growth of pine trees diminished in all plots exposed to RFR. The decreased growth began after 1970, which coincided with the initial operation of the station and was subsequently observed throughout the period of study. The effects of many other environmental and anthropogenic factors were also evaluated but no significant effects on tree growth were correlated. This may have been the first detailed field study of plants and RFR.

Many studies of EMF and plants are today conducted in laboratories and have often focused on growth promotion to create higher yields of food-producing plants. Effects of static EMF, pulsed EMF, ELF-EMF, and RF-EMF have been reported. There are, in fact, over 200 studies on plants and EMF alone — too numerous to review here. See Part 2, Supplement 4, for a Table of studies on plant seedlings and development based on the types of EMF's tested.

As noted in Supplement 4 and in Halgamuge [627], frequently static and ELF-magnetic fields generally improve plant growth whereas RFR retards it. This is the opposite of results from animal and animal-cell culture experiments in which ELF-MF usually produces the same effects as RFR. It is interesting to note that Hajnorouzi et al. [639] and Radhakrishma et al. [640] proposed that MF decreases environmental stress in plants whereas Vian et al. [641, 642] considered RFR as a systemic stressor. A major morphological difference between animal and plant cells is that plant cells have a cell wall that is an active physiological organelle which regulates growth and cell division and controls cellular communications. The cell wall contains a considerable amount of water [643]. Is it possible that absorption of RFR by cell-wall water causes a microthermal effect that adversely affects plant cell functions and even causes cell death, whereas thermal effects are not likely to occur with ELF-EMF exposure.

Some plant roots have been found sensitive to both ELF and RFR. Belyavskaya [644] found a strong cytochemical reaction in pea root cells after exposure to low level magnetic fields. Kumar et al. [645] found cyto- and genotoxicity in root meristems of *Allium cepa* with 900-MHz and 1,800-MHz RFR. Chandel et al. [646] studied cytotoxic and genotoxic activity on DNA integrity in root meristems of *A. cepa* using 2,100-MHz RFR and found exposure caused DNA damage with a significant decrease in HDNA accompanied by an increase in TDNA while TM and OTM did not change significantly compared to controls. Biological effects were dependent on the duration of exposure with maximum changes seen at 4 h.

In a series of studies, Stefi et al. [647–649] investigated the effects of long term RFR exposure from the base units of common cordless DECT phone systems (pulsed transmission mode 1,882 MHz, 24 h/day, 7 d/week) on various plant species (*Arabidopsis thaliana, Pinus halepensis, Gossypium hirsutum* respectively) and found structural and biochemical alterations. Compared to controls in Faraday cages, exposed plant biomass was greatly reduced and leaf structure was only half as thick. Leaves were thinner and possessed greatly reduced chloroplasts which contributed to overall reduced vitality. Root systems were also adversely affected. They concluded that RFR is a stressor and noxious to plant life. A study of similar design [650] did not find the same effects on maize (*Zea mays*) which they attributed to that plant's structural differences although chloroplasts were severely affected (see also Kumar et al. [651]).

Jayasanka and Asaeda [652] published a lengthy review that focused on microwave effects in plants. Studies indicate effects depend on the plant family and growth stage involved; and exposure duration, frequency, and power density, among other factors. They concluded that even for short exposure periods (<15 min to a few hours), nonthermal effects were seen that can persist for long periods even if initial exposures were very short. In addition, they noted that since base stations operate 24 h/day, neither short exposures nor recovery periods are possible in natural habitats as plants are continuously exposed throughout their life cycles. They said that variations in the power density and frequency of microwaves exert complex influences on plants, and that clearly diverse plant species respond differently to such factors. They concluded it is necessary to rethink the exposure guidelines that currently do not take nonthermal effects into consideration.

There are numerous reports of adverse RFR effects on mature flora. Waldman-Salsam et al. [653] reported leaf damage in trees near mobile phone towers/masts. In a detailed long-term field monitoring study from 2006 to 2015 in two German cities, they found unusual and unexplainable tree damage on the sides of trees facing the towers and correlated it to RFR measurements vs. control areas without exposures. They found that tree-side differences in measured values of power flux density corresponded to tree-side differences in damage. Controls, which consisted of 30 selected trees in low radiation areas without visual contact to any phone mast and power flux density under 50 $\mu W/m^2$, showed no damage. They concluded that nonthermal RFR from mobile phone towers is harmful to trees and that damage that affects one side eventually spreads to the whole tree.

Vian et al. [642] published a review of plant interactions with high frequency RFR between 300 MHz and 3 GHz and noted that reports at the cellular, molecular, and whole plant scale included: numerous modified metabolic activities (reactive oxygen species metabolism, α- and β-amylase, Krebs cycle, pentose phosphate pathway, chlorophyll content, and terpene emission among others); altered gene expression (calmodulin, calcium-dependent protein kinase, and proteinase inhibitor); and reduced growth (stem elongation and dry weight) after nonthermal RFR exposure. They said changes occur in directly exposed tissues as well as systemically in distant tissues and proposed that high-frequency RFR be considered a genuine environmental factor highly capable of evoking changes in plant metabolism.

Halgamuge [627] also published a review that found weak non-thermal RFR affects living plants. The author analyzed data from 45 peer-reviewed studies of 29 different plant species from 1996 to 2016 that described 169 experimental observations of physiological and morphological changes. The review concluded that the data substantiated that RFR showed physiological and/or morphological effects (89.9%, $p<0.001$). The results also demonstrated that maize, roselle, pea, fenugreek, duckweeds, tomato, onions and mungbean plants are highly sensitive to RFR and that plants appear more responsive to certain frequencies between 800 and 1,500 MHz ($p<0.0001$); 1,500 and 2,400 MHz (p 0.0001); and 3,500 and 8,000 MHz ($p=0.0161$). Halgamuge [627] concluded that the literature shows significant trends of RFR influence on plants.

There is particular concern for impacts to flora and 5G since millions of small antennas mounted on utility poles, transmitting in MMW and other broadband frequencies, already are — or will soon be — in very close proximity to vegetation, creating both near- and -far field exposures. As noted in Halgamuge [627], the following are some studies investigating GHz frequencies already in use or planned for 5G that found significant effects on plants: Tanner and Romero-Sierra [654] on accelerated growth of Mimosa plant (10 GHz, 190 mW/cm^2, 5–10 min); Scialabba and Tamburello [655] on reduced hypocotyls growth rate in radish (*Raphanus sativus*) (10.5 GHz, 8 mW or 12.658 GHz, 14 mW for 96 h); Tafforeau et al. [656] induced meristem (actively dividing group of cells) production in *Linum usitatissimum* (105 GHz for 2 h at 0.1 mW/cm^2); and Ragha et al. [657] (9.6 GHz, 30 min) found germination depended on exposure parameters on *Vigna radiata*, *Vigna aconitifolia*, *Cicer arietinum* and *Triticum aestivum* plants. This is an area in immediate need of further investigation given the results from the previous studies.

A thorough review of RFR effects to trees and other plants was published by Czerwinski et al. [622] who reported that ecological effects on whole plant communities could occur at a very low exposure level of 0.01–10 $\mu W/cm^2$ — certainly comparable to limits examined in this paper. They focused on frequencies between 0.7 and 1.8 GHz and included multiple complex indicators for plant types, biometrics, and environmental factors. It was the first comprehensive paper that extended beyond using narrower research methods. They noted that although the literature on the effects of RFR on plants is extensive, not a single field study had assessed the biological response at the level of a whole plant community, biome, or ecosystem, but rather focused mostly on short-term laboratory studies conducted on single species. They said, "…This dissonance is particularly striking in view of the fact that alterations in a plant community's structure and composition have long been considered to be well founded, sensitive and universal environmental indicators." The paper serves as a predictive model for complex future field studies on larger ecosystems.

Interesting EMF synergistic effects were found with static magnetic fields and bacteria in plants. Seeking nonchemical methods to improve seed germination after prolonged periods of storage when seed viability can deteriorate, Jovičić-Petrović et al. [658] studied the combined effects of bacterial inoculation (*Bacillus amyloliquefaciens* D5 ARV) and static magnetic fields (SMF, 90 mT, 5 and 15 min) on white mustard (*Sinapis alba* L.) seeds. Their results found that biopriming with the plant growth-promoting *B. amyloliquefaciens* increased seed growth by 40.43%. Seed response to SMF alone was dependent on treatment duration. While SMF at 5 min increased the germination percentage, exposure at 15 min lowered seed germination compared with the control. However, the negative effect at the longer exposure was neutralized when combined with the bacterial inoculation. Both germination percentages were significantly higher when SMF was combined with the bacteria (SMF, 5 min, + D5 ARV; and SMF, 15 min + D5 ARV; 44.68 and 53.20%, respectively) compared with control. They concluded that biopriming and SMF treatment gave better results than bacterial inoculation alone. The highest germination percentage — 53.20% of germinated seeds — was seen with the bacterium and 15 min exposure to 90 mT, demonstrating a synergistic effect. They concluded that such techniques can be used for old seed revitalization and improved germination.

Even aquatic plants have been found sensitive to artificial electric fields. Klink et al. [659] assessed electric field exposures on growth rates and the content of trace metals of *Elodea canadensis*. Plants were exposed in a laboratory to an electric field of 54 kV/m for seven days. Plant length and Fe, Mn, Ni, Pb, and Zn were measured. Results showed the applied electric fields slightly enhanced root growth. They also found changes in mineral absorption; Mn and Ni were significantly lower while Pb and Zn were significantly higher in exposed plants. Fe content did not differ between control and exposed plants. They concluded that electric fields had potential use for phytoremediation in trace metal contaminated waters. This study also has implications for long term aquatic plant health in general.

Also working with electric fields, Kral et al. [660] found fascinating regeneration in plant root tips in *Arabidopsis* at varying electric field exposures and time durations with the weaker exposures producing the most growth. They found that imposed electric fields can perturb apical root regeneration and that varying the position of the cut and the time interval between excision and stimulation made a difference. They also found that a brief pulse of an electric field parallel to the root could increase by up to two-fold the probability of its regeneration, perturb the local distribution of the hormone auxin, and alter cell division regulation with the orientation of the root towards the anode or the cathode playing a role.

While mechanisms are still unclear regarding how EMFs affect plants, oxidative effects appear to play a significant role. Oxidative changes have been reported in many studies in plants after exposure to EMF [578, 639, 661–671]. EMF-related stress has been proposed by Vian et al. [641, 642], Roux et al. [672, 673], and Radhakrishma et al. [640]. Other mechanisms affecting plants such as ferromagnetism, radical-pairs, calcium ions and cryptochromes have also been proposed [674, 675].

It is apparent that plant growth and physiology — with their root systems anchored in the ground while their 'heads' manifest in the air — are affected by exposure to EMF in complex synergistic ways and that they are susceptible to multi-frequency exposures throughout their life spans.

Conclusion

Effects from both natural and man-made EMF over a wide range of frequencies, intensities, wave forms, and signaling characteristics have been observed in all species of animals and plants investigated. The database is now voluminous with *in vitro*, *in vivo*, and field studies from which to extrapolate. The majority of studies have found biological effects at both high and low-intensity man-made exposures, many with implications for wildlife health and viability. It is clear that ambient environmental levels are biologically active in all non-human species which can have unique physiological mechanisms that require natural geomagnetic information for their life's most important activities. Sensitive magnetoreception allows living organisms, including plants, to detect small variations in environmental EMF and react immediately as well as over the long term, but it can also make some organisms exquisitely vulnerable to man-made fields. Anthropogenic EMF may be contributing more than we currently realize to species' diminishment and extinction. Exposures continue to escalate without understanding EMF as a potential causative and/or co-factorial agent. It is time to recognize ambient EMF as a potential novel stressor to other species, design technology to reduce exposures to as low as reasonably achievable, keep systems wired as much as possible to reduce ambient RFR, and create laws accordingly — a subject explored more thoroughly in Part 3.

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Part 2: supplements

Supplement 1: Genetic Effects of RFR Exposure
Supplement 2: Genetic Effects at Low Intensity Static/ELF EMF Exposure
Supplement 3: Biological Effects in Animals and Plants Exposed to Low Intensity RFR
Supplement 4: Effects of EMF on plant growth

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Part 2. Supplement 1.
Genetic Effects at Low Level RFR Exposure

RFR studies	**Power density/SAR (<0.1 W/Kg)**	**Effects observed**
Aitken et al. (2005)	Mice to 900-MHz RFR for 7 days at 12 h/day; SAR 0.09 W/kg	Mitochondrial genome damage in epididymal spermatozoa.
Akdag et al. (2016)	Male Wistar-Albino rats to 2400 MHz RFR from a Wi-Fi signal generator for a year; SAR 0.000141 (min)-0.007127 (max) W/kg	DNA damage in testes.
Alkis et al. (2019a)	Rats exposed to 900 MHz (brain SAR 0.0845 W/kg), 1800 MHz (0.04563 W/kg), and 2100 MHz (0.03957 W/kg) RFR 2 h/day for 6 months	Increased DNA strand breaks and oxidative DNA damage in brain.
Alkis et al. (2019b)	Rats exposed to 900 MHz, 1800 MHz, and 2100 MHz RFR 2 h/day for 6 months; maximum SAR over the rat 0.017 W/kg	DNA strand beaks and oxidative DNA damage in testicular tissue.
Atasoy et al. (2013)	Male Wister rats exposed to 2437 MHz (Wi-Fi) RFR; 24 h/day for 20 weeks; maximum SAR 0.091 W/kg	Oxidative DNA damage in blood and testes.
Beaubois et al. (2007)	Leaves of tomato plant exposed to 900-MHz RFR for 10 min at 0.0066 mW/cm^2	Increased expression of leucine-zipper transcription factor (bZIP) gene.
Belyaev et al. (2005)	Lymphocytes from human subjects exposed to GSM 915 MHz RFR for 2 h ; SAR 0.037 W/kg;	Increased condensation of chromatin.
Belyaev et al. (2009)	Human lymphocytes exposed to UMTS cell phone signal (1947.4 MHz, 5 MHz band	Chromatin affected and inhibition of DNA double-strand break.

	width) for 1 h; SAR 0.04 W/kg	
Bourdineaud et al. (2017)	Eisenia fetida earthworms exposed to 900 MHz for 2 h; SAR 0.00013-0.00933 W/kg	DNA genotoxic effect and HSP70 gene expressions up regulated.
Campisi et al. (2010)	Rat neocortical astroglial to CW 900 MHz RFR for 5, 10, or 20 min; incident power density 0.0265 mW/cm^2	Significant increases in DNA fragmentation.
Chaturvedi et al. (2011)	Male mice exposed to 2450 MHz RFR, 2 h/day for 30 days; SAR 0.03561 W/kg	Increased DNA strand breaks in brain cells.
Deshmukh et al. (2013)	Male Fischer rats exposed to 900 MHz (0.0005953 W/kg), 1800 MHz (0.0005835 W/kg), and 2450 MHz (0.0006672 W/kg) RFR for 2 h/day, 5 days/week for 30 days.	Increased DNA strand breaks in brain tissues.
Deshmukh et al. (2015)	Male Fischer rats exposed to 900 MHz (0.0005953 W/kg), 1800 MHz (0.0005835 W/kg), and 2450 MHz (0.0006672 W/kg) RFR for 2 h/day, 5 days/week for 180 days.	Increased DNA strand breaks in brain tissues.
Deshmukh et al. (2016)	Male Fischer rats exposed to 900 MHz (0.0005953 W/kg), 1800 MHz (0.0005835 W/kg), and 2450 MHz (0.0006672 W/kg) RFR for 2 h/day, 5 days/week for 90 days.	Increased DNA strand breaks in brain tissues.
Eker et al. (2018)	Female Wistar albino rats exposed to 1800-MHz RFR for 2 h/day	Caspase-3 and p38MAPK gene expressions increased in eye tissues.

	for 8 weeks; SAR 0.06 W/kg	
Furtado-Filho et al. (2014)	Rats of different ages (0-30 days) exposed to 950 MHz RFR for 0.5 h/day for 51 days (21 days of gestation and 6-30 days old): SAR pregnant rat 0.01-0.03 W/kg; neonate 0.88 W/kg, 6-day old 0.51 W/kg, 15-day old 0.18 W/kg, 30-day old 0.06 W/kg.	Decreased DNA strand breaks in liver of 15-day old and increased breaks in 30-day old rats..
Gulati et al. (2016)	Blood and buccal cells of people lived close (<400 meters) to a cell tower; 1800 MHz, Maximum power density (at 150 meters) 0.00122 mW/cm^2, some subjects lived in the area for more than 9 yrs	Increased DNA strand breaks in lymphocytes and micronucleus in buccal cells.
Gürler (2014)	Wistar rats exposed to 2450 MHz RFR 1 h/day for 30 consecutive days; power density 0.0036 mW/cm^2	Increased oxidative DNA damage in brain and blood.
Hanci et al. (2013)	Pregnant rats exposed 1 h/day on days 13-21 of pregnancy to 900-MHz RFR at power density 0.0265 mW/cm^2.	Testicular tissue of 21-day old offspring showed increased DNA oxidative damage.
He et al. (2016)	Mouse bone marrow stromal cells exposed to 900 MHz RFR 3 h/day for 5 days; SAR 4.1 x 10^{-4} W/kg (peak), 2.5 x 10_{-4} W/kg (average)	Increased expression of PARP-1 mRNA
Hekmat et al. (2013)	Calf thymus exposed to 940 MHz RFR for	Altered DNA structure at 0 and 2 h after exposure.

	45 min; SAR 0.04 W/kg	
Keleş and Süt (2021)	Pregnant rats exposed to 900-MH RFR at 0.0265 mW/cm2; 1 h/day from E13.5 until birth; thoracis spine of offspring examined.	Down regulation of H3K27me3 gene, am epigenetic modification to the DNA packaging protein Histone H3 in motor nerons.
Kesari and Behari (2009)	Male Wistar rats exposed to 50 GHz RFR for 2 h/day for 45 days; SAR 0.0008 W/kg	Increased in brain tissue DNA strand.
Kumar R. et al. (2021)	Male Wistar rats exposed to 900, 100, 2450 MHz RFR at SARs of 5.84×10^{-4} W/kg, 5.94×10^{-4} W/kg and 6.4×10^{-4} W/kg respectively for 2 h per day for 1-month, 3-month and 6-month	Microwave exposure with increasing frequency and exposure duration brings significant ($p < 0.05$) epigenetic modulations which alters gene expression in the rat hippocampus. Global DNA methylation was decreased and histone methylation was increased.
Kumar S. et al. (2010)	Male Wistar rats exposed to 10-GHz RFR for 2 h a day for 45 days, SAR 0.014 W/kg	Increased micronucleus in blood cells.
Kumar S. et al. (2013)	Male Wistar rats exposed to 10 GHz RFR for 2 h a day for 45 days; SAR 0.014 W/kg	Increased micronucleus in blood cells and DNA strand breaks in spermatozoa.
Marinelli et al. (2004)	Acute T-lymphoblastoid leukemia cells exposed to 900 MHz RFR for 2-48 h, SAR 0.0035 W/kg	Increased DNA damage and activation of genes involved in pro-survival signaling.
Markova et al. (2005)	Human lymphocytes exposed to 905 and 915 MHz GSM signals for 1 h; SAR 0.037 W/kg	Affected chromatin conformation and 53BP1/gamma-H2AX foci
Markova et al. (2010)	Human diploid VH-10 fibroblasts and human	Inhibited tumor suppressor TP53 binding protein 1 (53BP1) foci

	adipose-tissue derived mesenchymal stem cells exposed to GSM (905 MHz or 915 MHz) or UMTS (1947.4 MHz, middle channel) RFR for 1, 2, or 3 hr; SAR 0.037-0.039 W/kg	that are typically formed at the sites of DNA double strand break location.
Megha et al. (2015a)	Fischer rats exposed to 900 and 1800 MHz RFR for 30 days (2 h/day, 5 days/week), SAR 0.00059 and 0.00058 W/kg	Reduced levels of neurotransmitters dopamine, norepinephrine, epinephrine, and serotonin, and downregulation of mRNA of tyrosine hydroxylase and tryptophan hydroxylase (synthesizing enzymes for the transmitters) in the hippocampus.
Megha et al. (2015b)	Fischer rats exposed to 900, 1800, and 2450 MHz RFR for 60 days (2 h/day, 5 days/week); SAR 0.00059, 0.00058, and 0.00066 W/kg	Increased DNA damage in the hippocampus
Nittby et al. (2008)	Fischer 344 rats exposed to 1800 MHz GSM RFR for 6 h; SAR whole body average 0.013 W/kg, head 0.03 W/kg	Expression in cortex and hippocampus of genes connected with membrane functions.
Odaci et al. (2016)	Pregnant Sprague - Dawley rats exposed to 900 MHz RFR 1 h each day during days 13 - 21 of pregnancy; whole body average SAR 0.024 W/kg	Testis and epididymis of offspring showed higher DNA oxidation.
Pandey et al. (2017)	Swiss albino mice exposed to 900-MHz RFR for 4 or 8 h per day for 35 days; SAR 0.0054-0.0516 W/kg	DNA strand breaks in germ cells.
Pesnya and Romanovsky (2013)	Onion (Allium cepa) exposed to GSM 900-MHz RFR from a cell	Increased the mitotic index, the frequency of mitotic and chromosome abnormalities, and

	phone for 1 h/day or 9 h/day for 3 days; incident power density 0.0005 mW/cm^2	the micronucleus frequency in an exposure-duration manner.
Phillips et al. (1998)	Human Molt-4 T-lymphoblastoid cells exposed to pulsed signals at cellular telephone frequencies of 813.5625 MHz (iDEN signal) and 836.55 MHz (TDMA signal) for 2or 21 h. SAR 0.0024 and 0.024 W/Kg for iDEN and 0.0026 and 0.026 W/kg for TDMA)	Changes in DNA strand breaks
Qin et al. (2018)	Male mice exposed to 1800-MHz RFR 2 h/day for 32 days, SAR 0.0553 W/kg	Inhibition of testosterone synthesis might be mediated through CaMKI/RORα signaling pathway.
Rammal et al. (2014)	Tomato exposed to a 1250-MHz RFR for 10 days at 0.0095 mW/cm^2	Increased expression of two wound-plant genes.
Roux et al. (2006)	Tomato plants exposed to a 900-MHz RFR for 2-10 min at 0.0066 mW/cm^2	Induction of stress gene expression.
Roux et al. (2008)	Tomato plants exposed to a 900-MHz RFR for 10 min at 0.0066 mW/cm^2	Induction of stress gene expression.
Sarimov et al. (2004)	Human lymphocytes exposed to GSM 895-915 MHz signals for 30 min; SAR 0.0054 W/kg	Condensation of chromatin was observed.
Shahin et al. (2013)	Female mice (Mus musculus) exposed to continuous-wave 2.45 GHz RFR 2 h/day for 45v days; SAR 0.023 W/kg	Increased DNA strand breaks in the brain.

Sun Y. et al. (2017)	Human HL-60 cells exposed to 900 Hz RFR 5 h/day for 5 days; peak and average 0.00041 and 0.00025 W/kg, respectively.	Increased oxidative DNA damage and decreased mitochondrial gene expression.
Tkalec et al. (2013)	Earthworm (Eisenia fetida) exposed to comtinupus-wave and AM-modulated 900-MHz RFR for 2 - 4 h; SAR 0.00013, 0.00035, 0.0011, and 0.00933 W/kg	Increased DNA strand breaks.
Tsybulin et al. (2013)	Japanese Quail embryos exposed in ovo to GSM 900 MHz signal from a cell phone intermittently (48 sec ON/12 sec OFF) during initial 38 h of brooding or for 158 h (120 h before brooding plus initial 38 h of brooding): SAR 0.000003 W/kg	The lower duration of exposure decreased DNA strand breaks, whereas higher duration resulted in a significant increase in DNA damage.
Vian et al. (2006)	Tomato plants exposed to a 900-MHz RFR for 10 min at 0.0066 mW/cm^2	Induction of mRNA encoding the stress-related bZIP transcription factor.
Yakymenko et al. (2018)	Quail embryos exposed to GSM 1800 GHz signal from a smart phone (48 s ON/12 s OFF) for5 days before and 14 days during incubation, power density 0.00032 mW/cm^2	Increased DNA strand breaks and oxidative DNA damage.
Zong et al. (2015)	Mice exposed to 900 MHz RFR 4 h/day for 7 days; SAR 0.05 W/kg	Attenuated bleomycin-induced DNA breaks and repair,

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Table 1

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Part 2. Supplement 2.
Genetic Effects at Low Intensity Static/ELF EMF Exposure

Static and ELF EMF Studies	magnetic flux density	Effects observed
Agliassa et al. (2018)	Arabidopsis thaliana (thale cress) exposed to 0.00004 mT static magnetic field for 38 days after sowing	Changes in gene expression in leaf and floral meristem.
Baek et al. (2019)	Mouse embryonic stem cells exposed to hypomagnetic field (<0.005 mT) up to 12 days	Induced abnormal DNA methylation.
Bagheri Hosseinabadi et al. (2020)	Blood samples from thermal power plant workers; mean levels of exposure to ELF magnetic and electric fields were 0.0165 mT (±6.46) and 22.5 V/m (±5.38), respectively.	DNA strand breaks .in lymphocytes.
Baraúna et al. (2015)	Chromobacterium violaceum bacteria cultures exposed to ELF-EMF for 7 h at 0.00066 mT	Five differentially expressed proteins detected including the DNA-binding stress protein.
Belyaev et al. (2005)	Human lymphocytes exposed to 50 Hz magnetic field at 0.015 mT (peak) for 2 h (measurements made at 24 and 48 h after exposure).	Induced chromatin conformation changes.
Dominici et al. (2011)	Lymphocytes from welders (average magnetic field exposure from personal dosimeters 0.00781 mT (general environmental level 0.00003 mT)	Higher micronucleus frequency correlated with EMF exposure levels; decreased in sister chromatid exchange frequency.

Heredia-Rojas et al. (2010)	Human non-small cell lung cancer cells (INER-37) and mouse lymphoma cells (RMA E7) (transfected with a plasmid with hsp70 expression when exposed to magnetic field and contains the reporter for the luciferases gene) exposed to a 60-Hz magnetic field at 0.008 and 0.00008 mT for 20 min.	An increased in luciferase gene expression was observed in INER-37 cells.
Liboff et al. (1984)	Human fibroblasts dring the middle of S phaseexposed to 15 Hz-4 kHz sinusoidal MF	Enhanced DNA synthesis at between 5-25 μT
Sarimov et al. (2011)	Human lymphocytes exposed to 50-Hz magnetic field at 0.005-0.02 mT for 15-180 min	Magnetic field condensed relaxed chromatin and relaxed condensed chromatin.
Villarini et al. (2015)	Blood leukocytes from electric arc welders presumably exposed to 50-Hz EMF (mean 0.0078 mT; range: 0.00003-0.171 mT)	Decreased DNA strand beaks.
Wahab et al. (2007)	Human peripheral blood lymphocytes exposed to 50 Hz sinusoidal (continuous or pulsed) or square (continuous or pulsed) magnetic fields at 0.001 or 1 mT for 72 h.	Increase in the number of sister chromatid exchange/cell
Zendehdel et al. (2019)	Peripheral blood cells of male power line workers in a power plant. The median value of the magnetic	Increased in DNA strand breaks.

	field at the working sites was 0.00085 mT.	

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Part 2. Supplement 3
Biological Effects in Animals and Plants Exposed to Low-Intensity RFR

		SAR (W/kg)	Power density ($\mu W/cm^2$)	Effects reported
Aitken et al. (2005)	Mice exposed to 900 MHz RFR, 12/day. 7 days	0.09		Genotoxic effect in sperm.
Akdag et al. (2016)	Rats exposed to 2400 MHz RFR from a Wi-Fi signal generator for a year	0.000141 (min)-0.007127 (max)		DNA damage in testes.
Alimohammadi et al. (2018)	pregnant mice exposed to 915 MHz RFR; 8h/day, 10 days.		0.045	Offspring had increased fetal weight, enlarged liver and tail deformation
Alkis et al. (2019a)	Rtas exposed to 900; 1800; and 2100 MHz RFR; 2 h/day. 6 months	Brain SAR: 900 MHz - 0.0845; 1800 MHz-0.04563; 210 MHz-0.03957		DNA single strand break and oxidative damages in frontal lobe.
Alkis et al. (2019b)	Rats exposed to 900; 1800; and 2100 MHz RFR; 2 h/day. 6 months	maximum SAR over the rat body 0.017		DNA strand beaks and oxidative DNA damage in testicular tissue.
Atasoy et al. (2013)	Rats exposed to 2437 MHz (Wi-Fi) RFR; 24 h/day for 20 weeks	maximum SAR 0.091		Oxidative DNA damage in blood and testes.

Balmori et al. (2010)	Frog (Rana temporaria) exposed to 88.5 – 1873.6 MHz, cell phone base station emissions; 2 months from egg phase to tadpole		0.859-3.25 (1.5-3.8 V/m)	Retarded development and increased mortality rate.
Balmori et al (2015)	White stocks lived within 200 m of a Phone mast, GSM-900 MHz and DCS-1800 MHz signals		1.48	Affected reproduction rate.
Bartos et al. (2019)	Cockroach exposed to broadband RF noise		429 nT	Light-dependent slowing of circadian rhythm.
Beaubois et al. (2007)	Tomato plant exposed to 900-MHz RFR for 10 min		6.6	Increased expression of leucine-zipper transcription factor (bZIP) gene in leaves.
Bedir et al. (2018)	Rat exposed to 2100 MHz RFR, 6 or 19 h/day, 30 days	0.024		Oxidative stress-mediated renal injury.
Belyaev et al. (1992)	E. coli exposed to 51.62-51.84 and 41.25-41.50 GHz RFR, 5-15 min		1	Suppressed radiation-induced repair of genome conformation state.
Belyaev et al. (2005)	915 MHz GSM signal, 24 & 48 hr	0.037		Genetic changes in human white blood cells
Belyaev et al. (2009)	915 MHz, 1947 MHz; GSM, UMTS signals 24 & 72 hr	0.037		DNA repair mechanism in human white blood cells
Bourdineaud et al. (2017)	Earthworm (Eisenia fetida) exposed to 900 MHz RFR, 2 hr	0.00013-0.009		DNA modification.

Burlaka et al. (2013)	Japanese quail embryos exposed to GSM 900 MHz RFR; 158-360 hr		0.25	Oxidative DNA damage and free radical formation
Capri et al. (2004)	900 MHz, GSM signal, 1 hr/day, 3 days	0.07		Cell proliferation and membrane chemistry
Cammaerts and Johansson (2015)	Brassicaceae lepidium sativum (cress d'alinois) seed exposed to 900 and 1800 MHz RFR, 4, 7, and 10 days		0.007-0.01	Defect in germination.
Cammaerts et al. (2013)	Ants exposed to GSM signal for 180 h		0.1572	Affected food collection and response to pheromones.
Cammaerts et al. (2014)	Ants exposed to GSM signal for 10 min		0.5968	Affected social behavior.
Campisi et al. (2010)	Rat neocortical astroglial cells exposed to 50-Hz modulated 900 Mhz RFR, 5-20 min		26	Free radical production and DNA fragmentation.
Czerwinski et al. (2020)	Plant community exposed to cell phone base station radiation		0.01-0.1	Biological effects observed.
Chaturvedi et al. (2011)	Rat brain cells exposed to 2450 MHz RFR, 2 h/day for 30 days	0.03561		Increased DNA strand breaks.
Comelekoglu et al. (2018)	Rat sciatic nerve exposed to 1800 MHz RFR, 1 hr/day, 4 weeks	0.00421		Changes in electrical activity, increased catalase, and degeneration of myelinated fibers.

De Pomerai et al. (2003)	Protein exposed to 1 GHz RFR, 24 & 48 hr	0.015		Protein damages
Deshmukh et al. (2013)	Rats exposed to 900, 1800, and 2450 MHz RFR ; 30 days	0.0006-0.0007		DNA strand breaks in brain.
Deshmukh et al. (2015)	Rats exposed to 900, 1800, and 2450 MHz RFR; 180 days	0.0006-0.0007		Declined cognitive functions, increased brain HSP70 and DNA strand break.
Deshmukh et al. (2016)	Rats exposed 900, 1800, and 2450 MHz; 90 days	0.0006-0.0007		Declined cognitive functions, increased brain HSP70 and DNA strand break in rats
Dutta et al. (1984)	human neuroblastoma cells exposed to 915 MHz RFR, sinusoidal AM at 16 Hz	0.05		Increase in calcium efflux.
Dutta et al. (1994)	Escherichia coli cultures containing a plasmid with a mammalian gene for enolase were exposed for 30 min to 147 MHz RFR AM at16 or 60 Hz	0.05		Enolase activity in exposed cultures RFR at AM at 16 Hz showed enhanced activity enhanced, and AM at 60 Hz showed reduced activity. (Modulation frequencies. 16 and 60 Hz, caused similar effects.)
Eker et al. (2018)	Rats exposed to 1800 MHz RFR, 2 hr/day for 8 weeks	0.06		Increased caspase-3 and p38MAPK expressions in eye.
Fesenko et al. (1999)	Mice exposed to 8.15 – 18 GHz RFR, 5 hr to 7 days, direction of response depended on exposure duration		1	Changes in immunological functions.

Forgacs et al. (2006)	Mice exposed to 1800 MHz RFR, GSM- 217 Hz pulses, 576 µs pulse width; 2 hr/day, 10 days	0.018		Increase in serum testosterone.
Frątczak et al. (2020)	Ticks exposed to 900 MHz RFR		0.1	Ticks attracted to the RFR, particularly those infected with Rickettsia (spotted fever).
Friedman et al. (2007)	Rat and human cells exposed to 875 MHz RFR, 30 min		5	Activation of signaling pathways.
Furtado-Filho et al. (2014)	Pregnant rats exposed to 950 MHz RFR for 0.5 h/day for 51 days (21 days of gestation and 6-30 days old)	SAR pregnant rat 0.01-0.03 W/kg; neonate 0.88 W/kg, 6-day old 0.51 W/kg, 15-day old 0.18 W/kg, 30-day old 0.06 W/kg		Decreased DNA strand breaks in liver of 15-day old and increased breaks in 30-day old offspring.
Gandhi et al. (2015)	People who lived within 300 m of a mobile-phone base station.		1.15	Increased DNA damage in lymphocytes, more in female than in male subjects.
Garaj-Vrhovac et al. (2011)	Operators of two types of marine radars (3, 9.4, and 5.5 GHz); average time on job 2-16 yrs	0.0005-0.004 (time averaged)		Increased genetic damages in blood lymphocytes

Gremiaux et al. (2016)	Rose exposed to 900 MHz RFR, 3x 39min every 48 h at 2 stages of development	0.00072		Delayed and reduced growth.
Gulati et al. (2016)	People lived close (<400 meters) to a cell tower; 1800 MHz, , some subjects lived in the area for more than 9 yrs		Maximum power density (at 150 meters) 1.22	Increased DNA strand breaks in lymphocytes and micronucleus in buccal cells.
Gulati et al. (2020)	DNA damage in human lymphocytes	Cells exposed to UMTS signals at different frequency channels used by 3 G mobile phone (1923, 1947.47, and 1977 MHz) for 1 or 3 h; SAR 0.04 W/kg		DNA damage found only in cells exposed to 1977-MHz field.
Gupta et al. (2018)	Rtas exposed to 2450 MHz RFR; 1h/day 28 days	0.0616		Cognitive deficit, loss of mitochondrial functions, activation of apoptotic factors in hippocampus; affected cholinergic system.
Gurler et al. (2014)	Rats exposed to 2.45 GHz RFR, 1 h/day, 30 days		3.59	Increased DNA damage in brain.

Halgamuge et al. (2015)	Growth parameters of soybean seedlings	GSM 217 Hz-modulated (4.8×10^{-7}, 4.9×10^{-5}, and 0.0026 W/kg) SAR or CW (0.00039 and 0.02 W/kg) 900-MHz RFR for 2 h		Modulated and CW fields produced different patterns of growth effects. There was an amplitude effect and extremely low-level modulated field (4.8×10^{-7} W/kg) affected all parameters.
Hanci et al. (2013)	Pregnant rats exposed 1 h/day on days 13-21 of pregnancy to 900-MHz RFR		26.5	Testicular tissue of 21-day old offspring showed increased DNA oxidative damage.
Hanci et al. (2018)	Rats exposed to 900 MHz RFR, 1 h/day to postnatal day 60.	0.0067		Changes in morphology and increase in oxidative stress marker in testis.
Hassig et al. (2014)	Cows exposed to 916.5 MHz signal similar to GSM base station, 30 days 16 h 43 min per day		38.2	Changes in redox enzymes (SOD. CAT, GSH-px
He et al. (2016)	Mouse bone marrow stromal cells exposed to 900 MHz RFR 3 h/day for 5 days	2.5×10^{-4}		Increased expression of PARP-1 mRNA
Hekmat et al. (2013)	Calf thymus exposed to 940 MHz RFR, 45 min	0.04		Conformational changes in DNA.

Ivaschuk et al. (1997)	Nerve growth factor-treated PC12 rat pheochromocytoma cells 836.55 MHz TDMA signal, 20 min	0.026		Transcript levels for c-jun altered.
Ji et al. (2016)	Mouse bone-marrow stromal cells exposed to 900 MHz RFR, 4 hr/day for 5 days		120	Faster kinetics of DNA-strand break repair.
Keleş et al. (2019)	Rats exposed tp 900 MHz RFR; 1h/day, 25days	0.012		Higher number of pyramidal and granule neurons in hippocampus.
Kesari and Behari (2009)	Rats exposed to 50 GHz RFR; 2hr/day, 45 days	0.0008		Double strand DNA breaks observed in brain cells
Kesari and Behari (2010)	Rats exposed to 50 GHz RFR; 2 hr/day, 45 days	0.0008		Changes in oxidative processes and apoptosis in reproductive system.
Kesari et al. (2010)	Rats exposed to 2450 MHz RFR at 50-Hz modulation, 2 hr/day, 35 days	0.11		DNA double strand breaks in brain cells
Kumar et al. (2010a)	Rats exposed to 10 GHz RFR, 2h/day 45 days	0.014		Cellular changes and increase in reactive oxygen species in testes
Kumar et al. (2010b)	Rats exposed to 10 GHz RFR, 2 h/day, 45 days; or 50 GHz, 2h/day, 45 days	0.014 (10 GHz) 0.0008 (50 GHz)		Genetic damages in blood cells.

Kumar et al. (2013)	Rats exposed to 10 GHz RFR for 2 h a day for 45 days	0.014		Increased micronucleus in blood cells and DNA strand breaks in spermatozoa.
Kumar et al. (2015)	maize seedlings exposed to 1899 MHz RFR, 0.5-4 h		33.2	Retarded growth and decreased chlorophyll content.
Kumar et al. (2021)	Epigenetic modulation in the hippocampus of Wistar rats	Rats exposed to 900 MHz, 1800 MHz, and 2450 MHz RFR at a specific absorption rate (SAR) of 5.84×10^{-4} W/kg, 5.94×10^{-4} W/kg and 6.4×10^{-4} W/kg respectively for 2 h per day for 1-month, 3-month and 6-month periods.		Significant epigenetic modulations were observed in the hippocampus, larger changes with increasing frequency and exposure duration.
Kwee et al. (2001)	Transformed human epithelial amnion cells exposed to 960 MHz GSM signal, 20 min	0.0021		Increased Hsp-70 stress protein.
Landler et al. (2015)	Juvenile snapping turtle (c. serpentina) exposed to 1.43 MHz RFR, 20 min		20-52 nT	Disrupted magnetic orientation.

Lazaro et al. (2016)	50, 100, 200, 400 m from ten mobile telecommunication antennas		0.0000265 - 0.106	Distance-dependent effects on abundance and composition of wild insect pollinators
Lerchl et al. (2008)	383 MHz (TETRA), 900 and 1800 MHz (GSM) 24 hr/day, 60 days	0.08		Metabolic changes in hamster.
López-Martín et al. (2009)	Pulse-modulated GSM and unmodulated signals; 2 hr	0.03-0.26		c-Fos expression in brain of picotoxin-induced seizure-prone rats
Magras and Xenos (1997)	Mice in 'antenna park'-TV and FM-radio, exposure over several generations		0.168	Decrease in reproductive functions.
Marinelli et al. (2004)	Human leukemia cell exposed to 900 MHz CW RFR 2 - 48 hr	0.0035		Cell's self-defense responses triggered by DNA damage.
Makova et al. (2005)	human white blood cells exposed to 915 and 905 MHz GSM signal, 1 hr	0.037		Altered chromatin conformation.
Markova et al. (2010)	in human diploid VH-10 fibroblasts and human adipose-tissue derived mesenchymal stem cells exposed to GSM (905 MHz or 915 MHz) or UMTS (1947.4 MHz, middle channel) RFR for 1, 2, or 3 hr;	0.037-0.039		Inhibited tumor suppressor TP53 binding protein 1 (53BP1) foci that are typically formed at the sites of DNA double strand break location.

Megha et al. (2015a)	Rats exposed to 900 and 1800 MHz RFR for 30 days (2 h/day, 5 days/week)	0.00059 and 0.00058		Reduced levels of neurotransmitters dopamine, norepinephrine, epinephrine, and serotonin, and downregulation of mRNA of tyrosine hydroxylase and tryptophan hydroxylase (synthesizing enzymes for the transmitters) in the hippocampus.
Megha et al. (2015b)	Rats exposed to 900, 1800, and 2450 MHz RFR for 60 days (2 h/day, 5 days/week)	0.00059, 0.00058, and 0.00066		Increased DNA damage in the hippocampus.
Monselise et al. (2011)	Etiolated duckweed exposed to AM 1.287 MHz signal form transmitting antenna		0.859 (1,8-7.8 V/m)	Increased alanine accumulation in cells.
Navakatikian and Tomashevskaya (1994)	Rats exposed to 2450 MHz CW and 3000 MHz pulse-modulated 2 μs pulses at 400 Hz, Single (0.5-12 hr) or repeated (15-60 days, 7-12 hr/day)	0.0027		Behavioral and endocrine changes, and decreases in blood concentrations of testosterone and insulin. CW-no effect
Nittby et al. (2007)	Rats exposed to 900 MHz GSM signal, 2 hr/wk, 55wk	0.0006		Reduced memory functions.
Nittby et al. (2008)	Rats exposed to 915 MHz GSM signal, 6 hr	0.013 (whole body average); 0.03 (head)		Altered gene expression in cortex and hippocampus.

Novoselova et al. (1999)	Mice exposed to RFR from 8.15 -18 GHz, 1 sec sweep time-16 ms reverse, 5 hr		1	Changes in Functions of the immune system.
Novoselova et al. (2004)	Mice exposed to RFR from 8.15 -18 GHz, 1 sec sweep time-16 ms reverse, 1.5 hr/day, 30 days		1	Decreased tumor growth rate and enhanced survival.
Novoselova et al. (2017)	Mice exposed to 8.15 -18 GHz RFR, 1 Hz swinging frequency, 1 hr		1	Enhanced plasma cytokine.
Odaci et al. (2016)	Pregnant Sprague - Dawley rats exposed to 900 MHz RFR 1 h each day during days 13 - 21 of pregnancy	0.024		Testis and epididymis of offspring showed higher DNA oxidation.
Özsobacı et al. (2020)	Human kidney embryonic cells (HEK293) exposed to 3450 MHz RFR, 1 h		1.06	Changed oxidative enzyme activity and increased apoptosis.
Panagopoulos and Margaritis. (2010a)	Flies exposed to GSM 900 and 1800 MHz RFR, 6 min/day, 5 days		10	‘Window’ effect of GSM radiation on reproductive capacity and cell death.
Panagopoulos and Margaritis. (2010b)	Flies exposed to GSM 900 and 1800 MHz RFR, 1- 21 min/day, 5 days		10	Reproductive capacity of the fly decreased linearly with increased duration of exposure.
Panagopoulos et al. (2010)	Flies exposed GSM 900 and 1800 MHz RFR, 6 min/day, 5 days		1-10	Affected reproductive capacity and induced cell death.
Pandey et al. (2017)	Mice exposed to 900-MHz RFR for	0.0054-0.0516		DNA strand breaks in germ cells.

	4 or 8 h per day for 35 days			
Pavicic et al. (2008)	Chinese hamster V79 cells exposed to 864 and 935 MHz CW RFR, 1-3 hrs	0.08		Cell growth affected.
Perov et al. (2019)	Rats exposed to 171 MHz CW RFR, 6h/day, 15 days	0.006		Stimulation of adrenal gland activity.
Persson et al. (1997)	Rats exposed to 915 MHz RFR -CW and pulse-modulated (217-Hz, 0.57 ms; 50-Hz, 6.6 ms) 2-960 min.	0.0004		Increase in permeability of the blood-brain barrier. CW more potent.
Pesnya and Romanovsky (2013)	Onion exposed to GSM 900-MHz RFR from a cell phone for 1 h/day or 9 h/day for 3 days.		0.5	Increased mitotic index, frequency of mitotic and chromosome abnormalities, and micronucleus frequency.
Phillips et al. (1998)	Human leukemia cells exposed to 813.5625 MHz (iDEN); 836.55 MHz (TDMA) signals, 2 hr and 21 hr	0.0024		DNA damage observed.
Piccinetti et al. (2018)	Zebrafish exposed to 100 MHz RFR, 24-72 h post-fertilization	0.08		Retarded embroyonic development.
Postaci et al. (2018)	Rats exposed to 2600 MHz RFR, 1 h/day, 30 days	0.011		Cellular damages and oxidative damages in liver.

Pyrpasopoulou et al. (2004)	Rats exposed to 9.4 GHz GSM (50 Hz pulses, 20 µs pulse length) signal, 1-7 days postcoitum	0.0005		Exposure during early gestation affected kidney development.
Qin et al. (2018)	Mice exposed to 1800-MHz RFR, 2 h/day for 32 days	0.0553		Inhibition of testosterone synthesis.
Rafati et al. (2015)	Frog gastroenemius muscle exposed to cell phone jammers; 1 m away, 3x 10 min periods	For different jammers:0.01-0.05		Latency of contraction of prolonged.
Ranmal et al. (2014)	Tomato exposed to 1250-MHz RFR for 10 days.		9.5	Increased expression of two wound-plant genes.
Roux et al. (2006)	Tomatoes exposed to 900-MHz RFR for 2-10 min		6.6	Induction of stress gene expression in tomato.
Roux et al. (2008a)	Tomatoes exposed to 900 MHz RFR		6.6	Changes in Gene expression and energy metabolism.
Roux et al. (2008b)	Tomato plants exposed to 900 MHz RFR (>30 min)		6.6	Changes in energy metabolism in leave of tomato plant.
Salford et al. (2003)	Rats exposed to 915 MHz GSM, 2 hr	0.02		Nerve cell damage in brain.
Sarimov et al. (2004)	Human lymphocytes exposed to 895-915 MHz GSM signal, 30 min	0.0054		Chromatin affected similar to stress response.

Schwarz et al. (2008)	Human fibroblasts exposed to 1950 MHz UMTS signal, 24 hr	0.05		Changes in genes.
Shahin et al. (2013)	Mice exposed to 2450 MHz RFR, 2 h/day for 45 days	0.023		Increased DNA strand breaks in the brain.
Singh et al. (2012)	Hung beans exposed to 900 MHz RFR, 0.5-2 h		8.54	Reduced root length and number of roots per hypocotyls.
Sirav and Seyhan (2011)	Rats exposed to CW 900 MHz or 1800 MHz for 20 min	CW 900 MHz (0.00426 W/kg) or 1800 MHz (0.00146 W/kg)		Increased blood-brain barrier permeability in male rats, no significant effect on female rats.
Sirav and Seyhan (2016)	Rats exposed to pulsed-modulated (217 Hz, 517 µs width) 900 MHz or 1800 MHz 6 RFR for 20 min	0.02		In male rats, both frequencies increased blood-brain barrier permeability, 1800 MHz is more effective than 900 MHz; in female rats, only 900 MHz filed caused an effect.
Somosz et al. (1991)	Rat embryo 3T3 cells exposed to 2450-MHz 16-Hz square modulated RFR	0.024		Increased the ruffling activity of the cells, and caused ultrastructural alteration in the cytoplasm. CW was less effective.
Soran et al. (2014)	Plants exposed to GSM and WLAN signals		10 (GSM) 7 (WLAN)	Enhanced release of terpene from aromatic plants; essential oil contents in leaves enhanced by GSM radiation but reduced by WLAN radiation in some plants.

Stagg et al. (1997)	Glioma cells exposed to 836.55 MHz TDMA signal, duty cycle 33%, 24 hr	0.0059		Glioma cells showed significant increases in thymidine incorporation, which may be an indication of an increase in cell division.
Stankiewicz et al. (2006)	Human white blood cells exposed to 900 MHz GSM signal, 217 Hz pulses-.577 ms width, 15 min	0.024		Immune activities of human white blood cells affected.
Sun Y. et al. (2017)	Human HL-60 cells exposed to 900 Hz RFR, 5 h/day for 5 days	peak and average SAR 4.1 x 10^{-4} and 2.5 x 10^{-4} W/kg		Increased oxidative DNA damage and decreased mitochondrial gene expression.
Szymanski et al. (2020)	Human cells exposed to Pulse-modulated 900 MHz RFR, two 15-min exposure	0.024		Human blood mononucleus cells demonstrated high immunological activity of monocytes and T-cell response to concanavalin A.
Tkalec et al. (2013)	Earthorm exposed to continuous-wave and AM-modulated 900- MHz RFR for 2 - 4 h	0.00013, 0.00035, 0.0011, and 0.00933		Increased DNA strand breaks.
Tsybulin et al. (2012)	Japanese Quail embryos exposed to GSM 900 MHz signal during first 38 h or 14 days of fertilization		0.2	Enhanced development and survival in Japanese Quail embryos probably via a free radical-induced mechanism.
Tsybulin et al. (2013)	Japanese Quail embryos exposed to GSM 900 MHz signal, 48 sec on/12 sec off; 38 or 158 h	0.003		Decreased DNA strand break at 38 h and increased in 158h exposure in cells.

Vargová et al. (2017)	Ticks exposed to 900 MHz RFR		0.07	Ticks showed greater movement activity, with jerking movement of whole body or first pair of legs.
Vargová et al. (2018)	Ticks exposed to 900 MHz and 5000 MHz RFR		0.105	In a tube with half shielded for RFR, ticks exposed to 900 MHz concentrated on exposed side, and escaped to shielded side when exposed to 5000 MHz
Velizarov et al. (1999)	Human epithelial amnion cells exposed to 960 MHz GSM signal, 217 Hz square-pulse, duty cycle 12%, 30 min	0.000021		Decreased proliferation
Veyret et al. (1991)	Exposure to 9.4 GHz 1 μs pulses at 1000 pps, also with or without sinusoidal AM between 14 and 41 MHz, response only with AM modulation, direction of response depended on AM frequency	0.015		Changes in functions of the mouse immune system.
Vian et al. (2006)	Tomato plants exposed to 900 MHz RFR		6.6	Stress gene expression in plant.

Vilić et al. (2017)	Oxidative effects and DNA damage in honey bee (Apis mellifera) larvae		Honey bee larvae were exposed to 900-MHz at unmodulated field at 27 $\mu W/cm^2$ and modulated (80% AM 1 kHz sinusoidal) field at 140 $\mu W/cm^2$, for 2 hr.	Oxidative effect with exposure to unmodulated field. DNA damage increased after exposure to modulated field.
Waldmann-Salsam et al. (2016)	Mobile phone mast, long-term exposure		>0.005	Damages to trees
Wolke et al. (1996)	Heart muscle cells of guinea pig exposed to 900, 1300, 1800 MHz, square-wave modulated at 217 Hz; Also 900 MHz with CW, 16 Hz, 50 Hz and 30 KHz modulations	0.001		Changed calcium concentration in heart muscle cells.
Yakymenko et al. (2018)	Quail embryos exposed to GSM 1800 GHz signal from a smart phone (48 s ON/12 s OFF) for5 days before and 14 days during incubation		0.32	Increased DNA strand breaks and oxidative DNA damage.

Yurekli et al. (2006)	945 MHz GSM, 217 Hz pulse-modulation 7 hr/day, 8 days	0.0113		Free radical chemistry.
Zong et al. (2015)	Mice exposed to 900 MHz RFR, 4 h/day for 7 days	0.05		Attenuated bleomycin-induced DNA breaks and repair.

Author Note: *Many of the biological studies are acute, mostly one-time, exposure experiments, whereas exposure to ambient environmental man-made EMF is chronic. Acute and chronic exposures will likely end up with different consequences. Living organisms can compensate for the effect at the beginning of exposure and growth promotion in plants could be a result of over-compensation. After prolonged exposure, a breakdown of the system could occur, leading to detrimental effects. This sequence of response is basically how a living organism responds to stressors. The timeline of response depends on the physiology of an organism and also the intensity of exposure*

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Supplement 4. Effects of EMF on plant growth

	Experimental conditions	**Results**
STATIC MAGNETIC FIELD		
Abdani Nasiri et al.(2018)	medicinal sage;15-30 mT, 5 min	enhanced growth
Baghel et al. (2016)	soybean; 200 mT, 1h,	increased growth
Bahadir et al. (2018)	sweet pea *;* 125 mT, 24-72 h	promoted germination
Bhardwaj et al. (2012)	cucumber; 100-250 mT, 1-3 h	increased germination rate, length of seedling and dry weight
Ćirković et al. (2017)	wheat ; 340 mT, 16 h	increased growth rate
Florez et al. (2007)	maize;125 and 250 mT, 1 min to 10 days	increased growth rate
Jovičić-Petrović et al. (2021)	White mustard seed, 90 mT, 5 or 15 min	suppressed germination, but synergistic with a plant growth-promoting bacterial strain Bacillus amyloliquefaciens D5 ARV
Kataria et al. (2020)	soybean; 200 mT, 1 h	stimulated germination and promoted growth
Kim et al. (2016)	agricultural plants ; 130-250 mT, 4 days	increased stem and root lengths
Patel et al. (2017)	maize; 200 mT, 1 h	enhanced germination
Payez et al. (2013)	wheat; 30 mT, 4 days	promoted growth
Razmioo andAlinian (2017)	Cumin seed; 150, 250 500 mT or 1T for min	improved germination, growth and oil and essential contents
Shabrangy et al. (2021)	barley seeds, 7 mT, 1,3, or 6 h	Improved seed germination rate, root and shoot lengths, and biomass weight
Vashisth and Joshi (2017)	maize; 50-250 mT, 1-4 h	enhanced seed growth
Vashisth and Nagarajan (2008)	chickpea; 0-250 mT, 1-4 h	increased speed of germination, seedling length and dry weight
Xu et al. (2013)	rock cress, removal of the local geomagnetic field (~45 μT)	suppressed growth
PULSED MAGNETIC FIELD		

Bhardwaj et al. (2016)	green pea; 100 mT, 1 h, 6-min on/off	enhanced germination and growth
Bilalis et al. (2012)	corn; 3 Hz; 12.5 nT, 1 x 10^{-6} wave duration, 0-15 min	promoted plant growth and yield
Efthimiadou et al. (2014)	tomato; 3 Hz, 12.5 mT, 1 x 10^{-6} s duration, 0-15 min	enhanced plant growth
Radhakrishnan et al. (2012a)	soybean; 1 Hz, 1.5 µT, 5 h/day for 20 days	improved plant growth
Radhakrishnan et al. (2012b)	soybean; 10 Hz, 1.5 µT, 5 h/day for 20 days	improved plant growth
ELF MAGNET FIELD		
De Souza et al. (2008)	lettuce; 60-Hz, 120-160 mT, 1-5 min	enhanced growth and final yield
Fischer et al. (2004)	sunflower and wheat; 16.67 Hz; 20 µT, 12 days	increased fresh and dry weights and growth rate
Huang and Wang (2008)	Mung bean; 10-60 Hz modulated, 12 h, 6.38-16.20 µT	20 and 60 Hz, enhanced growth; 30, 40 and 50 Hz inhibited growth
Leelapriya et al. (2003)	cotton;10 Hz, 0.1 mT, 5 h/day for 20 days	enhanced germination
Naz et al. (2012)	okra; 50 Hz, 99 mT, 3 and 11 min	increased germination
Novitskii et al. (2014)	radish; 50 Hz, 500 µT,5 days	stimulated lipid formation
Shine et al. (2011)	soybean; 50 Hz, 0-300 mT, 30-90 min	improved germination parameters and biomass
Yano et al. (2004)	radish; 60 Hz, 50 µT plus a parallel 48-µT static magnetic field, 10-15 days	decreased CO_2 uptake , fresh and dry weights and leaf area
RFR		
Cammaerts and Johansson (2015)	Garden cress; 900 and 1800 MHz, 0.007-0.01 µW/cm^2, 10 days	decreased germination
Grémiaux et al. (2016)	rose, 900 MHz, 0.00072 W/kg, 3 hr once or 3 times, every 48 hr	delayed and reduced growth
Halgamuge et al. (2015)	Soybean seedling. 900 MHz GSM pulsed or CW, 0.45 mW/cm^2, 2 h	GSM radiation reduced outgrowth of epicotyls; CW exposure reduced outgrowth of roots and hypocotyls.
Kumar et al. (2015)	maize;1800 MHz, 0.5-4 h, 33.2 µW/cm^2	retarded growth and reduced chlorophyll content

Mildažienė et al. (2019)	sunflower seed; 5.28 MHz, 5, 10, 15 min 0.74 mT	changes in phytohormone balance, development and leaf protein expression
Payez et al. (2013)	wheat; 10 KHz, 4 days, 25 mW/cm^2	reduced water intake, increased speed of growth, reduced seeding vigor index I
Senavirathna et al. (2014)	Parrot feather (Myriophyllum aquaticum), 2000 MHz, 0.142 mW/cm^2, 1 h	Reduction in growth
Singh et al. (2012)	Mung bean; 900 MHz, 8.54 $\mu W/cm^2$, 0.5-2 h	reduced root length and number of roots per hypocotyls
Tkalec et al. (2009)	Onion; 400 and 900 MHz, 2h, 446 $\mu W/cm^2$	induced mitotic aberrations due to impairment of the mitotic spindle

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Review Article

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Effects of non-ionizing electromagnetic fields on flora and fauna, Part 3. Exposure standards, public policy, laws, and future directions

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Abstract: Due to the continuous rising ambient levels of nonionizing electromagnetic fields (EMFs) used in modern societies—primarily from wireless technologies—that have now become a ubiquitous biologically active environmental pollutant, a new vision on how to regulate such exposures for non-human species at the ecosystem level is needed. Government standards adopted for human exposures are examined for applicability to wildlife. Existing environmental laws, such as the National Environmental Policy Act and the Migratory Bird Treaty Act in the U.S. and others used in Canada and throughout Europe, should be strengthened and enforced. New laws should be written to accommodate the ever-increasing EMF exposures. Radiofrequency radiation exposure standards that have been adopted by worldwide agencies and governments warrant more stringent controls given the new and unusual signaling characteristics used in 5G technology. No such standards take wildlife into consideration. Many species of flora and fauna, because of distinctive physiologies, have been found sensitive to exogenous EMF in ways that surpass human reactivity. Such exposures may now be capable of affecting endogenous bioelectric states in some species. Numerous studies across all frequencies and taxa indicate that low-level EMF exposures have numerous adverse effects, including on orientation, migration, food finding, reproduction, mating, nest and den building, territorial maintenance, defense, vitality, longevity, and survivorship. Cyto- and geno-toxic effects have long been observed. It is time to recognize ambient EMF as a novel form of pollution and develop rules at regulatory agencies that designate air as 'habitat' so EMF can be regulated like other pollutants. Wildlife loss is often unseen and undocumented until tipping points are reached. A robust dialog regarding technology's high-impact role in the nascent field of electroecology needs to commence. Long-term chronic low-level EMF exposure standards should be set accordingly for wildlife, including, but not limited to, the redesign of wireless devices, as well as infrastructure, in order to reduce the rising ambient levels (explored in Part 1). Possible environmental approaches are discussed. This is Part 3 of a three-part series.

Keywords: aeroecology; electroecology; International Council on Non-ionizing Radiation Protection (ICNIRP); Migratory Bird Treaty Act (MBTA); National Environmental Policy Act (NEPA); non-ionizing electromagnetic fields (EMFs); radiofrequency radiation (RFR); rising ambient levels; U.S. Federal Communications Commission (FCC).

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Introduction

This is Part 3 and concludes a three-part series on electromagnetic field (EMF) effects to wildlife.

Part 1 focused on measurements of rising background levels in urban, suburban, rural, and deep forested areas as well as from satellites. Discussed were different physics models used to determine safety and their appropriateness to current exposures. The unusual signaling characteristics and unique potential biological effects from 5G were explored. The online edition of Part 1 contains a Supplement Table of measured global ambient levels.

Part 2 is an in-depth review of species extinctions, exceptional non-human magnetoreception capabilities, and other species' known reactions to anthropogenic EMF exposures as studied in laboratories and in the field. All animal kingdoms are included and clear vulnerabilities are seen. Part 2 contains four Supplement Tables of extensive low-level studies across all taxa, including ELF/RFR genotoxic effects.

Part 3 discusses current exposure standards, existing federal, and international laws that should be enforced but often are not, and concludes with a detailed discussion of aeroecology—the concept of defining air as habitat that would serve to protect many, though not all, vulnerable species today.

Government exposure standards

Extremely Low Frequency (ELF)

In the U.S., there are no federal government exposure standards for humans, much less wildlife, for the extremely low frequency (ELF) bands between 0 and 300 Hz. Within this range are the 50–60 Hz exposures common to powerlines and electric utility wiring that continue to rise due to our increasing energy demands, as well as electric utility grounding practices that use the Earth itself as the return neutral for excess current back to substations. Today in many regions, rather than run additional neutral lines (at significant expense) on utility poles along roadways to handle the extra harmonic load that all of our new electronic and wireless devices place on the lines, utilities siphon off excess voltage every few poles apart directly into the ground. Earth itself becomes the neutral line, sometimes with significant accumulations near substations that can elevate contact currents in nearby homes and outdoor environments, affecting pets and urban wildlife, as well as on underground metal gas pipelines that can form dangerous corrosion and hotspots [1]. In addition, new technologies like "wireless electricity"—called wireless power transfer (WPT)—to charge electric vehicles, batteries, computers, and chargers are coming on the market, creating novel ambient wireless and DC power exposures that we have never seen before, spanning from ELF through the 9 kHz to 40 GHz frequency bands. The technology is in nascent stages but involves transmission of power via RFR, most likely in the microwave bands at 2.45 GHz, to a special receiver called a rectenna that then converts it back to DC power for use in an ELF ambient capacity. The goal is to get rid of wires. This is a completely new exposure to which many species of flora and fauna are sensitive (see Part 2). Such industrial-scale grounding practices and wireless ELF/RFR have never been studied as environmental factors for air, land-based, or underground wildlife. This includes potential damage to flora with vulnerable root systems in the ground while their primary growth is above ground level (AGL), making flora susceptible to both ELF and radiofrequency radiation (RFR) exposures. Standards-setting groups may soon turn attention to ELF in light of WPT that is coming on the market with virtually no environmental review.

The U.S. Federal Communications Commission

In the U.S., the Federal Communications Commission (U.S. FCC) has jurisdiction over the licensing of electromagnetic spectrum use between 100 kilohertz (kHz) and 100 gigahertz (GHz), which includes cable TV/Internet, amateur radio, AM/FM commercial broadcast stations, wireless cellular facilities, satellite communications, and all other communications devices/services (See Figure 1). There are adopted and enforceable exposure standards in the radiofrequency bands between 300 kHz and 100 GHz under FCC—a non-health agency that relies on other agencies and outside expert groups for advice regarding human exposures ([2, 3], and see Part 1). FCC's 1997 standards were reviewed and reaffirmed in 2020 with minimal changes [4].

The model for the FCC standards are human-centric, based on short-term, acute high-intensity exposures to RFR that are capable of heating tissue the way a microwave oven cooks food. Thermal heating effects were well-quantified decades ago and are reasonably easy to regulate while allowing technology to flourish. It is the ubiquitous lower intensity exposures that are problematic and unregulated (see Part 2, Supplement 3 for effects at very low intensity exposures).

It is important to understand that the FCC standards (and other similar models) are exposure limits, not emissions allowances from generating sources although the two are intricately linked. As such, the standards are distance related with accessibility to a generating source being the most important factor, and they are relevant only to locations that are accessible to workers and/or members of the public [2, 5, 6]. This means that despite safety factors built in to such standards, ambient levels are largely unregulated outside of built environments.

However, while standards by any group are derived with only humans in mind, all measurement factors are potentially relevant metrics to species in the wild. Thus the large body of research intended to help set exposure limits for humans are germane to determining new standards to protect wildlife, at least in some very broad ways. But in regulating for wildlife, factors involving rising ambient levels (see Part 1) must include both exposure and emission considerations, due to the increased sensitivity to EMF/RFR of many species (see Part 2) based on taxonomy, size, physiology, habitat, magnetoreception, seasonal

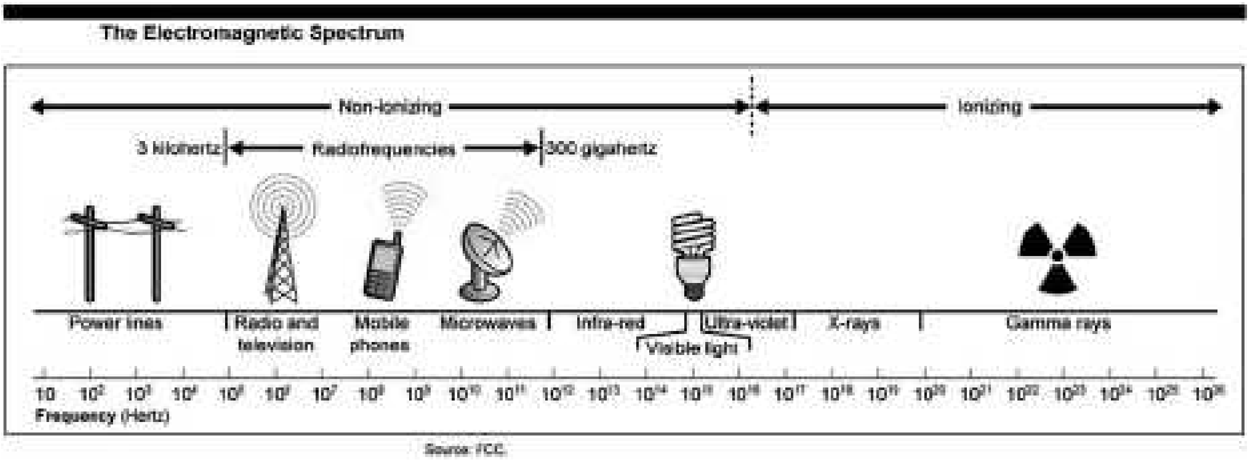

Figure 1: Illustration shows FCC area of regulatory responsibility between 100 kilohertz (kHz) up to the far microwave bands in the non-ionizing section of the spectrum. The frequency range for FCC limits cover from 300 kHz to 100 GHz. ([5] p. 3).

migration, and many other factors. Many airborne species, for example, have the ability to reach close proximities to antennas mounted on towers or buildings and routinely reach areas with detrimental levels of RFR even at some distance from transmitters. And several bird species fly at altitudes high enough to experience exposures from satellite systems that humans would never encounter. In essence, other species can experience both near-and-far-field exposures that humans rarely, if ever, experience and likely move in and out of such fields on a routine and/or seasonal basis.

Below is information on how governments regulate this subject regarding human exposures that point to possibilities for wildlife protection.

The U.S. FCC exposure standards are a two-tiered model based on recommendations from key regulatory agencies and two expert organizations: the National Council on Radiation Protection and Measurements (NCRP) report in 1986 [7, 8] and a subcommittee recommendation from 1992 to the American National Standards Institute (ANSI) by the International Electronics and Electrical Engineers (IEEE; [9]). The NCRP is a non-profit corporation chartered by the U.S. Congress to develop information and recommendations across many public and private sectors on radiation protection. The ANSI is a non-profit, privately funded, membership organization that coordinates the development of voluntary U.S. national standards used across all industry sectors. The IEEE is a non-profit, privately funded, technical, and professional/industry group that widely represents the technology sector with a membership of over 300,000 engineers and scientists worldwide; they have almost no biologists or members with medical backgrounds. ANSI, IEEE, and FCC are not health or environment-related entities, yet they play pivotal roles in non-ionizing radiation exposure regulation. NCRP does include human health expertise on their review panels. These various groups issue exposure guidelines. Once a government entity with enabling authority adopts such guidelines, they become enforceable and the government entity can require the private sector to abide by them as well as impose fines when they transgress. The FCC was given authority over RFR exposure standards adoption and enforcement by The Telecommunications (TCA) Act of 1996 [10].

At the impetus of the U.S. Environmental Protection Agency (U.S. EPA), the multi-agency Radiofrequency Interagency Working Group (RFIAWG) was formed in the 1990s. EPA, which has primacy over environmental radiation effects, was specifically defunded for non-ionizing radiation research and oversight in 1996 [11] just as the TCA was coming into effect. In lieu of EPA writing its own RFR exposure standards at the time—something they were poised to do and took criticism for not completing—EPA instead recommended a two-tiered exposure standard (see below) be adopted at FCC taken from recommendations by both NCRP and ANSI/IEEE, which FCC did in 1996. Subsequent to that, the RFIAWG also sent a letter in 1999 to the IEEE committee responsible for developing RF standards that listed 14 major topics and/or areas of concern related to any future revision of the IEEE standard [12]. Those concerns have yet to be addressed. The RFIAWG was comprised of key bioelectromagnetics scientists from seven or more U.S. federal regulatory agencies, representing health, the environment, and professional exposures (One of the authors of this paper was on RFIAWG representing the U.S. Fish and Wildlife Service). Although RFIAWG still exists on paper, it rarely meets, if at all, and is no longer the analytical advisory authority it once was to FCC. Consequently FCC regulates and issues rule-makings in an environmental vacuum, other than minimal comments provided by the Food and Drug Administration (U.S. FDA) which advises on devices like cell phones over which it has authority.

FCC is often now seen as an agency that is captured by the industries it is supposed to regulate [13] and because of cutbacks at key advisory agencies like EPA, FCC lacks the wider expertise upon which it relies to conduct thorough assessments regarding exposure safety [11].

What today's exposure standards measure

Most of the current guidelines used in Western countries are based on the specific absorption rate (SAR)—the rate of energy absorbed per unit mass of biological tissue with units expressed in watts per kilogram (W/kg) or milliwatts per kilogram (mW/kg) of tissue. Harmful effects from which the SAR was originally derived were based upon relatively few animal studies in the 1980s [14, 15] in which behavioral disruption was observed at approximately 4 W/kg when test animal body temperatures rose by about 1°C. Safety factors were built in to allow for unknown/unidentified effects and are reflected in the allowances noted below, but it is important to know that these additional margins are purely hypothetical. SARs are also studied on fluid-filled phantom laboratory models in the shape of human body parts, as well as cadavers which can never reflect the complexities of whole living electrodynamic organisms. SARs are extremely difficult, if not impossible, to measure in living models.

The FCC standards divide exposure allowances (based on the baseline or 4 W/kg) into two tiers legally defined as:

- **Occupational/controlled limits based on ANSI/IEEE:** Applies when people are exposed due to employment, provided they are fully aware of exposures and can exercise control over them. SAR is 0.4 W/kg, reflecting a safety factor of 10.
- **General population/uncontrolled limits based on NCRP:** Applies to when the general public may be exposed, or when people who are exposed as a consequence of employment may not be fully aware of potential exposure, or cannot exercise control over the exposure. SAR is 0.08 W/kg, reflecting a safety factor of 50.
- Limits are different for cell phone exposures when partial body exposure would be experienced and is derived by complicated methods of scaling from the whole body exposure. The SAR for partial body exposure is 1.6 W/kg measured over 1.0 g cube of tissue—a limit that all cell phones must meet in the U.S., and which is stricter than what is used in Europe as recommended by the ICNIRP guidelines (see below) at 2.0 W/kg averaged over 10 g of tissue. SAR evaluation continues to be required as the only acceptable compliance metric for portable devices below 6 GHz.
- In addition, there are whole-body SAR limits at 0.08 W/kg related to various factors including size, shape, and orientation toward a generating source, among other things. There are also higher SAR allowances for the body's extremities defined as hands, wrists, feet, and ankles, where the limit is 4 W/kg as averaged over any 10 g of tissue and where some peak allowances can be up to 8 W/kg over 1 g of tissue (it is assumed that extremities can absorb more energy without tissue heating [the ear—or pinna—was included as an extremity in 2013 – see discussion below]). There are also resonant SAR peaks for humans (maximum absorption rates) reflected in the illustration below. For whole-body human irradiation of a 6′ male, peak resonant SARs are reached in the bands between 70 and 100 Megahertz (MHz)—the middle of the FM radio band, where exposures are therefore most stringent (see Figure 2).

The frequency range for FCC limits covers from 300 kHz to 100 GHz and is dependent on frequency as defined in maximum permissible exposures (MPE). MPE's are given in terms of power density—milliwatts per centimeter squared (mW/cm^2)—or in field strength as volts per meter (V/m) or amperes per meter (A/m). Often far-field exposures from infrastructure are given in mW/cm^2 and MPE. (For a table of FCC MPE limits for occupational and general populations see reference [5], p. 15).

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) compared to the FCC

Countries throughout Europe and Canada have adopted standards based on recommendations by The International Commission on Non-Ionizing Radiation Protection (ICNIRP), a self-selecting group chartered in Germany in 1992 that functions as a collaborating non-state entity with the World Health Organization [16– 18]. ICNIRP is a

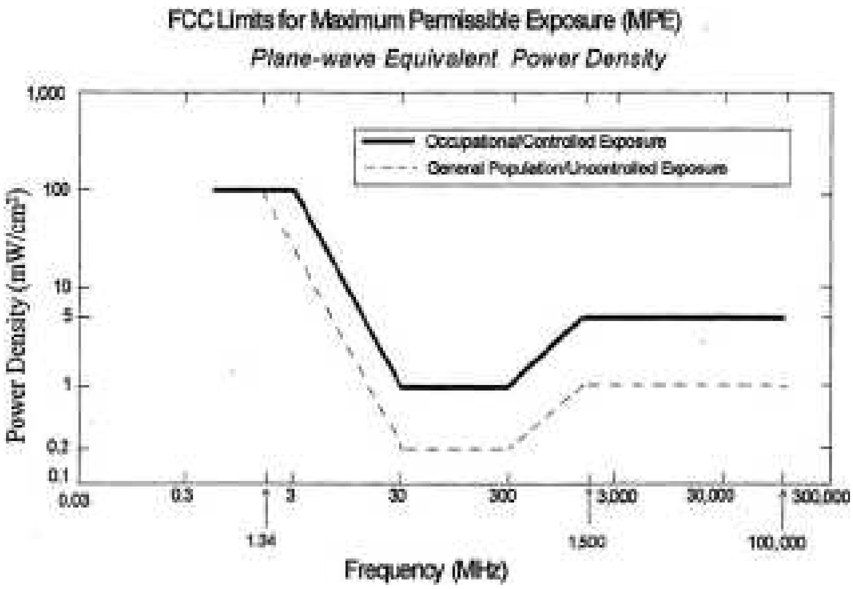

Figure 2: Worker limit is the solid line; general public is the dotted line.
Note that the strictest limit is in the 30–300 MHz range where human whole body resonance occurs. Standards-setting organizations have all made limits strictest in that region. Also note that higher limits are allowed on both sides of that area ([2] p. 69).

relatively new entity in standards setting, given that the ANSI-IEEE basic thermal exposure framework was first delineated and published in 1968 (at higher allowances) and the U.S. NCRP's basic reports on RF were published in 1986 and 1993 ([7, 8], respectively).

The FCC standards remain more stringent than ICNIRP's although in 2020 ICNIRP published an update of their 1998 allowances and adopted a few of FCC's measurements. Both remain two-tiered, human-centric, thermal-based models. ICNIRP differs in some exposure levels and averaging times, as well as allowances in some lower as well as upper frequency ranges that are more lenient than FCC. There is variation between countries that have adopted other standards, i.e., Italy and Switzerland use standards far below FCC and ICNIRP (see below).

By way of comparison: For power density (MPE) the U.S. standards are between 0.2 and 1.0 mW/cm^2 and for SAR between 0.08 and 0.40 W/kg of human tissue. For cell phones and uncontrolled environments, FCC SAR levels require hand-held devices to be at or below 1.6 W/kg averaged over 1.0 g cube of tissue. For whole body exposures in uncontrolled environments, the limit is 0.08 W/kg. Canada, which previously had used the ICNIRP standard, now uses the FCC's 1.6 W/kg averaged over any 1.0 g of tissue and for whole body exposures, the limit is 0.08 W/kg. The peak spatially-averaged SAR in the limbs, averaged over any 10 g of tissue, is 4 W/kg. In European countries and elsewhere where the ICNIRP standard is used, the SAR limit for hand-held devices is higher than FCC at 2.0 W/kg averaged over 10 g cube tissue mass (than measurement, which changed in 2020, used to be over any contiguous tissue). Whole body exposure limits are the same at 0.08 W/kg but until recently were averaged differently: in the FCC standards they are averaged over 30 min; ICNIRP used to be averaged over 6 min but has now gone to 30 min for whole body exposures too [19]. ICNIRP's local body-area SARs are still averaged over 6 min.

The 2020 ICNIRP revision made some other critical changes that many find troubling (see below). Hardell et al. [20] published a recent thorough review and analysis of why these standards are not as protective of public health as many assume.

Longstanding criticism of FCC and ICNIRP standards

The longstanding primary criticism of both the FCC and ICNIRP standards is that they are based on short-term acute exposures for tissue heating—unlike today's more realistic long-term chronic low-level exposures—and that the safety factors of 10 and 50 below that acute heating threshold are purely suppositional [21]. There are other flaws with how these standards are written, for instance the effect of time averaging diminishes the biological significance of peak intensity short-term exposures. And because real-life exposures can be quite organ-specific, such as a cell phone held against the head or carried in a pocket, partial body exposure guidelines for specific organs may not be accurate, especially after the FCC ruled in 2013 that the human ear (pinna) can be classified as an appendage like arms or legs [22, 23], thereby allowing cell phones to transmit at higher levels with higher SAR limits.

This reclassification only changes exposures to the ear. FCC standards are still 1.6 W/kg as averaged over 1 g of tissue, except for extremities where the limit is 4 W/kg as averaged over 10 g of tissue (For occupational exposures, the localized SAR limit is 8 W/kg as averaged over 1 g of tissue, except for within the extremities where it is limited to 20 W/kg as averaged over 10 g of tissue). The ear now fits that higher allowance even though the auricle is simply not an 'extremity.' The auricle is histologically very different from arms or legs and lacks bone, tendon, and skeletal muscle. It is also very close to the human brain and eyes. In addition auricle nerves are innervated by the vagus nerve which in turn innervates many other vital organs in the body, including the heart, GI-tract, and reproductive organs. The higher allowance may also affect the eyes as many now text and look directly into a cell phone screen. This entire new classification should be reconsidered. The eye is a highly conductive aqueous saline organ—the exact opposite of cartilage. The reclassification is inviting adverse effects to the ear, the brain, the eyes, and potentially other systems in the body [23]. It also exponentially increases ambient RFR levels with the number of active cell phones in operation at any given location. Health concerns over human eyes directly translate to species with eye structures similar to humans which includes most mammals. But in other species, effects are potentially more dire. Many insect species, for instance, have compound eye structures with sometimes thousands of lenses in addition to which insects do not dissipate heat efficiently. Their smaller size also makes them a resonant match with RFR's higher frequencies.

Given the scale of human cell phone use today, that technology's contribution alone to ambient levels is not insignificant (see Part 1). Yet people rarely understand that their cell phone may cause downstream effects to other species. Raising the power density output of cell phones may be an environmental factor in and of itself. In fact many of the fundamental criticisms of the human exposure standards may have consequences at the ecosystem level to wildlife species (see Part 2 and below).

In addition, no current exposure standards at FCC or ICNIRP take into consideration signal modulation, wave form, or cumulative exposures from multiple low-power devices transmitting simultaneously—all biologically important factors that have been found in numerous studies to be independent of frequency alone (see Parts 1 and 2). And both FCC and ICNIRP categorically exclude whole classes of low-power devices from review if they adhere to a certain transmission level around 1 mW effective radiated power (ERP).

In other words, there are multiple problems and significant deficits with the most widely adopted exposure standards as originally conceived, formulated, written, and defended. Both major entities have recently reinforced and justified their exposure parameters despite decades of recent research pointing to adverse effects from exposures far below heating thresholds. Both FCC and ICNIRP are actually dosimetry-based models—meaning a defined minimum exposure that will allow technology to function without causing gross short-term adverse heating effects—rather than true biological models based on thresholds where effects are seen [12].

Today a growing number of people, domestic pets, and urban and suburban wildlife are exposed to 24 h EMFs from individual devices, products, and infrastructure [21, 24–27]. Popular wireless devices such as baby monitors, smart grid/meters, home and industrial appliances, WiFi routers, remote controls, security systems, personal "assistants" like Amazon's Alexa and Apple's Siri, and some wireless laptop computers fall at, or below, the power density level of 1 mW ERP which qualifies them for categorical exclusion (CE, or CatEx) from licensing review. This can include CatEx for small cell infrastructure too but there is complex overlap in some situations.

There is a distinction between "no license required" for low-power individual consumer devices vs. "no environmental review pursuant to a CatEx" for low power infrastructure. Small cell networks do require FCC licensing because they use the spectrum, even though individual antennas can be categorically excluded as low-powered. And because issuing a license is a major federal action, NEPA should apply, even though under some circumstances, a CatEx can satisfy NEPA compliance—see below. Today, FCC CatExs include most consumer wireless products and the infrastructure for hundreds of thousands of individual 4G and 5G small cells. Exclusion criteria are based on such factors as type of service, antenna height, and operating power. CatExs are not exclusions from compliance itself, but rather exclusions from performing routine evaluations to demonstrate such compliance and therein lay problems because no one is monitoring. Qualifying for CatEx is based on manufacturer's declarations. According to FCC OET Bulletin 65 (2 p. 12), "… the exclusion itself from performing routine evaluation will be a sufficient basis for assuming compliance, unless an applicant or licensee is otherwise notified by the FCC or has reason to believe that the excluded transmitter or facility encompasses exceptional characteristics that could cause non-compliance …" In other words, much of this semi-regulated area is based on the honor system.

CatEx does not mean that significant exposures are unrealistic or unlikely, especially from cumulative exposures from many devices working simultaneously as is the case in most homes and workplaces today. Although infrastructure is the dominant contributor to outdoor pollution (see Part 1), cell phones and some domestic WiFi systems can be significant contributors to ambient exposures in indoor as well as outdoor environments at levels known to affect wildlife (see Part 2, Supplement 3). What are widely thought to be local indoor transmitters such as personal WiFi and home signal boosters, can and do penetrate walls to become outdoor exposures too. Every new application, though functioning within its own categorically excluded parameter, adds that much more to the aggregate, in essence creating a synergistic effect with the sum of exposures being greater than the individual effects of each component part. Although aggregate RFR levels are not supposed to exceed the FCC or ICNIRP regulations, no regulatory entity today measures, enforces, or attempts to mitigate for this [23] unless complaints are filed over interference issues with other systems. Each CatEx exists within its own technical realm, considered safe if kept under 1 mW ERP. Most such excluded devices and/or networks have considerable overlap, creating multiple exposures, and possible elevated effects. This is not a realistic, scientifically sound, or safe way to determine actual exposures to humans, domestic animals, or wildlife from aggregate, ambient radiation.

5G: changes at FCC and ICNIRP

5G is poised to bring radical changes to the ambient landscape from individual devices and especially infrastructure exposures, yet the major standards-setting groups have recently reinforced and justified their existing exposure allowances [3, 18, 19]. They continue to adhere to acute dosimetry-based frameworks rather than true biological models based on more sensitive thresholds where effects are seen. Plus, a most urgent area in need of clarification concerns how traditional standards have been written from the outset, which may, in fact, be based on a fundamental theoretical flaw. We may not even be using the correct physics model in today's standards setting (see Part 1) in light of actual exposures. The entire justification for adhering to thermoregulatory models rests on the classic physics theory of non-ionizing radiation not having enough energy to knock electrons off cellular orbits and thereby cause DNA damage. This may not be the most accurate model regarding biological reactions/interactions with low-level energy found in current exposures [28–32]. The classic theory is based on a mathematical calculation best suited to ionizing radiation and a narrow definition of a one-cell, one-photon concept whereas today's exposures are many simultaneous and often-overlapping streaming photons arriving at multiple cells from multiple angles at the same time in what behave more like photon wave "packets" rather than single photons [33–39] Our entire regulatory concept needs further attention if we are to truly understand and trust where we are headed with 5G's new technology.

To better accommodate 5G's buildout, all exposure limits at FCC and INCIRP may soon become more lenient. FCC has opened a new docket (Docket #19-226) to target the need for different regulations for 5G [40], even as they have stated their current regulations are adequate for 5G exposures [3]. The new FCC docket covers a wider frequency range from 3 kHz to 3 THz for permissible human exposures and has allocated certain applications in the millimeter (MMW) bands from 57.05 to 64 GHz for unlicensed use, meaning CatEx for some devices and infrastructure. FCC is also seeking comments on applying localized exposure limits above 6 GHz in parallel to the localized exposure limits already established below 6 GHz, as well as specifying new conditions and methods for averaging RFR for both time and exposure area. They are also seeking comment on new issues raised by WPT devices [3].

There have been numerous comments submitted to FCC regarding Docket 19-226 by citizens, organizations, and professional groups like the American Public Power Association (APPA) urging FCC not to further expand unlicensed operations in the 6 GHz bandwidth due to possible interference with present licensed systems, among many other issues. Numerous comments also center on health/environmental concerns [41].

There has been significant discussion at FCC and ICNIRP about changing SAR exposure categories that are now used for cell phones and other mobile/portable devices to a mW/cm^2 power density exposure measurement (MPE) for devices above 6 GHz, which 5G phones will be. FCC states that for portable devices operating at frequencies above 6 GHz, 'special frequency' considerations are necessary [2]. The localized SAR criteria used by the FCC only apply at operating frequencies between 100 kHz and 6 GHz. For portable devices that operate above 6 GHz (e.g., 5G millimeter-wave devices) they say that localized SAR is not an appropriate means for evaluating exposure; that at the higher frequencies, exposure from portable devices should be evaluated in terms of power density MPE limits instead of SAR, adding that power density values can be either calculated or measured, as appropriate, at a minimum distance of 5 cm from the radiator of a portable device to show compliance with FCC standards (2 p. 43–44). They do not elaborate on their reasons but it may have to do with the assumption that MMW do not penetrate skin deeply, which has been proven false (see Part 1 and below).

With 5G in mind, ICNIRP (2020) also addressed the subject of special “transition frequency” [19]—the frequency at which the measurement quantity changes—regarding local RF restrictions. Prior to 2020, the ICNIRP SAR was used up to 10 GHz (vs. FCC’s 6 GHz), while power density was used above 10 GHz. They noted that the different quantities are used because SAR may underestimate superficial exposures at higher frequencies, whereas power density may underestimate deeper exposures at lower frequencies. As a pragmatic approach, ICNIRP reduced the transition frequency from 10 to 6 GHz to “… provide the most accurate account of exposure overall” [19].

ICNIRP’s 2020 update [16–19] includes new allowances for 5G that many find disturbing [20, 42–45]. The new guidelines allow higher power densities above 6 GHz that replaced the SAR values, larger temperature increases in localized areas that may exceed thermal thresholds for both short and long periods of time, and divide skin into different types with different allowances (Type-1 tissue includes all tissues in the upper arm, forearm, hand, thigh, leg, foot, pinna and the cornea, anterior chamber and iris of the eye, epidermal, dermal, fat, muscle, and bone tissue. Type-2 tissue includes all tissues in the head, eye, abdomen, back, thorax, and pelvis, excluding those defined as Type-1 tissue). ICNIRP adheres to a thermal-effects-only model and now indicates assumed safety with increases to 5 °C in skin, the cornea and iris, and bones, as well as a 2 °C increase in brain temperatures on an indefinite basis. Their 1998 guidelines only allowed a 1 °C maximum increase for localized tissue and overall body temperature. Their rationale for the increased 2020 allowances stated that the 1998 safety margins were too conservative. For comparisons between ICNIRP’s 1998 and 2020 allowances, see ICNIRP [19], and charts in Leszczynski [46] as well as Hardell et al. [20].

In the U.S., there has been significant longstanding pressure from industry over the years to harmonize FCC standards with ICNIRP—an action that FCC has resisted. As of this writing, which excludes any new standards pertinent to 5G being adopted, the current FCC standards are still more stringent in some frequency bands, exposures, and time allowances than ICNIRP’s [47].

Other countries have adopted more stringent standards than FCC or ICNIRP based on different health criteria orientation—some more precautionary than others [25, 48]. There are calls to disband ICNIRP [49] as well as numerous lawsuits in various states of deposition against the U.S. FCC regarding NEPA enforcement (see below), federal preemptions in favor of industry over local/state infrastructure review and siting [50], and the adequacy of FCC’s exposure standards [51]. A 2021 court ruling found that the FCC’s decision terminating its inquiry into the adequacy of the RF health standards was unlawful [51]. There are other significant issues—such as the defunding of the U.S. EPA for nonionizing EMF research and oversight—that are mentioned in this 2021 case [11].

What wildlife may be experiencing

At a 100–200 ft (30.5–61 m) distance from a cell phone tower/base station (i.e., antennas or antenna arrays), a person or animal moving through the area can be exposed to a power density of 0.001 mW/cm^2 (i.e., 1.0 μW/cm^2). The SAR at such a distance can be 0.001 W/kg (i.e., 1.0 mW/kg) for a standing man. Throughout this three-part series, we defined low-intensity exposure where effects are seen to RFR for power density at 1 μW/cm^2 and a SAR of 0.001 W/kg. The reason for using such a very low level is to show that biological effects have been widely observed much lower than at the 4 W/kg used in standards setting. (For extensive tables of studies that match these low levels, see Part 2, Supplement Tables 1–4).

Many biological effects have been documented at low intensities comparable to what the population—and therefore wildlife—experience within 200–500 ft (61–152 m) of a cell tower [21]. These can include effects seen in *in vitro* studies of cell cultures and *in vivo* studies of animals after exposures to low-intensity RFR. Reported effects include: genetic, growth, and reproductive alterations; increases in permeability of the blood brain barrier; stress protein increases; behavioral changes; molecular, cellular, and metabolic alterations; and increases in cancer risk (see Part 2 Supplement 3 for broad animal effects and Supplement 4 for flora effects).

Unlike field research, *in vitro* and *in vivo* laboratory studies are conducted under highly controlled circumstances, often with immobilized test animals, typically at near-field exposure, for set durations, at specific frequencies and intensities. Extrapolations from laboratory research to species in the wild are difficult to make regarding uncontrolled far-field exposures, other than, for example, to seek possible correlations with laboratory-observed DNA, behavioral, or reproductive damage. In the wild, there is more genetic variation and mobility, as well as variables that confound precise data assessment. There are also numerous variables like orientation toward the generating source, exposure duration, animal size, species-specific physical characteristics, and genetic variation that also come into play. Assessments for wildlife may vary considerably depending on abundant factors.

It is highly likely that the majority of wildlife species are constantly moving in and out of varying artificial fields. Although precise exposure data are difficult to estimate, there is a growing body of evidence that finds damage to various wildlife species near communications structures, especially where extrapolations to, or measurements of, radiation exposure have been made [52–63].

The introduction of 5G broadband using frequencies in the mid-MHz through mid-GHz millimeter wave (MMW) bands—radiating from both land and satellite-based transmitters in urban, suburban, and rural/forested areas —has the ability to impact numerous species at very low intensities based on several mechanisms. These involve a plethora of unique magnetoreception factors in non-human species, depending on taxonomy, size, season, and habitat (see Part 2). Some of these include resonance factors and intense heating effects for some insect species as insects do not dissipate heat and therefore have no thermoregulatory compensatory responses; interference with orientation in some insect and bird species based on the presence of natural magnetite and cryptochrome in their physiologies that enable complex interactions with the Earth's geomagnetic fields and sunlight for all their life's activities; and adverse die-off effects in flora such as trees in close proximity to infrastructure like small cells, to name but a few (see Parts 1 and 2 and their Supplements for a more thorough analysis). 5G's effects on insects alone have the ability to create holes in critical food webs affecting all other species, and ultimately humans.

The exposure allowances used by FCC and ICNIRP are already higher in the MMW bands to be used in 5G. This is based on whole human body resonance factors and partly on efficient skin absorption—estimated at 90–95% MMW incident energy absorbed in human skin [64]. But this simplistic assessment does not factor in that skin tissue—human and some non-human species alike—contains critical structures like blood and lymphatic vessels, nerve endings, collagen, elastin fibers, and hair follicles, as well as sweat, sebaceous, and apocrine glands. MMW effects to skin have been found to be considerable in glandular tissue with multiple cascading effects throughout the human body even without deep penetration [65]. One study by Cosentino et al. [66] found effects to unilamellar vesicles made of phospholipid—or lipid vesicles—with decreased cell membrane water permeability and partial dehydration of the cell membrane, as well as cell membrane thickening/rigidity seen at 52–72 GHz at incident power densities of 0.0035–0.010 mW/cm^2. Human sweat ducts in particular may act as coiled helical antennas and propagate MMW energy as a waveguide deep into the body at these higher frequency exposures causing uniquely higher SARs [67] not reflected in today's standards. Where there are similar physical characteristics in other species, the above information would also apply.

Because of sub-millimeter depths of penetration in skin tissue with MMW, "superficial" SARs as high as 65–357 W/kg are possible. Eyes are of particular concern in all species. MMW frequencies penetrate less than 1/64 of an inch (0.4 mm)—about the thickness of three sheets of paper. That is thick enough to penetrate deeply into thin-skinned amphibian frog and salamander species, for instance, as well as most flora, and is more than half the depth of some small insects that are primary food sources for other species. The wavelength of MMWs is shorter (about 1/8th inch or 3.2–5 mm long) than microwaves used in cell phone/WiFi technology at 2.4 GHz (6.3 inch or 12.5 cm). The shorter the wavelength, the higher the energy density per wavelength unit. In this case, with MMWs it is about 25 times higher than with cell technology microwaves [68]. This means MMW are capable of resulting in significant damage throughout the biome, including possibly to all flora and fauna present, but effects are not due to wavelength alone. The multiple biological effects from intense energy absorption at very short wavelengths—e.g., in human skin cells or any thin-skinned species, and especially in insects that lack efficient heat dissipation—may cause intense heating with concomitant cellular destruction and organism death. Many of these effects are independent of power density, and therefore not covered by current regulations which are power-density and/or SAR-based. In other words, thermal exposure standards that may protect humans against heating have the ability to cause thermal damage to other species with more extreme consequences.

There are other interesting environmental characteristics regarding MMW. For instance, Betskii et al. [69] pointed out that MMW radiation, unlike other frequencies, is virtually absent from the natural environment due to strong absorption by the atmosphere. The authors hypothesized that low-intensity MMW may have broad nonspecific effects on biological organisms and that vital cell functions may be governed by coherent electromagnetic EHF waves. Their study results found alternating EHF/MMWs were used for interaction between adjacent cells, thereby interrelating and controlling intercellular processes in the entire organism. Other authors [70–73] expounded on the idea that because MMW are absent in the environment, living cells may make specific and dedicated use of them. While these ideas are theoretical, they may plausibly explain the high MMW sensitivity observed in biological subjects (see Part 1), especially in human therapeutic applications which have long been popular in Russia.

MMW below 100 GHz are maximally absorbed by water vapor (H_2O) at 24 GHz, and by oxygen (O_2) at 60 GHz [74–76], raising the possibility that 5G could destabilize the climate even more than current trends, especially from satellite transmission. Rain, foliage, and other things easily attenuate MMW signals so 5G must operate at higher power density, as well as utilize different modulation characteristics such as phasing to enhance signal propagation's penetration through physical objects like building walls. At 60 GHz, 98% of transmitted energy is absorbed by atmospheric oxygen. As far back as 1997, the FCC issued a report [74] on MMW propagation characteristics, noting that between 200 MHz and 95 GHz, there was significant signal loss at 40 GHz due to foliage (see Part 1), as well as resonant matches for atmospheric water vapor at 24 GHz and oxygen at 60 GHz.

Despite this, the FCC has already licensed the buildout of 5G in the 24, 28, 37, 39, and 47 GHz ranges thus far with higher bands extending above 95 GHz allocated for future use. FCC has also allocated MMW from 57.05 to 64 GHz for unlicensed use; ICNIRP may follow. Concerns include both land-based networks as well as satellite transmissions. By the time satellite transmissions reach the Earth's surface, the power density is low (see Part 1) but with 5G's phased array signals, the biologically active component is in the waveform, not power density alone. There is no research to predict how this will affect wildlife in remote areas but given what is known about extreme sensitivity to EMFs in many species, it is likely that effects will occur and likely go undetected. Even weak signals from satellites using phased array characteristics may be a significant contributor to species effects in remote regions (see Part 1 and Part 2, Supplement 3).

Much of the research on MMW and phased array with accompanying unusual biological effects—e.g., precursor formation capable of causing deep nonlinear body penetration (see Part 1)—has been done in lossy materials like water. We therefore have models to suggest that 5G may have particular effects not only on insect populations (due to resonance factors) and amphibians (due to thin membranes and deep body penetration) but also in some aqueous species since water is a highly conductive medium. Both aqueous environments and the high water content in living organisms may make MMW exposures particularly unique due to the way MMWs propagate though water with virtually no impedance [77–82].

In addition, Betskii and Lebedeva [83] described the complex hypothetical mechanism that stochastic resonance (see Part 2) may play in very sensitive water-containing biological species to very-low intensity EMF (in μm ranges) based on the generation of intrinsic resonance frequencies by water clusters that fall between about 50 and 70 GHz. When biological species are exposed to extremely weak EMF at these frequencies, their water-molecule oscillators can lock on to the external signal frequency and amplify the signal by means of synchronized oscillation or regenerative amplification. Since MMWs pass through aqueous media almost without loss but also with high absorption, in the process they are capable of deep penetration involving internal tissue and organ structures. The researchers summarized a long list of MMW effects that included EHF strong absorption by water and aqueous solutions of organic and inorganic substances; effects to the immune system; changes in microbial metabolism; stimulation of ATP (adenosine 5′-triphosphate) synthesis in green-leaf cells; increases in crop capacity (e.g., pre-sowing-seed treatment); changes in certain properties of blood capillaries; stimulation of central nervous system receptors; and the induction of bioelectric responses in the cerebral cortex. Biological effects were dependent on exposure site, power flux density, and wavelength in very specific ways. In addition, low-intensity MMWs were detected by 80% of healthy people, but perception was asymmetrical. Peripheral applications were found to affect the spatiotemporal organization of brain biopotentials, resulting in cerebral cortex nonspecific activation reactions. MMW-induced effects are perceived primarily by the somatosensory system with links to almost all regions of the brain. The authors also discussed water and aqueous environments' unique role on MMW effects, which induce convective motion in the bulk and thin fluid layers and may create compound convective motion in intra and intercellular fluid. This can result in transmembrane mass transfer and charge transport can become more active. EHF can also increase protein molecule hydration. The theory of stochastic resonance playing a mechanistic role in the effects noted in the above study deserves further investigation given its known function in non-human species perception abilities that are used for survival (see Part 2).

And then there's the role of unique wildlife magnetoreceptor cells. Akoev et al. [84] studied MMW effects to the specialized electroreceptor cells called Ampullae of Lorinzini in anesthetized rays (an elasmobranch fish) and found that the spontaneous firing in the afferent nerve fiber from the cells could be enhanced or inhibited by MMWs at 33–55 GHz continuous wave (CW). The most sensitive receptors increased firing rates at intensities of 1–4 mW/cm^2, which produced less than a 0.1 °C temperature increase. The authors emphasized they were not observing just a MMW bioeffect but rather a specific response to that frequency range by a unique electro-receptor cell. This one study points out the inadequacy of assuming that MMW's superficial skin penetration is enough to base exposure-standard extrapolations to nonhuman species (For an extensive reviews of other MMW studies pertinent to wildlife, see Parts 1 and 2).

In wildlife, especially small thin-membrane amphibians like frogs and salamanders, even at penetration less than 1/64 of an inch (0.4 mm), deep body penetration would result. In some insect species that would equal deadly whole body resonance exposure [85]. In a study, Thielens et al. [86], modeled three insect populations and found that a shift of just 10% of the incident power density to frequencies above 6 GHz would lead to an increase in absorbed power between 3 and 370% in some bee species, possibly leading to behavior, physiology, and morphology changes over time, ultimately affecting their survival. Insects smaller than 1 cm showed peak absorption at frequencies above 6 GHz. In a 2020 follow-up study of RFR, Thielens et al. [87] used *in-situ* exposure measurements near 10 bee hives in Belgium and numerical simulations in honey bee (*Apis mellifera*) models exposed to plane waves at frequencies from 0.6 to 120 GHz—frequencies carved out for 5G. They concluded that with an assumed 10% incident power density shift to frequencies higher than 3 GHz, this would lead to an RFR absorption increase in honey bees between 390 and 570%—resulting in possible catastrophic consequences for bee survival.

In birds, hollow feathers have piezoelectric properties that would allow MMWs to penetrate deep within the avian body cavity [88, 89]. 5G's complex phased MMWs may also be capable of disrupting crucial biological function in other species and critical ecosystems with broad effects throughout their entire food webs. In addition, the top end of these ranges reach infrared (IR) frequencies, some of which are actually visible to other species, especially birds, and could impede their ability to sense natural magnetic fields necessary for migration [90] as well as other crucial aspects of avian life.

Any assumed wildlife protection in exposure standards for humans is purely hypothetical at the ecosystem level. Chronic long-term, low-level ambient exposures to MMWs are yet to be studied but some extrapolations can be made based on the extensive database that does exist (see Parts 1 and 2, plus Supplements). FCC rules do not require an Environmental Assessment (EA) for new towers, for example, unless a proposed structure can be proven to negatively affect birds or other species federally listed as threatened or endangered (see below). EAs as currently applied can include effects from physical tower placement itself, but not typically RFR exposures. As a result, no one is required to assess ambient environmental EMF effects, let alone answer questions about impacts to other species from such technologies (see the Section "Discussion: synthesis of linear and nonlinear disciplines needed" below for some reasons why this situation exists at the federal level). There is a critical hole in our regulatory environmental apparatus when it comes to electroecology.

Regulations and laws pertinent to EMF

There are several significant U.S. federal environmental statutes and their implementing regulations intended to protect wildlife and their habitats. All potentially apply directly or indirectly to the impacts created by EMF if we choose to use these statutes in that capacity. In some cases, treaty protocols and international laws also extend to Canada, Mexico, Russia, and elsewhere. Some states, provinces, counties, and cities also have similar laws in place but space precludes detailed listing here. The focus of the sections below is on key U.S. federal laws and those of Canada and Europe that could incorporate EMF into assessment considerations.

The Endangered Species Act of 1973

While the Migratory Bird Treaty Act of 1918 (MBTA)—discussed in detail below—is the oldest U.S. environmental wildlife protection law, having been enacted over 100 years ago, the Endangered Species Act (ESA) of 1973 (16 U.S.C. 1531 et seq). [91] is considered the key U.S. environmental statute. The ESA is intended to recover plant and animal species from extinction, preventing further extinctions or extirpations, and provides subsequent protections including at ecosystem levels. ESA has been amended many times over the years[1] [92]. Somewhat like the MBTA, ESA was designed to implement an international protocol called the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) [93], which

1 To view the entire contents of each section of the Endangered Species Act of 1973 as amended and to click on a section title below that corresponds with your interest see: https://www.fws.gov/endangered/laws-policies/esa.html. Many section pages include audio or slideshow summaries that provide a more general overview of that section. Or to download the entire Act or individual sections in PDF format from US FWS's document library, go to: https://www.fws.gov/endangered/esa-library/index.html.

itself was designed to protect plant and animal species worldwide through restrictions on such trade.

ESA was implemented to protect all plant and animal species listed as threatened or endangered, and to protect habitats designated as critical. ESA also contains provisions for designating species as *candidates* under Section 4(b)3(A) [94] for possible future threatened or endangered status—i.e., listings that may have been warranted but precluded for one reason or another, or are in need of additional population assessment before determinations can be made. While the process is supposed to be based strictly on sound scientific review and findings, politics have often impacted listing decisions. Nevertheless, since its passage in 1973, some 1,400 plant and animal species have been afforded protections, with many on the path to recovery (e.g., grizzly bears and gray wolves) or fully recovered (e.g., Bald Eagles and Peregrine Falcons). ESA is a longstanding highly successful environmental law.

The ESA is administered by two agencies: The U.S. Fish and Wildlife Service [95] and the U.S. National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) [96]. U.S. FWS maintains a worldwide ESA list of threatened and endangered species and is responsible for overseeing terrestrial and freshwater organisms, including four species of marine mammals—i.e., manatees, polar bears, walrus, and sea otters. The NMFS oversees all ESA listed marine wildlife, including large and small cetaceans, sea turtles, and anadromous and steelhead salmon, as well as some flora critical to marine wildlife survival such as Johnson's sea grass which is important for shelter and sea bottom nursery habitat.

All oversight agencies use the ESA as part of their enforcement toolkit.

The ESA regulations make it illegal to kill, harm or otherwise "take" a listed species. ESA definitions include:

- **"Take":** A "taking" under ESA is defined as to "… harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct."
- **Endangered:** A species is listed as: endangered if it faces a significant risk of extinction in the near foreseeable future throughout all or a significant portion of its range.
- **Threatened:** A threatened species is defined as at risk of becoming endangered in the near future.

The ESA and its implementing regulations include a detailed consultation process. Under Sections 7 and 10 [97, 98] the regulations can authorize "incidental or accidental take." Under Section 7, a federal agency must consult with either U.S. FWS or NMFS (depending on the species and/or habitat affected) and specifically provides that, "… each federal agency shall, in consultation with and with the assistance of the U.S. FWS or NMFS, insure that any action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species which is determined to be critical" [97]. Further, the "action agency," meaning the agency that retains discretionary federal control and is responsible for its actions on the environment, must determine at the earliest possible time whether any listed species or critical habitat may be affected in any manner by the proposed action. In the case of RFR, the FCC is the action agency whose licensing effects from EMFs on ESA-listed migratory birds, for example, must be addressed. That includes radiation from any communications tower, device, or whole communications networks. More specifically, the action agency must consider the *potential* risks/impacts from RFR emitted from towers or other sources. Unfortunately, such determinations have yet to occur for wildlife at FCC. (For an inventory of listed species, see reference [99]).

Under Section 10 of the ESA, private landowners can develop their own habitat conservation plans, which must be approved by U.S. FWS. These may also allow for some level of "take" of listed species [100]. Under Section 11 [101], citizens can file lawsuits against U.S. FWS or NMFS for actions they deem illegal under the statute and such suits may proceed if litigants prove they have legal standing (For some examples of legal suits brought by the Department of Justice, see reference [102]).

For decades, the ESA—a most significant law—has been challenged by politicians, numerous industries, and some public segments, including Congressional attempts to defund the programs altogether. But the ESA is vitally worth protecting and has stood the test of time thus far.

The Migratory Bird Treaty Act (MBTA) of 1918

The Migratory Bird Treaty Act of 1918 [103], as amended, is over 100 years old and still among the most effective laws protecting avian species [26]. Migratory birds—those that migrate across U.S., Canadian, Mexican, and/or Russian borders, of which 1,093 species are currently protected in the United States [104]—are a public trust resource that belong to every U.S. citizen. Almost all native North American continental birds are protected by the MBTA. Exceptions include the Wild Turkey, Asian Pheasant, Lesser and Greater Prairie Chicken, other grouse species, European Starlings, English Sparrows, and Monk Parakeets (among others) which have been accidentally or intentionally introduced to the U.S. The ESA also addresses birds [105].

The MBTA implements/regulates bilateral protocols with Canada, Mexico, Japan, and Russia regarding the shared migratory bird resources of the U.S. and its treaty partners [26]. It is a strict *prima facia* liability statute, meaning that proof of criminal *intent* in the injury or killing of birds is not required by U.S. FWS or the Department of Justice for cases to be made. The statute currently protects migratory birds, their parts, eggs, feathers, and nests, with migratory bird nests protected during the breeding season, while eagle nests are protected year-round. A federal permit is required to "possess" a migratory bird and its parts, but the MBTA contains no provisions for the accidental or incidental "take" (i.e., causing injury or death) of a protected migratory bird, even where normal, legal business practices or personal activities are involved. Bird death, injury, and crippling loss are the only "takings" that matter under the MBTA, not the circumstances under which they occur, although those circumstances can certainly come under investigation.

When the MBTA was enacted, Congress was serious and intended the "take" of even one protected migratory bird to be a violation of the statute, sometimes backed by extensive fines and criminal penalties [26]. Examples include: the 1999 Moon Lake Electric Cooperative fined $100,000 for electrocuting migratory birds; the 2009 criminal settlement with PacifiCorp for $10,500,000 for electrocuting birds (the final settlement resulted in $400,000 in fines, $200,000 restitution to the State of Wyoming, and $1,900,000 to the National Fish and Wildlife Foundation for eagle conservation); and the 2012 settlement agreement with Duke Energy Wind Facility for $1,000,000 for bird deaths from wind turbine blade collisions. All of these settlements involved several years of probation for company executives, and required significant improvements to facilities (an author of this paper was involved with these criminal cases while at the U.S. FWS) [26].

Unfortunately there were recent potentially serious erosions of the legal interpretations involving MBTA. Up until 2017, companies could be fined under criminal misdemeanor provisions when steps to avoid or minimize "take" of birds were not implemented—especially if U.S. FWS's Office of Law Enforcement had made requests to proponents to avoid/minimize dangers and such recommendations were ignored or minimally implemented. In late 2017, the former Trump Administration refused to enforce the MBTA for so-called "accidental or incidental take," while only enforcing provisions for poaching (illegal harvest) and illicit trade in birds and their parts in its then new legal opinion (M-37050). But on March 8, 2021, under a new Administration, the U.S. Department of the Interior withdrew M-37050 after a U.S. District Court invalidated the rollback of the MBTA [106] (One of the authors of this paper was involved in these court cases).

The MBTA has no consultation process like that under ESA's Section 7, and it does not authorize "incidental or accidental take" which ESA does under ESA Sections 7 and 10 [26, 97, 98]. Where "take" was likely to occur under MBTA, various agencies, entities, and individuals were working proactively with U.S. FWS (especially its Office of Law Enforcement, Ecological Service Field Offices, and Division of Migratory Bird Management) to implement all necessary and appropriate steps to avoid or minimize any future damage to birds. MBTA was intended to protect all migratory birds—no excuses accepted but solutions were appraised by U.S. FWS officials—while the ESA allowed some room to negotiate and remediate. But M-37050, as discussed above, until it was invalidated by the court and withdrawn by the Department of the Interior [106], completely upended that protective balance, demonstrating how fragile some of these longstanding effective laws can be due to political caprice. Both the ESA and MBTA could pertain to ambient EMF if applied that way.

Birds of Conservation Concern: how U.S. agencies track non-listed but imperiled migratory birds

There are two primary ways that U.S. federal agencies keep track of birds. In addition to ESA-listed birds, the U.S. FWS maintains the list of Birds of Conservation Concern (BCC) [107]. There are currently at least 147 species designated nationally of the 1,093 species now protected and the number grows with each BCC update [104]. When U.S. FWS regional lists are included in the overall tally, there are some 272 BCC species (>26% of all protected birds) designated in trouble [104]. BCC lists require periodic reviews/updates under provisions of the Fish and Wildlife Conservation Act (16 U.S.C. 2901–2912) [108]. The overall objective of the U.S. FWS is to maintain bird populations at stable or increasing numbers—a daunting challenge due to both direct and indirect impacts, including EMFs discussed in detail in Part 2. The BCC list is designed to serve as an early warning system of birds in trouble but not yet candidates for listing under the ESA [26]. A species designation on the BCC list could impact both infrastructure siting as well as potentially measured or modeled/projected rising ambient EMF levels in some regions (see Part 1).

Federally listed bird species are those protected under the ESA. On the List of Threatened and Endangered Species, there are currently 77 endangered and 15 threatened birds [104]. An endangered species faces significant risk of extinction in the near foreseeable future throughout all or a significant portion of its range, while a threatened species is at risk of becoming endangered in the near future. Extinction is irreversible and permanent.

Collectively, migratory birds are in decline, some precipitously (see Part 2), with numbers of both listed and BCC species increasing [26, 107]. With 272 BCC-designated species and 92 Federally Endangered and Threatened migratory birds, out of 1,093 protected migratory birds, at least 364 (>33%) species are in trouble. Those numbers continue to increase at a sizable rate and once a bird population is in trouble, reversing its decline is extremely difficult [26, 109, 110]. The MBTA has no provisions for acquiring and protecting bird habitats although there have been bilateral discussions between the U.S., Canada, Mexico, Japan, and Russia that have resulted in some bird habitat protection efforts.

Other protections: presidential Executive Order 13186—Migratory birds, and The Bald and Golden Eagle Protection Act

In January 2001, the Migratory Bird Executive Order 13186 [111] was signed by President Clinton. It stipulates that, "… each Federal agency taking actions that have, or are likely to have, a measurable negative effect on migratory bird populations …" is to develop and implement a Memoranda of Understanding (MOU) "… to promote the conservation of migratory bird populations." Simply put, if the actions of a federal agency are now, or will in the near future, impact bird populations, that agency is to sign and implement an MOU with the U.S FWS in an effort to protect migratory birds and their habitats [26]. While many of the previous Executive Orders in place from the Clinton, Bush, and Obama administrations were rescinded by the Trump Administration, E.O. 13186 was not among them. An executive order from the White House does not have the full force of a law implemented by the U.S. Congress, but in this case E.O. 13186 does have the force of the MBTA clearly backing it. E.O. 13186 provides specific opportunities for habitat protection, land management, and conservation planning. U.S. FWS has the responsibility under the E.O. to protect migratory birds and their habitats.

In addition to protections under the MBTA, the U.S. FWS is also responsible for maintaining stable and/or increasing breeding populations of Bald (*Haliaeetus leucocephalus*) and Golden (*Aquila chrysaetos*) Eagles under The Bald and Golden Eagle Protection Act [112, 113]. The definition of "take" under BGEPA is broader than under MBTA, and includes provisions against pursuit, shooting, poisoning, capturing, killing, trapping, collecting, molesting, and disturbing both species (ref. [112], 50 C.F.R. 22.3). Permits are required from U.S. FWS for "disturbance take" and "take resulting in mortality" (ref. [112], 50 C.F.R. 22.26), and for "take of nests" (ref. [112], 50 C.F.R. 22.27). Disturbing, injuring or killing eagles without an "eagle take" permit under BGEPA could result in criminal culpability. Any infrastructure-related EMF effects to Bald or Golden Eagles would be actionable under these regulations.

The National Environmental Policy Act: how it applies to environmental EMF and categorical exclusions

The second most iconic U.S. environmental law, after the ESA, is the 50 year old National Environmental Policy Act [114, 115]. Among the most effective laws ever passed, it was signed by President Nixon in 1970 and has become an important means for protecting wildlife in the face of large government actions. As such it is a constant target for various industries regulated by the government, most recently the telecommunications industry seeking exemptions from the FCC for any effects from their operations, including RFR [50].

NEPA has been applied to any major federal, state, or local project where a federal regulatory nexus or action is involved, including actions taken by federal agencies themselves. This includes:

- Where federal funding had been, is, or will be used.
- Where a permit has been issued by a federal agency.
- Where work or action by a federal agency has been contracted for a project [26].

Courts have also expanded the purviews of NEPA. In addition, the NEPA legislation established the Council for Environmental Quality (CEQ) which is housed within the U.S. Executive Office of the President to advise the President on the state of the environment and environmental policy.

The primary role of NEPA rules is to establish national environmental policy and to determine the regulations that require all federal agencies to prepare EAs, and/or Environmental Impact Statements (EISs) that accompany official reports and/or recommendations whenever they are submitted to Congress for funding. A vast array of federal agencies is involved in NEPA review/compliance, including agencies like the Environmental Protection Agency (EPA) and U.S. FWS.

Unlike MBTA and BGEPA, which are both strict liability statutes (see above), NEPA regulations have no criminal or civil penalties or sanctions. As such, all enforcement of NEPA must go through the courts which may order a federal agency to require a proponent to perform NEPA-compliant analysis and performance. This would include, for instance, compliance with the previously described bird protection laws where migratory birds could be impacted by EMF and other radiation exposures.

To effectively apply NEPA, an evaluation is required of the relevant environmental effects of a federal project. For instance, in the case of environmental EMFs, assessing the impacts of 5G on wildlife (including insects and migratory birds), NEPA review should be performed by the FCC before instituting any rulings that would facilitate 5G buildout, or an evaluation of an action mandated by NEPA where the "nexus" conditions apply. This process begins when an agency or commission, such as the FCC or the Federal Energy Regulatory Commission, develops a proposal that addresses the need to take an action. If that action is covered under NEPA, three levels of analysis are required by the action agency (i.e., the agency with responsibility for its action on the environment) for that action to be in compliance with NEPA. These include where applicable:

- Preparation of a CatEx.
- Preparation of an EA.
- The determination of either a Finding of No Significant Impact (FONSI) or …
- The preparation/release of an EIS if there will likely be significant impact to species or habitats.

Because NEPA allows public review and comment on these documents and the process, this provides a venue for litigation and possible court action.

A CatEx [116] is a list of actions that an agency has determined do not individually or cumulatively significantly affect the quality of the human environment ([116], 40 C.F.R. §1508.4). A lot of things can slip through the cracks with such exclusions. The "quality of the human environment" represents a key phrase in interpreting NEPA. As such, if a proposed action such as the use of 5G and its impacts on wildlife were to be included in an agency's CatEx—say by FCC and U.S. FWS—the agency must ensure that no extraordinary circumstances might cause the proposed action to affect the environment (in this case, humans and wildlife). Extraordinary circumstances include negative effects/impacts on endangered species, protected cultural sites, and wetlands. If the proposed action is not included in the description provided in the CatEx, an EA must be prepared and can be published in the *Federal Register*, which allows the public to comment, and if necessary, to litigate. (Notice of all EISs must be published in the Federal Register; some, but not all, agencies choose to also publish notice of EAs—no absolute requirements to do so exist. The Council of Environmental Quality [CEQ] regulations also do not mandate notice of EAs—only EISs).

The release of an EA and a FONSI represent specific public documents which include information on the need for a proposal, a list of alternatives, and a list of agencies and persons consulted in the drafting of the proposal. "The purpose of an EA is to determine the significance of the proposal's environmental outcomes and to look at alternatives for achieving the agency's objectives. An EA is supposed to provide sufficient evidence and analysis for determining whether to prepare an EIS, aid an agency's compliance with NEPA when no EIS is necessary, and it facilitates preparing an EIS when one is necessary." [115, 116].

If it is determined that a proposed federal action does not fall within a designated CatEx or does not qualify for a FONSI, then the responsible agency—which in the case of 5G buildout would involve the FCC with significant input from U.S. FWS—must prepare an EIS. The purpose of an EIS is to help public officials make informed decisions based on the relevant environmental consequences and the alternatives available.

From the information presented in Parts 1 and 2 of this paper and elsewhere, the environmental consequences of 5G and rising background levels of RFR could be catastrophic to some species. The drafting of an EIS includes public parties, outside parties, and other federal agency input concerning its preparation. These groups subsequently comment on the draft EIS. However, the FCC has systematically categorically excluded many devices and current technologies that use RFR, as well as ruling that their exposure standards extend to 5G exposures [4, 117], thus allowing their use/buildout to proceed without full NEPA/EIS review.

Even when NEPA has been applied to an RFR exposure situation, there have been problems. Part 1 included discussion of a U.S. military training proposal throughout a protected wilderness area that involved a lengthy, but ultimately inadequate, NEPA review with the U.S. FWS (see Part 1 for further details). What that case revealed was the necessity for environmental agencies to have their own inhouse bioelectromagnetics expertise with knowledge of nonionizing radiation effects to wildlife—something now lacking throughout regulatory agencies. In light of continuing new information, to do otherwise fosters large loopholes through which entire networks of low-power infrastructure can avoid larger environmental review.

It is important to note, as described above, that all small cells intended for 5G deployment, are categorically excluded by the FCC, thereby bypassing NEPA requirements despite significant studies (see Part 2) of adverse effects to all taxa that would apply for review under EAs, and EISs. Part 1 explored measured levels from the 1980s to today's measured rising background RFR that should also apply to NEPA review, given the expansion of a large new technology like 5G about to make its own significant contribution. Instead, FCC categorically excluded small cells from NEPA without any examination of the unique signaling characteristics of 5G that are new to broadband telecommunications technology in the built environment, or 5G's higher frequencies to be used widely at significant scale that may especially impact insects and birds (see above, "Government exposure standards"). Instead, FCC ruled that states and municipalities must streamline small cell network applications and buildouts without NEPA [117]—a position that was successfully challenged in U.S. courts [50].

At the moment, NEPA requirements still stand. But other suits challenging FCC's small cell streamlining without also updating their exposure standards were less successful [118]. Under the former Trump Administration, industry-friendly legislation was introduced [119] that would have excused the FCC from all NEPA review as a matter of course. No other federal agency with the ability to impact the environment had ever gotten such a pass. The bill did not succeed but such an attempt again demonstrates the fragility of these iconic environmental protections.

Canada's environmental laws and regulations: Species at Risk Act, and Migratory Birds Convention Act

In conjunction with U.S. laws that are observed across borders, Canada has some strong regulations of its own such as the Species at Risk Act and the Migratory Birds Convention Act (MBCA).

The Species at Risk Act, known as SARA [120], is similar in many respects to the U.S. ESA. SARA encourages the various government entities in Canada—e.g., Provincial, Federal, First Nations, territorial, county, city, town, and fort—to cooperate in protecting wildlife species in Canada. SARA also includes protocols for consultation and cooperation with Aboriginal/First Nations peoples which Canada views as essential to successfully implementing the statute.

Like the U.S. ESA, SARA can affect entities or individuals who own property or have a vested interest in land where a species at risk (designated in the List of Wildlife Species at Risk [121] is found at any time throughout the year. The statute also defines critical habitat, designated in the SARA Public Registry [122]. Like the purposes of the ESA, SARA is intended to prevent wildlife species in Canada from disappearing; to recover wildlife species extirpated (i.e., no longer found in the wild in Canada), endangered or threatened as a result of human activity; and to manage species of special concern so as to avoid threatened or endangered designation [123]. To accomplish these purposes and goals, SARA establishes how governments, organizations, and individuals in Canada should work together, and establishes guidelines for implementing a species assessment process to ensure the protection and recovery of species. Like the ESA, SARA incorporates penalties for violations; and like NGOs in the U.S. that support/publicize specific issues pertaining to threatened and endangered species, Canada also has NGOs doing the same thing [124].

Canada's Migratory Birds Convention Act (MBCA) of 1994

As with the U.S.'s MBTA, the vast majority of bird species in Canada are protected by the 1994 MBCA [125]. Passed in 1917 and updated in 1994 and 2005, MBCA implements the Migratory Birds Convention, a treaty signed with the United States in 1916. The Canadian Federal government is authorized to pass, implement, and enforce Migratory Bird Regulations [126] designed to protect the species included in the Convention. The lists of bird species protected by Canada and the U.S. may be different. Bird species that are not listed in Canada or the U.S., and/or defined under Article 1 of the MBCA, may or may not be protected by Provincial or territorial legislation, or by SARA, or the UN Convention on Biological Diversity [127] which is an international legal instrument for "… the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" that has been ratified by 196 nations [128].

Persons, industries or other entities making any decisions (e.g., installing cell towers) that would impact the protected status of a bird species in Canada should also consult SARA. Environment and Climate Change Canada requires that three criteria be met to qualify for the list of bird species protected in Canada under the MBCA. They include:

(1) Birds designated in Article 1 of the MBCA as amended under the 1995 Protocol [128].
(2) Species native or naturally occurring in Canada noted under regulations.
(3) Species known to regularly occur in Canada. Although species that occur infrequently (i.e., “accidentals”) and that meet criteria 1 and 2 are not included on this list, they continue to be considered as having protection under the MBCA any time they occur in Canadian territory.

While birds such as grouse, quail, pheasants, ptarmigan, and turkeys—which also in the U.S. are not migratory and/ or have been introduced (e.g., pheasants)—are not protected under MBCA nor the MBTA, in Canada birds such as hawks, owls, eagles, falcons, cormorants, pelicans, crows, jays, kingfishers, and some species of blackbirds are also not protected under MBCA. This represents a significant difference between MBTA protection in the U.S., and eagle protection under the U.S. Bald and Golden Eagle Protection Act (discussed above) where all birds in the latter category are protected in the United States.

There are three introduced bird species that do not meet criterion 2 above, but continue to appear on the MBCA list. They include the Mute Swan (*Cygnus olor*), the Eurasian Collared-Dove (*Streptopelia decaocto*), and the Sky Lark (*Alauda arvensis*). Environment and Climate Change Canada [128] continues to consult with provincial and territorial governments, which share responsibility for the management of birds in Canada, regarding a proposal to remove these species from the list of MBCA birds. Until a decision is reached by the concerned parties, these three species will remain under MBCA protection. The list of birds protected under the MBCA follows the American Ornithologists’ Union’s Check-list of North American Birds, and its supplements to 2014, on matters of taxonomy, nomenclature, and sequence [129].

European environmental laws: European Union (EU) initiatives addressing endangered species and habitat protection

The EU, with its 27 member nations, has recently implemented a four-pronged approach to better address species protection, recovery, and restoration of imperiled plants and animals found on the continent [130, 131]. This includes:

– Species protection through a Birds Directive.
– Species protection under a Habitats Directive.
– Ensuring that plants and animals are not threatened by illegal and/or unsustainable international wildlife trade through stronger implementation of CITES—the Convention discussed above [93].
– Developing and implementing an EU pollinators initiative to reverse negative impacts to pollinators including effects from EMF/RFR [132].

The EU began an ambitious effort in 2011 to develop and implement a Biodiversity Strategy to institute the framework for this four-pronged approach above. The Strategy includes the following targets:

(1) Protect 100% more habitats and 50% more species above 2011 levels.
(2) Establish green infrastructure and restore at least 15% more ecosystems.
(3) Achieve more sustainable agriculture and forestry.
(4) Make fisheries more sustainable and the seas healthier.
(5) Combat invasive alien species.
(6) Help stop or reverse the global loss of biodiversity.

At this writing, the EU may still be on track to achieve their strategy, although progress calls for a much greater effort among all parties involved, and the transition from BREXIT is creating many difficulties, unknowns, and complexities [130–132].

It is clear that all industrialized Western countries are trying to address serious environmental issues with more and/or less success—depending on politics, funding, and the will to act. EMF as an environmental pollutant needs to be part of that effort.

Airspace as habitat: aeroecology

Birds, bats, insects, and other species that use airspace for critical life functions are of cornerstone significance to us all. Birds, for instance, provide key ecosystem functions that fuel multi-billion dollar industries through pollination and insect/weed/seed control in the agribusiness sector, as well as in the forestry industries. Without migratory birds, there would be untold problems and money spent globally for more pesticides, herbicides, and other chemicals. In addition, in the U.S. alone, feeding, photographing, and observing birds fuels a $32 billion annual recreation industry, representing 20% of the U.S. adult population engaging in these activities. Human/bird-related activities are reportedly more popular than golf [26, 133].

Birds also have spiritual significance to indigenous peoples. A number of migratory bird species—notably Bald and Golden Eagles, Common Ravens (*Corvus corax*), American Crows (*Corvus brachyrhynchos*), hawks, falcons, doves, owls, and hummingbirds—are revered and protected by the Tribal laws of several U.S. indigenous American Tribes and Canadian First Nation peoples. Some of these very species are at considerable risk from habitat disturbance/fragmentation, injury, and death, including from EMF and other radiation impacts which will undoubtedly increase exponentially without a change in human awareness.

We have a legal, moral, and ethical obligation to protect migratory species of every kind, the airborne included. Impacts from EMF may add to species declines and ultimately threaten their survival if we do not understand and respond appropriately because airspace is as critical a habitat as are water and soils for non-airborne species. Thus far we have failed to muster the macroscale vision of the air-as-habitat concept that also includes flora, which are exquisitely sensitive to the ELF of the Earth's geomagnetic fields with their root systems underground as well as to RFR with their primary stem and leaf growth in the air (see Part 2 and Part 2 Supplement 4). Humans have collectively done a poor job of addressing impacts to living organisms that use the airspace—most especially migratory birds, bats and beneficial insects—along with being negligent in protecting what is on, as well as below, the ground, and in aqueous environments. We need to understand EMF as a form of energetic air pollution, especially biologically active anthropogenic RFR that is endemic today in airspace.

Defining the habitat of airspace

The airspace used by plants and animals includes the space just above ground level (AGL) to ceilings in excess of 26,245 ft (8 km) AGL. These upper ranges are used, for example, by Demoiselle Cranes (*Grus virgo*) and other migratory bird species, as well as Golden Eagles which prey on the cranes and other quarry. But airspace should be considered as habitat for a variety of plants and animals too that use and depend on it during, and in some cases throughout, significant portions of their lives. These living organisms include, but are not limited to, flying insects, some arachnids, birds, bats, flying squirrels, flying fish, and some reptiles, as well as seeds, spores, vegetative plant parts, and forest canopies. Organisms use airspace for purposes of transport, dispersal, feeding, mating, territorial defense, escape, migration, daily movements, and for other reasons [134]. In most cases, unimpeded airspace is critical to mating, nesting, survival, food acquisition, territorial defense, daily movements, and migrations of birds and bats (including microchiropterans and megachiropterans) [27, 109, 110].

Impacts to species using airspace have been well documented, including of migratory birds and communication towers and their guy-wire support structures [135]—annual mortality now conservatively estimated at 6.8 million birds killed in the U.S. and Canada solely from collisions with communication structures [136–139]. However, the impacts to migratory birds, other wildlife, and plants generally do not include adequate cumulative effects analyses (cumulative biologically and under the legal mandates of NEPA). Cumulative effects under NEPA must consider and evaluate all impacts from all human-built structural sources including EMFs that they may emit and/or receive, where applicable.

Currently, environmental impacts from RFR on wildlife are not being assessed by the FCC, EPA, or the Department of Interior (DOI), nor is ELF-EMF being considered by the Department of Energy (DOE) regarding powerline exposures. However, it is important to note that precedent was set in 2014 when DOI publicly charged that the FCC's standards for RFR from cellular towers were outdated, based on narrow thermal heating effects, and inadequate to protect migratory birds and other wildlife [139]. A letter from DOI's Director of the Office of Environmental Policy and Compliance was sent in February 2014 to the National Telecommunications and Information Administration (NTIA), housed in the Department of Commerce [140]. The letter—and subsequent meetings with staff from the U.S. FWS—resulted in the initiation of an EIS process under NEPA by NTIA to begin an independent research study to address the impacts of radiation from cell towers on migratory birds using the airspace. Unfortunately, efforts languished and were completely suspended under the former Trump Administration with nothing similar initiated subsequent to that as of this writing. Under NEPA, cumulative effects must include impacts from all human-related sources that affect humans, wildlife, plants, and all living organisms that depend on/use airspace for survival. The effects of EMF on flora and fauna remain widely unassessed [27, 110].

Air as an actual habitat is a relatively new concept for many in the scientific community, including federal agencies such as U.S. FWS whose goal (including for wildlife that use the airspace) has been to "do no harm" [141]. Reducing harm to wildlife that use the airspace is a tall order because a lot of things occupy it—both permanently and on a temporary basis—but we do not generally think of it that way. Airspace interference and adverse effects to wildlife comes in many forms. For instance, in addition to the communication-tower bird-collision mortality estimates referenced by Longcore et al. [138] above, Manville [142] estimated that 440,000 protected migratory birds were killed annually by blade strikes at U.S. commercial wind energy facilities in 2008. Smallwood [143] increased that estimate to 573,000 bird fatalities per year (including 83,000 raptor deaths) based on increases in commercial wind turbines, and estimated that an additional 888,000 bats died in turbine blade collisions annually in the U.S. In addition, based on the variety of survey methods used, differences in survey detail, longevity of assessment, and robustness, as well as differences in infrastructures being investigated, Loss et al. [144] estimated between 8 and 57 million birds are killed annually by collisions with power distribution and transmission lines, and between 0.9 and 11.6 million birds die from wire and infrastructure electrocution each year in the U.S. This is not to mention the estimated 1.4–3.7 billion birds (median = 2.4 billion) killed annually in the U.S. by domestic and feral cats at ground level and/or near-ground while birds are in flight [145]; or the annual estimated 97.6–976 million U.S. bird deaths from building window collisions [146] which Klem and Saenger [147] later estimated was greater than any other source of human-associated bird mortality. Taken collectively, this is massive anthropogenic-caused avian mortality, all of which occurs within the airspace. There are reduction strategies for some of these—like keeping domestic cats indoors and/or placing bells on their collars, installing non-reflective window panes, and using vertical axis designs in wind turbines—but these do not substantially solve the problem. ELF and RFR problems can only be handled at the transmission source through use reduction. Approaches that use frequencies such as radar to repel birds only create an additional ambient source capable of affecting another species, such as insects, in a different way.

The staggering avian mortality rates noted above fail to include impacts from pesticides, contaminants, oil spills, disease, parasites, natural mortality, predators, entanglement, and other non-airspace related sources. Impacts to individual animal and plant species are cumulative. The potential role that EMF plays in adverse effects to animals that use the airspace should be added to the list as a growing concern based on evidence presented throughout this three-part series of papers, and elsewhere.

Aeroecology—a macrovision

The interdisciplinary field of aeroecology has evolved to encompass a variety of issues affecting airspace. The concept was founded around 2008 by Dr. T.H. Kunz, Professor of Biology and Director of the Center for Ecology and Conservation Biology at Boston University who sadly died from Covid-19 complications in April 2020. Kunz laid out an aeroecology vision that includes technological solutions for studying animals that use the aerosphere as well as the key questions that unite aeroecology. Frick et al. [148] wrote an excellent review of this emerging unifying discipline.

Aeroecology integrates domains that include atmospheric science, animal behavior, ecology, evolution, earth science, geography, computer science, computational biology, and engineering [134, 149, 150].

In 2008, Kunz and colleagues organized a symposium in San Antonio, Texas, entitled, "Aeroecology: Probing and Modeling the Aerosphere: the Next Frontier." At that symposium and since, the concept evolved to define the field, including:

- The aerosphere comprises one of the three major components of our biosphere, yet it is one of the least understood substrata of the troposphere, especially in regard to how organisms interact with and are influenced by this highly variable and fluid environment [134].
- The biotic interactions and physical properties in the aerosphere provide significant selective pressures that influence the size and shape of organisms, as well as important influences affecting their behavioral, sensory, metabolic, and respiratory functions.
- While organisms that spend their entire lives on land or in the water tend to be less varied based on adaptive pressures, organisms that use the airspace can be immediately affected by the changing boundary layer conditions of the airspace.
- These conditions include winds, air density, oxygen concentrations, precipitation, air temperature, sunlight, polarized light, and moonlight, as well as geomagnetic and gravitational forces [134].

The authors of this paper would add to that growing list the impacts of ELF and RFR to organisms that use the airspace at varying durations and intensities.

The discipline of aeroecology allows us to better assess the impacts from anthropogenic factors affecting wildlife that use the airspace—ranging from nearly all, or significant portions of their lives, to minimal amounts of time. While no organism spends its entire life in the aerosphere, anthropogenic factors located within, or that directly or indirectly affect, the aerosphere can have significant impacts. These anthropogenic factors, for example, include skyscrapers, office buildings, homes, structural lighting, city/community lighting, power transmission and distribution wires and infrastructure, radio/television/cellular/emergency broadcast communication towers and structures, commercial wind turbines, industrial solar arrays (especially 'power' towers and large solar panel facilities), bridges, aircraft, air pollution, increases in greenhouse gases, climate change, and radiation emitted from communication structures and related devices, among others [26, 137]. Staff at U.S. FWS emphasized the importance of airspace as habitat, and garnered the attention of top service officials to respond through improved voluntary guidance addressing the various industries impacting airspace.

To study the impacts of communication structures on migratory birds (including from RFR), the U.S. Forest Service invited the Division of Migratory Bird Management at U.S. FWS, to design and develop a research protocol to study towers in several national forests in Arizona. While the protocol, which was written by one of the authors of this paper while at the U.S. FWS [151], would benefit from updating and peer-review, it nevertheless provides a framework for independent studies of EMF impacts to migratory birds, mammals, and other wildlife and plants in the field.

It is important that future studies be conducted by independent scientific sources without vested interests in the outcome. Such inquires clearly fall under the auspices of aeroecology. We first need the vision and will to move this forward.

Discussion: synthesis of linear and nonlinear disciplines needed

Nonionizing EMF is virtually uncontrolled as an environmental pollutant. This was observed as far back as the 1970s [152] and has only gotten progressively worse with each passing decade. There are several reasons for this, including the likelihood that in many regulatory agencies there is an assumption that the science is not robust or adequately developed upon which to base regulations, much less enforce them. There is also a pervasive attitude that risks to wildlife, if any, are minor compared to the human benefits of widespread wireless technology. Technology is seen as beneficial in many environmental circles for the information it can provide, for instance, via animal tracking devices (see Part 1), while potential adverse effects that create hidden variables from such devices rarely occur to environmental researchers. The need to study EMF effects is not obvious to many regulators or environmentalists. That may change once air is understood as 'habitat' and EMF is seen as an energetic pollution source.

Wildlife has also historically been considered resilient (despite much evidence to the contrary) and nonionizing radiation has been seen as relatively harmless beyond tissue heating and electric shock. If non-human species have been considered at all regarding EMF, broad but inaccurate assumptions have been made that protecting humans from the worst adverse effects also extend to other species. What has been lacking is the right government agency expertise with an understanding of how non-human species interact with exogenous EMFs, and at what intensities. There has never been funding in any agency to track or develop that area of interdisciplinary knowledge because the need was not obvious until recently. Other than at the FCC which is mostly staffed with engineers who lack knowledge of biology, civil scientists who are trained in bioelectromagnetics and/or biophysics are found throughout many regulatory agencies. Their work, however, is primarily focused on human health issues, not wildlife. Agencies tasked with wildlife protection have been completely defunded for such work—i.e., the U.S. FWS which does not have a bioelectromagnetics expert on staff, and most importantly the U.S. EPA which at one time had the world's foremost bioelectromagnetics basic research laboratory staffed with scientists who made groundbreaking discoveries (see Part 2, Mechanisms). Many agencies have simply not replaced what little bioelectromagnetics expertise they have had when those scientists retire and new ones have not been trained or hired. And it is only recently that environmental nonionizing radiation has increased to measurable levels high enough to warrant investigation to all living beings. Europe, for instance, is now taking an interest in potential 5G effects and developing standards that apply to wildlife protection [153].

One aspect of rising environmental EMF levels may, however, spur attention—the shadow role it could be playing in global climate change. Scientists know that what occurs in the ionosphere directly affects our weather patterns—of sudden importance given the dramatic increase in satellites being deployed globally for 5G telecommunications (see Part 1). Erratic weather and its consequences have grown to dangerous levels in most parts of the world. Thunderstorms increased 25% over

North America between 1930 and 1975, vs. between 1900 and 1930 [154]. That period directly parallels our first introduction of environmental EMFs along with other contaminants. As far back as 1975, a team of researchers at the Stanford University Radioscience Laboratories, then headed by Robert Helliwell, found evidence that powerline emissions are amplified within the magnetosphere [155], causing a veritable rain of electron precipitation into the ionosphere, which could theoretically lead to both highly localized as well as global changes in weather patterns. The technologies we have added since 1975—both ELF and RFR—which we assumed to be atmospherically benign, may not be as harmless as originally thought. The exponential growth planned for 5G broadband (including MMW) from satellites and millions of accompanying ground-based transmitters is certainly reason for caution. It is already well established that MMW bands at 60 GHz are maximally absorbed by atmospheric oxygen (O_2), as well as by H_2O at 24 GHz—ranges planned for 5G (see Part 1). Oxygen molecules readily absorb the 60 GHz frequency range and rain droplets easily attenuate signals [74–76, 156, 157]. In fact, at 60 GHz, 98% of transmitted energy is absorbed by atmospheric oxygen. This makes that frequency spectrum good for short-range transmission but no one understands how a large infusion of RFR in that band—or any other—may affect atmospherics. It could be highly destabilizing (see Part 1).

There is a need to re-integrate biology, which studies whole dynamic living systems, with the non-living sciences of physics and engineering that focus on how to create and make technology work. The latter have dominated EMF research and its applications in every way since the 1940s, including research protocols regarding human health and standards setting which are outside their areas of expertise. Today, physics and biology—although fundamentally very different disciplines with their own inherent cultures and biases—increasingly converge when it comes to environmental concerns. While we already understand how to make modern societies and accompanying technologies work, the most important questions now concern the potential effects to the living systems in the path of technology.

Electromagnetism is fundamental to life—indeed all living things function with biological microcurrent without which life would not exist. Technology, which also requires EMF to function, therefore speaks the same fundamental language as living cells. Yet biologists have consistently been left out of full participation in safety and environmental issues in anything other than cursory inclusion. If there is to be a better integration of physics and biology, it will need to be at the behest of the biology community. The physics/engineering disciplines have had the subject to themselves for decades and are somewhat territorial about it. Plus their inherent focus is on linear cause-effect dosimetry models in both technology design and exposure standards setting. They tend be less interested in the confounding complexities of biology which are mostly nonlinear and unpredictable.

The natural world typically demonstrates nonlinear dynamics, meaning that a small stimulus can result in a large, seemingly disproportionate outcome. The weather is nonlinear, for instance, as illustrated by the imagined "butterfly effect" in which a butterfly can theoretically flap its wings in Indonesia and cause a hurricane on the other side of the globe [158–160]. Some disease states are nonlinear, allergies being a prime example. A person with a severe peanut allergy can go into anaphylactic shock by merely being in the same room with the offending agent. Or someone with an allergy to bees, upon experiencing a sting, will react far out of proportion to the tiny amount of venom being injected by the insect. Physics and engineering, on the other hand, are highly linear—an exemplary asset in that realm. Humanity, after all, has no patience for machines or systems that don't work [161].

Until there is a synthesis between physics/engineering and biology, with an emphasis on nonlinear models, the potential environmental effects of our increasing EMF exposures will not be well understood. Each area has much to learn from the other. Biologists can benefit from the precision emphasized in physics and engineering while physicists and engineers can benefit for the savvy that biologists have acquired in environmental observation, measurement, quantification, hypothesis testing, and formulating policy in the face of scientific uncertainty.

Given the rising background levels in urban, rural, and some wilderness environments, EMF should be classified as an energetic air pollutant capable of adversely affecting wildlife and habitats as delineated throughout these papers. Cumulative effects should be taken into consideration from myriad sources, and continuing evidence should be evaluated by unbiased entities, including governments and NGO's. We can no longer presume that the status quo of ever-increasing EMF ambient levels is safe without much closer scrutiny.

Some solutions

Existing environmental laws in the U.S., Canada, and throughout Europe should be enforced. For example, in the U.S., NEPA and its EISs should be required each time a new broadly polluting EMF technology like 5G is introduced, not as the current policy is being interpreted through

"CatEx" or simple dismissal. EISs should be required for all new technologies that create pervasive ambient EMF such as 'smart' grid/metering, Distributed Antenna Systems (DAS), small cell networks, and the 5G "Internet of Things." Where wildlife species are affected, systems and networks that currently meet radiation levels for CatEx (and are therefore exempt from review) should be required to develop/implement NEPA and EIS reviews for cumulative exposures to wildlife from multi-transmission sources.

Efforts should begin to develop acceptable exposure and emissions standards for wildlife, which today do not exist. Setting actual exposure standards for wildlife will be an enormous challenge, and for some species there may be no safe thresholds, especially with 5G and MMW. We may simply need to back away from many wireless technologies altogether, especially the densification of infrastructure, and refocus on developing better dedicated wired systems in urban, suburban and rural areas. Environmentally sensitive wilderness areas should be considered off limits for wireless infrastructure. Once air is seen as 'habitat,' there may come a time when a cell phone call voluntarily *not made* will be understood as removing something detrimental from air's waste-stream, the way we now see plastic bags regarding terrestrial/aquatic pollution.

There are some reasonably simple things that can be done in the ELF ranges that would benefit insect, bird, and many wild mammal and ruminant species. For example, high-tension electric utility corridors can be built or changed to cancel magnetic fields with different wiring configurations. This is already widely done in the industry for other reasons but it also coincidentally eliminates at the source at least the magnetic field component for wildlife. There are other approaches too but further discussion is beyond the scope of this paper.

Research into the long-term, low-level ambient exposures to humans and wildlife is imperative given the picture that is emerging. There is a likelihood that low-level ambient EMF is a factor, or co-factor, in some of the adverse environmental effects we witness today—many previously discussed in this series of papers. There is currently no research in any industrialized country that looks to the broader implications to all flora and fauna from these rising background levels, even as effects to individual species are observed. This is an important, emerging environmental issue that must be addressed.

Conclusions

In this broad three-part review, we sought to clarify if rising ambient levels of EMF were within the range of effects observed in *in vitro, in vivo*, and field studies in all animal phyla thus far investigated. We further discussed mechanisms pertinent to different animal physiology, behavior, and unique environments. The intention was to determine if current levels have the ability to impact wildlife species according to current studies. The amount of papers that find effects at today's EMF levels to myriad species is robust. Some unusual patterns did emerge, including broadly in flora that react beneficially to static EMF but adversely to AC-ELF and especially to RFR.

There is a very large database supporting the hypothesis that effects occur in unpredictable ways in numerous species in all representative taxa from modern ambient exposures. Associations are strong enough to warrant caution. New enlightened public policies are needed, as well as existing laws enforced, reflecting a broader understanding of non-human species' interactions with environmental EMF. Emerging areas, such as aeroecology, help define airspace as habitat and bring better awareness of challenges faced by aerial species—including animals and plants. But we are in the nascent stages of understanding the full complexity and detailed components of electroecology—the larger category of how technology affects all biology and ecosystems.

Historically, control over the realm of nonionizing radiation has been the purview of the physics and engineering communities. It is time that the more appropriate branches of biological science, specializing in living systems, stepped up to fill in larger perspectives and more accurate knowledge. We need to task our technology sector engineers to create safer products and networks with an emphasis on wired systems, and to keep all EMF exposures as low as reasonably achievable.

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REVIEW

Genetic effects of non-ionizing electromagnetic fields

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ABSTRACT

This is a review of the research on the genetic effects of non-ionizing electromagnetic field (EMF), mainly on radiofrequency radiation (RFR) and static and extremely low frequency EMF (ELF-EMF). The majority of the studies are on genotoxicity (e.g., DNA damage, chromatin conformation changes, etc.) and gene expression. Genetic effects of EMF depend on various factors, including field parameters and characteristics (frequency, intensity, wave-shape), cell type, and exposure duration. The types of gene expression affected (e.g., genes involved in cell cycle arrest, apoptosis and stress responses, heat-shock proteins) are consistent with the findings that EMF causes genetic damages. Many studies reported effects in cells and animals after exposure to EMF at intensities similar to those in the public and occupational environments. The mechanisms by which effects are induced by EMF are basically unknown. Involvement of free radicals is a likely possibility. EMF also interacts synergistically with different entities on genetic functions. Interactions, particularly with chemotherapeutic compounds, raise the possibility of using EMF as an adjuvant for cancer treatment to increase the efficacy and decrease side effects of traditional chemotherapeutic drugs. Other data, such as adaptive effects and mitotic spindle aberrations after EMF exposure, further support the notion that EMF causes genetic effects in living organisms.

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Introduction

This is a review on studies on the genetic effects of non-ionizing electromagnetic fields (EMF). We will concentrate on two parts of the EMF spectrum which are common in our environment: static and extremely low-frequency electromagnetic fields (ELF-EMF) and radio-frequency radiation (RFR).

Studies are summarized in Supplements 1 (RFR) and 2 (static/ELF-EMF). Basically, there are two types of studies: genetic damages and gene expression. The research covers a wide area of biological systems: both in vitro and in vivo involving many animal and cell models, and various exposure conditions. First, a few words have to be said on the exposure set-ups used in these studies. It is relatively easy to set up a reliable exposure system for static and ELF-EMF. Most exposure systems used these studies are generally satisfactory. However, it is difficul to set up good exposure systems for RFR studies. In my opinion, most set-ups are relatively satisfactory, considering that there is no perfect guideline on what is a good system. However, preferably, incident power density and specific absorption rate should be provided in each study. These are generally lacking when telecommunication devices, such as cellular phones, are used in a study. It becomes difficul to compare the results of these studies with other studies using exposure systems. It is not totally without merit to use these devices for studies. If properly set up, these devices provide more realistic exposure parameters. A general problem is that some researchers generally showed ignorance on the independent variable, i.e., EMF, that they worked on.

Regarding biological measurements, with few exceptions, the researcher are generally knowledgeable in the methodology used. However, there are studies that showed that the researchers are not familiar with the methodology that they used in their studies. An example is the use of the “Comet assay” to determine DNA strand breaks. 31% of the studies listed in Supplements 1 and 2 used the “Comet assay”. A few words have to be said on it. Different versions of the assay have been developed. These versions have different detection sensitivities and can be used to measure different aspects of DNA strand breaks. A comparison of data from experiments using different versions of the assay may be misleading. Another concern is that most of the ‘comet assay’ studies were carried out by experimenters who had no prior experience on the assay. My experience with the ‘Comet assay’ is that it is a very sensitive assay and requires great care in performing. Thus, different detection sensitivities could result from different

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experimenters, even following the same procedures. One way to solve this experimental variation problem is for each researcher or laboratory to report their sensitivity of the 'Comet assay', e.g., threshold of detecting strand breaks in human lymphocytes exposed to x-rays. This information is generally not available from the EMF-genotoxicity studies. However, in one incidence, an incredibly high sensitivity was even reported (Malyapa et al., 1998), suggesting the inexperience of the researchers on the assay.

Supplements 1 and 2 show that the majority of studies reported genetic effects of EMF (66% for RFR and 79% for static/ELF-EMF). Thus, it is safe to conclude that genotoxic effects of EMF have been reported. The most common effects found are: DNA strand breaks, micronucleus formation, and chromosomal structural changes. There are not many studies on mutation. Thus, it is not known whether these genotoxic effects transform into mutation and involved in carcinogenesis. Interestingly, available data do not suggest mutagenic effect after RFR exposure (Chang et al., 2005; Meltz et al., 1990; Ono et al., 2004; Takahashi et al., 2002); whereas most static/ELF-EMF studies (Chahal et al., 1993; Mairs et al., 2007; Miyakoshi, 1997; Miyakoshi et al., 1998, 1996; Potenza et al., 2004; Wilson et al., 2015) suggested some mutagenic effects. Another interesting speculation is that ELF EMF acts as a promoter of cancer in the presence of an initiator by modulation of signaling pathways involved free radicals and apoptosis (Lacy-Hulbert et al., 1998). Such a possibility has not been well investigated.

There are similarly many studies that showed changes in gene expression after EMF exposure (Supplement 3). Changes in expression of many different genes have been reported. Studies in gene expression by static/ELF-EMF are far more diversified that those of RFR. The most interesting results are the expression of genes related to stress response both in vitro and in vivo in plans and animals. Another important finding is the expression of heat shock proteins, particularly HSP70, which is an important protein involving in protein misfolding and protecting cells from environmental stress.

The data point to four areas of interest: involvement of free radicals, effects at low-intensity of exposure, contributions of exposure parameters and biological system being studied, and interaction with other entities. Let us look at each of these four topics.

Involvement of free radicals (Citations of references in italic in this section are in Supplements 1 and 2)

Effects of EMF on cellular free radical processes have been reported in many experiments (cf. Lai, 2019; Yakymenko et al., 2016). It is conceivable that an increase in free radicals in cells could cause macromolecular damages including DNA. There are many reports on involvements of free radicals in genetic processes, including both reactive oxygen species and reactive nitrogen species: **RFR** – *Agarwal et al., 2009; Alkis et al., 2019a, b, 2021; Bektas et al., 2020; Bourdineaud et al., 2017; Burlaka et al., 2013; De Iuliis et al., 2009; Duan et al., 2015; Gajski and Garaj-Vrhovac 2009; Garaj-Vrhovac et al., 2009, 2011; Guler et al., 2010; Gürler et al., 2014; Houston et al., 2019; Kesari et al., 2011, 2014; Khalil et al., 2012; Kumar et al., 2010; Lai and Singh, 1997; Li et al. 2018: Liu et al., 2013a, b; Luukkonen et al., 2009; Manta et al. 2017; Magha et al., 2015b; Meena et al. 2014; Millenbaugh et al., 2008; Odacı et al., 2016; Pandey et al., 2017; Pandey and Giri, 2018; Qin et al., 2019; Sahin et al., 2016; Shahin et al., 2013, 2019; Sharma and Shukla, 2020; Sokolovic et al., 2015; Sun et al. 2017; Tkalec et al., 2013; Vafaei et al. 2020; Varghese et al., 2018; Veerachari and Vasan, 2012; Vilić et al., 2017; Wang et al., 2015; Wu et al., 2008; Xu et al., 2010; Yakymenko et al., 2018; Yao et al., 2008; Zong et al. 2015; Zothansiama et al., 2017;* **Static and ELF EMF** – *Alcaraz et al., 2014; Amara et al., 2007b; Ashta et al., 2020; Hosseinabadi et al., 2020; Bertea et al., 2015; Bułdak et al., 2012; Consales et al., 2018; Dong et al. 2019; Jajte et al., 2001; Jouni et al., 2012; Kimsa-Dudek et al. 2018; Kindzelskii and Petty, 2000; Lai and Singh, 1997b, 2004; Li et al., 2001; Luukkonen et al., 2014; Rageh et al., 2012; Shokrollahi et al., 2018; Solek et al., 2017; Wang et al., 2020; Wolf et al., 2005; Yin et al., 2016; Yokus et al., 2008; Yuan et al., 2020; Zhang et al., 2016*. Brief descriptions of these reports are in Supplements 1 and 2. However, changes in cellular free radical and genetic processes do not imply a cause–effect relationship. A convincing argument on direct involvement of free radicals on EMF-induced genetic changes comes from data showing that the effects could be blocked by free radical scavengers (e.g., antioxidants) e.g., see Lai and Singh (*1997; 2004*). The free radicals involved probably include both reactive oxidative species (ROS) and reactive nitrogen species (RNS) (*Lai and Singh, 2004*). RNS (e.g., nitric oxide) have longer mean free path than ROS (e.g., hydroxyl radical) and could cause more widespread cellular molecular damages. Nitric oxide can further enhance iron-mediated free radical formation via its effects on iron metabolism and release of iron from ferritin (Reif and Simmons 1990; Richardson and Ponka 1997) that generates ROS via the Fenton reaction. Nitric oxide can either be mutagenic or cytotoxic. It is mutagenic when the intracellular level of reduced glutathione is low, but cytotoxic (leading to apoptosis and inhibition of tumor growth) in a thiol-rich environment that favors the formations of toxic nitrosothiols (Felley-Bosco 1998). These situations could occur under EMF exposure.

The mechanisms on how EMF affects free radicals in cells are not known. There are various speculations. Readers may be interested to take a look at these publications: Barnes and Greenebaum (2015); Binhi and Prato (2017); Davila et al. (2005); Dodson et al. (2013); Hore (2019); Hore and Mouritsen (2016); Kirschvink et al. (2001); Landler and Keays (2018); Sheppard et al. (2017); Sherrard et al. (2018); and Sisakht et al. (2020).

Furthermore, it has to be pointed out that EMF-induced genetic effects have been observed without free radical changes *(Alcaraz et al., 2014; Ferreira et al., 2006; Furtado-Filho et al., 2014)* and free radical changes without genetic effects *(Frahm et al., 2006; Senturk et al., 2019; Tiwari et al., 2015; Tomruk et al., 2010)* have also been reported. This may imply that mechanisms other than free radicals are involved,

Effects at low exposure intensities

There are many reports of genetic effects induced by low intensities of EMF. The studies are listed in Supplement 4. This is an important topic to consider since living organisms are being constantly exposed to low levels of EMF in the occupational and public environments. This is particularly true for ELF-EMF, since intensities of ELF-EMF in the environment are in microtesla (μT) levels, even exposure to fields from electrical appliances rarely exceed 10 microtesla (i.e., 0.01 mT). However, most laboratory cell and animal studies in ELF-EMF used fields in the millitesla (mT) level.

A survey of level of RFR in the environment of various countries (Amoako et al., 2009; Aris et al., 2020; Bhatt et al., 2016; Dhami, 2012; Dode et al., 2011; Estenberg and Augustsson, 2014; Firlarer et al., 2003; Frei et al., 2009; Hardell et al., 2016, 2017; Henderson and Bangay, 2006; Joseph et al., 2008, 2010; Kim and Park, 2010; Kurnaz and Aygun, 2020; Lahham and Hammash, 2012; Lahham et al., 2015, 2017; Sagar et al., 2018; Tell and Kavet, 2014; Thuroczy et al., 2006; Urbinello et al., 2014; Viel et al., 2009; Waldmann-Selsam et al., 2016) gave a mean power density level of 0.00259 mW/cm^2 and median of 0.000545 mW/cm^2. Reports (Abuasbi et al. 2018; Al-Badi, 2012; AL-rajhi, 2014; Eskelinen et al., 2002; Ilonen et al., 2008; Lindgren et al., 2001; Röösli et al., 2011) on the levels of magnetic fields in the human environment came up with a mean level of 0.0036 mT and median level of 0.00062 mT. Much higher exposure levels could be found in occupational situations. Operators and technicians in a power plant could be exposed to 0.0126 mT, whereas the magnetic field level in the vicinity of a power transmission line could be as high as 0.0482 mT (Hosseinsbadi et al., 2020).

Besides genetic effects, other physiological processes have also been reported to be affected by low-intensity EMFs, e.g., **RFR**: retarded development of frog (Balmori, 2010; 88.5–1873.6 MHz cell phone base station emission; 0.00859–0.00325 mW/cm^2); slowing of circadian rhythm in cockroach (Bartos et al., 2019; broadband RF noise; 0.000429 mT); changes in electrical activities in rat sciatic nerve (Comelekoglu et al., 2018, 1800-MHz RFR; 0.00421 W/kg); delayed growth in rose (Grémiaux et al., 2016; 900 MHz RFR; 0.00072 W/kg); retarded memory in rat (Nittby et al., 2008; 900 MHz GSM signal; 0.0006 W/kg); adrenal gland stimulation in rat (Perov et al., 2019; 171 MHz RFR; 0.0006 W/kg); human blood mononucleus cells showed higher immunological activates (Szymanski et al., 2020; 0.024 W/kg) (see also the Table in Lai, 2018 on low-intensity effect on neurological functions); **static and ELF-EMF**: decreased number of living and quality of movement of sperms of mouse (de Bruyn and de Jager, 2010; 50-Hz MF 0.0005–0.077 mT) and free radicals (see Table 1: „Free radical effects observed at low intensities of static and ELF-EMF" in Lai, 2019, effects have been observed with exposure to a 50 Hz MF of 0.0005 mT). In addition, mechanisms have evolved for organisms to detect very low levels of static EMF, e.g., 26 nT (i.e., 0.000026 mT) in honey bees (Kirschvink et al., 1992); 20 microV/cm in platypus (Manger and Pettigrew, 1996); and 2–3 nT in songbird (Pakhomov et al., 2017). These capabilities of detecting very low-intensity static/ELF EMF fields is actually not surprising because they are results of evolution over millions of years to enable the survival of the species. On the other hand, these functions are much vulnerable to disturbance from recent man-made EMF. However, it is a little surprising that RFR at very low intensity could also cause biological effect. The RFR studied are mostly man-made and have only existed in the environment in the last several decades. This points to a possibility that EMFs (RFR and static/ELF EMF), in general, act on some common unknown basic biological mechanisms.

Interaction effects (citations of references in italic in this section are in supplements 1 and 2)

Another important observation of the studies is that EMF can interact with other entities and synergistically cause genetic effects. These entities include:

RFR: Chemical mutagens (*Baohong et al., 2005*); ultraviolet ray (*Baohong et al., 2007*); 17-β-estradiol (*Cervellati et al., 2013*); bee venum (*Gajski and Garaj-Vrhovac, 2009*);

garlic (*Gurler et al., 2014*); γ-radiation (*He et al.,* 2017*; Ji et al.,* 2016*; Jiang et al.,* 2013); clastogens (*Kim et al., 2008);* incoherent electromagnetic noise (*Lai and Singh, 2005; Wu et al., 2008; Yao et al., 2008*); lipopolysaccharide (*Lameth et al., 2020; Zuo et al., 2015*); mitomycin C (*Maes et al., 1996; Sannino et al.,* 2011,2017*; Zeni et al.,* 2012*a; Zhang et al., 2002*); x-rays (*Manti et al., 2008; Gapeyev et al., 2014;* Sannino et al., 2014); aphidicolin (*Tiwari et al., 2008);* picrotoxin (*López-Martín et al., 2009*); bleomycin (*Koyama et al., 2003;* Zong et al., 2015) and doxorubicin (*Zhijian et al., 2010*).

Static – and ELF-EMF: Zinc (*Amara et al., 2007*); Tremozolomide (*Ashta et al., 2020*); Cisplastin (*Buldak et al., 2012; El-Bialy et al., 2013; Chen et al., 2010; Mahmoudinasab and Saadat, 2018a; Sanie-Jahromi and Saadat, 2017; Sanie-Jahromi et al., 2016*); Bleomycin (*Cho et al., 2007; Sanie-Jahromi and Saadat, 2017*); Gadolinium (*Cho et al., 2014*); alkaline-ph (*Fan et al., 2018*); natural radioactivity in soil (*Jouni et al., 2012*); sodium fluoride (*Kimsa-Dudek et al., 2018, 2020);* gamma radiation (*Arruda-Neto et al., 2009; Kubinyl et al., 2010; Lagroye and Poney, 1997; Mairs et al.,* 2007); hydrogen peroxide and methyl methane sulfonate *(Koyama et al., 2008*); menadione (*Luukkonan et al., 2011, 2014, 2017; Markkanen et al., 2008*), morphine (*Mahmoudinasab and Saadat, 2018b*); X-ray (Miyakoshi et al., 1996*b; 1999, 2000; Teodori et al., 2014; Udroiu et al., 2015*); Xenobiotics (*Moretti et al., 2005*); lipopolysaccardide (*Nakayama et al., 2016*); heat (*Robison et al., 2002);* N-methyl-N'-nitro -N-nitrosoguanidine, 4-nitroquinoline N-oxide, benzene, 1,4-benzenediol, 1,2,4-benzenetriol (*Scassellati Sforzolini et al., 2004; Villarini et al., 2000);* mineral oil (*Skyberg et al., 2001*); Paclitaxel (*Sun et al., 2012*); IR (*Yoon et al., 2014*); $FeCl_2$ (*Zmyslony et al., 2000*); UV (*Zmyslony et al., 2000*).

Most of the compounds that have been shown to interact with EMF are mutagens. This is important because in real-life situations, a person is usually exposed simultaneously to EMF and many different environmental factors, including mutagens. On the other hand, some of these entities are drugs used in cancer chemotherapy. EMF can possibly be used as an adjuvant in chemotherapy to enhance the anticancer efficac of these drugs and decrease their side-effects. Thus, synergism of these entities with EMF should be further studied.

However, it is important to point out that are reports (listed below) that showed no significant interaction effects

RFR: Mitomycin C (*Hansteen et al., 2009; Kerbacher et al., 1990; Maes et al., 1997, 2000, 2001, 2006; Zhijian et al., 2009*); Adrimycin (*Kerbacher et al., 1990*); x-ray (*Maes et al., 2000; Stronati et al., 2006);* proflavin (*Meltz et al.,* 1990); 3-Chloro-4-(dichloromethyl)-5-Hydroxy-2 (5 H)-furanone (an environmental mutagen) (*Sannino et al., 2009; Verschaeve et al., 2006*).

Static – and ELF-EMF: Methylmethane sulfonate, chromate (*Cantoni et al., 1996*); UV (*Cantoni et al., 1996; Mizuno et al., 2014*); ionizing radiation, H_2O_2, mitomycin C (*Jin et al., 20112, 2014*); IR and H_2O_2 (*Jin et al., 2015; Yoon et al., 2014*); chemical mutagens (*Verschaeve et al., 2011*); heat (*Williams et al., 2006*).

Effects of waveform

Two other important findings of recent studies are that the effects of EMF are waveform specific and cell-type specific (Supplement 5). These findings underscore the complicity of interaction of EMF with biological tissues and may partially explain why effects were observed in some studies and not others. It is essential to understand why and how certain wave-characteristics of an EMF are more effective than other characteristics in causing biological effects, and why certain types of cells are more susceptible to the effect of EMF? The fact that "there are different biological effects elicited by different EMF wave-characteristics" is a critical proof for the existence of non-thermal effects

Wave-from dependency is one of the major puzzlements of Bioeletcromagnetics research. In the 1970s, research in the laboratories of Ross Adey (Bawin et al.,1975; 1978) and Carl Blackman (Blackman et al., 1979) showed the importance of modulations on the EMF-carrier frequency on calcium efflu from cells. Other biological effects of EMF also showed wave-form dependency, e.g., see discussion in Lai (2018) on neurological effects of RFR. And, research presented here also showed similar dependency in EMF-induced genetic effects. So far, there has not been a credible unifying explanation for the "wave-form dependency effect"

Regarding cell-type specificity, one can speculate that: 1. Cells that are metabolic active are more susceptible to EMF effects with an increase in generation of free radical in the mitochondria; 2. Cells that have higher anti-oxidative activities are less susceptible; 3. Transitional elements, e.g., iron, may play a role in the effect via the Fenton reaction (see Lai, 2019). Brain cells contain a relatively high concentration of free iron, particularly intercalated in the DNA molecules, and are more susceptible; 4. Cell cycle arrests are common in cells exposed to EMF. It may be a response to repair genetic damages caused by EMF. If damage could not be repaired, cell death occurs, particularly via apoptosis, which is a common outcome after EMF exposure. These effects are consistent with the gene expression studies, showing activation of genes involved in both cell death and repair. 5. If genetic damaged cells are allowed to survive, cancer may occur. However, if they die, the risk of cancer would actually be reduced. But, other detrimental health outcomes may occur, e.g., death of brain cells could lead to neurodegenerative diseases. Increased incidences of degenerative diseases (including Alzheimer's disease, amyotrophic lateral sclerosis, dementia, and motor dysfunctions) after EMF exposure, particularly under occupational conditions, have been reported (Gervasi et al. 2019; Gunnarsson and Bodin 2018, 2019; Huss et al. 2018; Koeman et al. 2017; Jalilian et al. 2018; Pedersen et al. 2017; Sorahan and Mohammed 2014).

Discussion

The main question is whether EMF exposure could cause genetic effects? It is pertinent here to quote a recent statement made by two prominent bioelectromagnetic researchers (Barnes and Greenebaum, 2020): "The evidence that weak radiofrequency (RF) and low-frequency fields can modify human health is still less strong, but the experiments supporting both conclusions are too numerous to be uniformly written off as a group due to poor technique, poor dosimetry, or lack of blinding in some cases, or other good laboratory practices." All in all, in the studies reviewed in Supplements 1 and 2, approximately 70% of them showed effects. One could say that EMF exposure can lead to genetic changes. Some genetic damages could eventually lead to detrimental health effects. However, the mechanisms remain to be uncovered. But, knowing the mechanism is not necessary to accept that the data are valid. It is also a general criticism that most EMF studies cannot be replicated. I think it is a conceptual and factual misstatement. Replication is also not a necessary and sufficient condition to believe that certain data are true. Scientific studies are hardly replicated. Rational funders do not generally fund replications. All scientists should know that it is very difficul to replicate exactly an experiment carried out by another lab. This is particularly true when the effects of EMF depend on many unknown factors. By the way, not many replication experiments have been carried out in EMF genetic-effect research to justify the statement that "data from EMF are not replicable". In some cases, the experimenters deliberately changed the procedures of an experiment that they were supposed to be replicating and claimed that their experiment was a replication, for example, compare the experimental procedures of Lai and Singh (1995) and Malyapa et al. (1998).

To prove an effect, one should look for consistency in data. Genetic damage studies have shown similar effects with different set-up and in various biological systems. And, the gene expression results (Supplement 3) also support the studies on genetic damages. Expression of genes related to cell differe -tiation and growth, apoptosis, free radical activity, DNA repair, and heat-shock proteins have been reported. These changes could be consequences of EMF-induced genetic damages. In addition, other effects of EMF, such as mitotic-spindle disruption (De Amicis et al., 2015; Hintzsche et al., 2011; Li et al., 2013; Schrader et al., 2011, 2008; Tkalec et al., 2009) and "adaptive" effects, i.e., the ability of concomitant exposure of RFR to decrease the genotoxic effects of other agents, such as ionizing radiation (He et al., 2017; Ji et al., 2016; Jiang et al., 2012, 2013; Sannino et al., 2014, 2017, 2011; Sun et al., 2016; Zeni et al., 2012; Zong et al., 2015) also support the notion that EMF exposure could affect genetic processes in cells. In conclusion, there are enough reasons to believe that genetic effects of EMF are real and possible.

During cell phone use, a relatively constant mass of tissue in the brain is exposed to the radiation at relatively high intensity (peak specific absorption rate (SAR) of 4–8 W/kg). Many papers have reported genetic effect/DNA damage at much lower SAR (or power density) (see Supplement 4). This questions the wisdom of the several exposure standard-setting organizations in using the obsolete data of 4 W/kg (whole-body averaged SAR) as the threshold for exposure-standard setting. Furthermore, since critical genetic mutations in one single cell are sufficien to lead to cancer and there are millions of cells in a gram of tissue, it is inconceivable that some standards have changed the SAR from averaged over 1 gm to 10 gm of tissue. (The limit of localized tissue exposure has been changed from 1.6 W/kg averaged over 1 gm of tissue to 2 W/kg over 10 gm of tissue. Since distribution of radiofrequency energy is non-homogenous inside tissues, this change allows a higher peak level of exposure.) What actually needed is a better refinement of SAR calculation to identify 'peak values' of SAR inside the brain.

Any effect of EMF has to depend on the energy absorbed by a biological entity and on how the energy is delivered in space and time. Aside from influences that are not directly related to experimentation (Huss et al., 2007), many factors could influence the outcome of an experiment in bioelectromagnetics research. Frequency, intensity, exposure duration, and the number of exposure episodes can affect the response, and these factors can interact with each other to produce different effects. In addition, in order to understand the biological consequences of EMF exposure, one must know whether the effect is cumulative, whether compensatory responses result, and when homeostasis will break down. A drawback in the interpretation and understanding of experimental data from bioelectromagnetic research is that there is no general accepted mechanism on how EMF affects biological systems. Since the energy level is not sufficien to cause direct breakage of chemical bonds within molecules, the effects are probably indirect and secondary to other induced chemical changes in the cell. The mechanisms by which EMF causes genetic effects are unknown. This author suspects that biological effects of EMF exposure are caused by multiple inter-dependent biological mechanisms.

Disclosure of Interest

The author declares no conflict of interest

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Supplement 1

Genetic effects of radiofrequency electromagnetic radiation (*study with no effect observed) Study reported effect =237 (66%); study reported no effect = 124 (34%) (Literature up to January 2021).

	Exposure conditions	Results
*Agarwal et al. (2009)	Human semen sample to cell phone radiation in talk mode for 1 h	No significant DNA damage, increase in reactive oxygen species; decrease in sperm motility and viability.
Aitken et al. (2005)	Mice to 900-MHz RFR for 7 days at 12 h/day; SAR 0.09 W/kg	Significant damage to Mitochondrial genome and nuclear β-globin locus in epididymal spermatozoa.
Akdag et al. (2016)	Male Wistar-Albino rats to 2400 MHz RFR from a Wi-Fi signal generator for a year; SAR 0.000141 (min)- 0.007127 (max) W/kg	No significant change in DNA single strand breaks (Comet assay) in brain, kidney, liver, and skin tissues, increased in testes.
Akdag et al. (2018)	Men who used cell phone for different durations per day; peak head SAR 0.45-0.79 W/kg	Increased DNA single strand breaks (Comet assay) in ear canal hair follicle cells; a dose-response relationship was observed.
Akhavan-Sigari et al. (2014)	Resected Glioblastoma multiforme (GBM) brain tumors from human patients	Increased mutant type of p53 expression in the peripheral zone of GBM in patient who use cell phone form $\geq$3h/day; the increase was significantly correlated with shorter overall survival time.
Alkis et al. (2019a)	Rats exposed to 900 MHz (brain SAR 0.0845 W/kg), 1800 MHz (0.04563 W/kg), and 2100 MHz (0.03957 W/kg) RFR 2 h/day for 6 months	Increased DNA single strand break (Comet assay), oxidative DNA damage, and oxidative stress in brain frontal lobe.
Alkis et al. (2019b)	Rats exposed to 900 MHz, 1800 MHz, and 2100 MHz RFR 2 h/day for 6 months; maximum SAR over the rat 0.017 W/kg	Increased DNA single strand beak (Comet assay), oxidative DNA damage and oxidative stress in testicular tissue.
Alkis et al. (2021)	Rats exposed to 1800	Significant increases in liver in 8-hydroxydeoxyguanosine, DNA single strand

	MHz (SAR 0.62 W/kg), 1800 MHz (0.04563 W/kg), or 2100 MHz (0.2 W/kg) RFR 2 h/day for 7 months	breaks (Comet assay), malondialdehyde, total oxidant status, oxidative stress index,
*Al-Serori et al. (2017)	Human U87 (wild-type) and U251 (mutated) glioblastoma cells exposed to intermittent (5 mi ON/10 min OF) UMTS 1750 MHz signal for 16 h, SAR 0.25, 0.5, and 1 W/kg	No effect on micronucleus frequency. Apoptosis was induced in U231 cells.
Al-Serori et al. (2018)	Ten human cell types exposed to intermittent (5 mi ON/10 min OF) UMTS 1750 MHz signal for 16 h, SAR 0.25, 0.5, and 1 W/kg	Increased in single strand breaks (Comet assay) in U87 p52- proficient glioblastoma cells grew under serum free condition; no effect on double strand breaks (γH2AX foci); nucleotide excision repair induced.
*Antonopoulos et al. (1997)	Human blood samples exposed to 380 MHz (17.65 Hz modulation, 0.08 W/kg); 900 MHZ (217 Hz modulation, 0.208 W/kg); or 1700 MHz (217 Hz modulation, 1.7 W/kg) for 48-68 h	No significant effect on cell cycle progression and frequency of sister-chromatin exchange in lymphocytes.
Atasoy et al. (2013)	Male Wister rats exposed to 2437 MHz (Wi-Fi) RFR; 24 h/day for 20 weeks; maximum SAR 0.091 W/kg	Increased oxidative DNA damage and decreased catalase and glutathione activities in blood and testes.
Atlı Şekeroğlu et al (2013)	Immature (whole body SAR 0.38-0.78 W/kg) and mature (0.31-0.52 W/kg) rats exposed to 900 MHz RFR 2 h/day for 45 days	Increased bone marrow cell chromosome aberration, micronucleus frequency, mitotic index and ratio of polychromatic erythrocytes. Cytogenetic damages in immature rats were significantly higher than in the mature rats. No recovery on day 15 post-exposure.
Balode (1996)	Blood samples from female Latvian Brown cows lived close to and in front of the Skrundra	Significantly higher micronucleus concentration was found in the erythrocytes of the exposed cows.

	Radar and from a control area	
Banerjee et al. (2016)	Buccal mucosal cells from subjects who used their cellular phone less than five years and less than three hours a week (low), and those who used more than five years and more than 10 hours a week comprised of the second group.	Micronucleated frequency in buccal mucosal cells was found to be significantly increased in longer cellular phone users.
Baohong et al. (2005)	Human lymphocytes exposed in vitro to 1800 MHz RFR (SAR 3 W/kg) for two hours and also co-treated with various mutagens	DNA strand break assayed (Comet assay) at 0 and 21 h after treatment. No effect when cells were exposed to RFR alone. But, RFR co-exposure enhanced the DMA damage induced by mitomycin C and 4-nitroquinoline-1-oxide.
Baohong et al. (2007)	Human lymphocytes exposed in vitro to 1800 MHz RFR (SAR 3 W/kg) for 0. 1.5, and 4 h. Cells were also co-treated with ultraviolet ray C	DNA damage as assayed by the Comet assay showed no significant effect with RFR alone. But, RFR co-exposure reduced DNA damage induced by ultraviolet C.
Beaubois et al. (2007)	Tomato plant leaves exposed to a 900-MHz RFR or 10 min at 0.066 mW/cm^2	Evoked rapid and substantial accumulation of basic leucine-zipper transcription factor (bZIP) mRNA in the terminal leaf with kinetics very similar to that seen in response to wounding. (Effect attenuated by calcium antagonist.)
Bektas et al (2020)	Pregnant women who used cell phone and Wi-Fi; placenta and cord blood samples were analyzed	Samples from cell phone users showed increased oxidative DNA damage and oxidative stress; Wi-Fi users showed increased oxidative DNA damage but no oxidative stress; more DNA single strand breaks (Comet assay) in cell phone users than in control (did not use cell phone nor Wi-FI) and Wi-Fi users; Wi-Fi and cell phone uses were synergistic.
Belyaev et al. (1992)	X-irradiated E. coli cells exposed to 51.62-51.84 GHz and 41.25-41.50 GHz millimeter-wave	Power density of 1 $\mu W/cm^2$ was sufficient to suppress X-radiation-induced repair of genome conformational state.

	RFR	
Belyaev et al. (2005)	Lymphocytes from human subjects exposed to GSM 915 MHz RFR for 2 h ; SAR 0.037 W/kg;	Increased condensation of chromatin; no significant difference between responses of blood samples of healthy and electro-hypersensitive subjects.
Belyaev et al. (2006)	Rats exposed to GSM 915 MHz RFR for 2 h, SAR 0.4 W/kg	Affected gene expression in brain cells; no significant effect on chromatin conformation and double strand DNA breaks.
Belyaev et al. (2009)	Human lymphocytes exposed to UMTS cell phone signal(1947.4 MHz, 5 MHz band width) for 1 h; SAR 0.04 W/kg	Chromatin affected and inhibition of DNA double-strand break co-localizing 53BPI/gamma-H2AX DNA repair foci; lymphocytes from electro-hypersensitive subjects responded differently to UMTS and GSM signals in the formation of DNA repair foci than in healthy subjects.
*Bisht et al. (2002)	Mouse embryo sarcoma fibroblast C3H 10T½ cells exposed to FDMA (835.62 MHz; SAR 3.2 or 5.1 W/kg) and CDMA (847.74 MHz; SAR 3.2 or 4.8 W/kg) RFR for 3, 8, 16 or 24h	No significant effect on micronucleus formation.
Bourdineaud et al. (2017)	earthworms (Eisenia fetida) exposed to 900 MHz for 2 h; SAR 0.00013-0.00933 W/kg	DNA genotoxic effect persisted for at least 24 h; gene expressions up regulated for HSP70 (heat shock protein), MEKKI (signal transduction); oxidative stress; and chemical and immune defenses.
*Bourthoumieu et al. (2010)	Human amniotic cells exposed to GSM-900 MHz RFR for 24 h; SAR 0.25 W/kg	No significant genotoxic effect was observed at 0 and 24 h after exposure by visual examination of chromosomal rearrangement.
*Bourthoumieu et al. (2011)	Human amniotic cells exposed to GSM-900 MHz RFR for 24 h; SAR 0.25, 1,2, and 4 W/kg	No significant change in the rate of aneuploidy of chromosomes 11 and 17 was found.
*Bourthoumieu et al. (2013)	Human amniotic cells exposed to GSM-900 MHz RFR for 24 h; SAR 0.25, 1,2, and 4 W/kg	No significant change in the expression and activation of the p53 protein was found. (p53 can cause cell cycle arrest and allow time for DNA repair or apoptosis.)
Burlaka et al. (2013)	Male Wister rats exposed to 245 MHz RFR for 2 h a day. 7 days a week for 2, 8, 15, or 30 days at 5-	Increased micronucleus formation was found in bone marrow erythropoietic cells after 15- day exposure; erythrocyte count, haemoglobin and haematocrit were

	10 mW/cm^2.	increased in peripheral blood after 8 and 15 days of exposure.
Buttiglione et al. (2007)	Human SH-SY5Y neuroblastoma cells exposed to modulated 900 MHz RFR for 24 h; SAR 1 W/kg	Increased Egr-1 gene expression paralleled with activation of the MAPK subtypes ERK1/2 and SAPK/JNK, and decrease in mRNA of Bcl-2 and surviving genes. RFR has anti-proliferative effect and causes cell cycle arrest at G2-M.
Cam and Seyhan (2012)	Hair root cells of human subjects after 15-30 min use of a 900-MHz GSM cell phone	Increased in DNA single strand breaks (Comet assay) was observed; more damages resulted after 30 min than after 15 min use.
Campisi et al. (2010)	Rat neocortical astroglial to 50 Hz-modulated or CW 900 MHz RFR for 5, 10, or 20 min; incident power density 0.0265 mW/cm^2	Significant increases in DNA fragmentation and reactive oxygen species were observed at 20 min only after exposure to the modulated RFR.
Cervellati et al. (2013)	Human placenta trophoblast-derived HTR-8/SVneo cells exposed to 1.8 GHz GSM RFR amplitude modulated by rectangular pulses of 217 Hz for 1 h; SAR 2 W/kg	Increased connexin Cx40 and Cx43 mRNA expression; decreased Integrin alpha1 and β 1 mRNA levels but enhanced Int alpha5 mRNA expression.
Chandel et al. (2019a)	Onion roots (Allium cepa L.) were exposed to 2350 MHz RFR for 1, 2, or 4 h, SAR 0.313 W/kg	Increased in mitotic index and chromosomal aberration; significant increase in DNA single strand break (Comet assay) at 2 and 4 h.
Chandel et al. (2019b)	Onion roots (Allium cepa L.) were exposed to 2100 MHz RFR for 1 or 4 h, SAR 0.282 W/kg	Increased mitotic index, chromosomal aberration, and DNA single-strand breaks (Comet assay) after 4 h of exposure.
*Chang et al. (2005)	Escherichia coli and Salmonella typhimurium exposed to 835 MHz RFR for 48h; SAR 4W/kg	835-MHz RFR neither affected the reverse mutation frequency nor accelerated DNA degradation in vitro. (Some interaction effects with mutagens were observed.)
Chaturvedi et al. (2011)	Male mice exposed to 2450 MHz RFR, 2 h/day for 30 days; SAR 0.03561 W/kg	Increased DNA single strand breaks (Comet assay) in brain cells.
*Chauhan et al. (2006a)	Human lymphoblastoma cells (TK6) exposed to pulsed-modulated,	No evidence of a general stress response with proto-oncogene and heat-shock protein gene transcriptions.

	intermittent (5 min ON, 10 min OFF) 1900-MHz RFR for 6 h; SAR 1 or 6 W/kg	
*Chauhan et al. (2006b)	Human –derived immune cell-lines HL-60 and MM6 cells exposed to pulsed-modulated, intermittent (5 min ON, 10 min OFF) 1900-MHz RFR for 6 h; SAR 1 or 10 W/kg	No evidence of detectable change in stress-related gene expression.
*Chauhan et al. (2007)	Human glioblastoma-derived cell-line (U87MG) and human monocyte-derived cell-line (MM6) exposed to pulsed-modulated, intermittent (5 min ON, 10 min OFF) 1900-MHz RFR for 24 and 6 h; SAR 0.1-10 W/kg	No evidence that the RFR exposure altered late onset gene expression in either cultured cell-lines.
Chavdoula et al. (2010)	Drosophila melanogaster flies exposed to GSM-900 MHz and DCS-1800 MHz cell phone radiation; 6 min per day for 5 days	Decreased insect's reproductive capacity with fragmented DNA (apoptosis) in the egg chamber.
*Chemeris et al. (2004)	Frog (Xenopus laevis) erythrocytes exposed to high peak power pulsed RFR (8.8 GHz, 180 ns pulse width, peak power 65 kW, repetition rate 50 Hz) for 40 min; SAR 1.6 kW/kg (peak SAR 300 MW/kg)	Increased DNA single strand breaks (Comet assay) caused by temperature rise.
*Chemeris et al. (2006)	Human whole blood leukocytes and isolated lymphocytes exposed to pulsed 8.8 Hz RFR (180 ns pulse width, peak power 65 kW, pulse repetition frequency 50 Hz) for 40 min: average SAR 1.6 kW/kg (peak	No change in DNA single strand breaks (Comet assay)

	300 mW/kg)	
Chen et al. (2012)	Saccharomyces cerevisiae yeast cells exposed to 1800 MHz RFR for 6 h; SAR 4.7 W/kg	Expression of several genes.
*Choi et al. (2020)	Human adipose tissue-derived stem cells (ASCs), Huh7 and Hep3B liver cancer stem cells (CSCs), HeLa and SH-SY5Y cancer cells, and normal fibroblast IMR-90 cells exposed to WCDMA-signal 1.7-GHz RFR for 72 h, SAR 1 and 2 W/kg	No significant effect on double strand breaks; increased intracellular reactive oxygen species and deceased proliferation.
*Ciaravino et al. (1991)	Chinese hamster ovary cells exposed to 2450-MHz pulsed RFR (SAR 33.8 W/kg) simultaneously with adriamycin for 2 h	RFR did not affect changes in cell progression and number of sister chromatid exchanges induced by adriamycin.
d'Ambrosio et al. (1995)	Human blood exposed to 9 GHz RFR (continuous-wave or 50-Hz amplitude modulated) for 10 min; SAR 90 W/kg	Increased in micronucleus frequency in lymphocytes after exposure to the amplitude modulated RFR.
d'Ambrosio et al. (2002)	Human blood cultures exposed to 1748 MHz RFR (continuous –wave or phase modulated (GMSK)) for 15 min: SAR ~5 W/kg	Micronucleus frequency in lymphocytes was increased only after exposure to phase-modulated RFR.
Danese et al. (2017)	Human whole blood exposed to 900 MHz RFR from a cell phone for 30 min	No change in frequency of γ-H2AX foci (double strand DNA breaks) in lymphocytes.
De Amicis et al. (2015)	Human fetal fibroblasts exposed to THz radiation (0.1-0.15 THz) for 20 min; SAR 15-20 W/kg	Increased total number of micronuclei and centromere positive micronuclei that could lead to chromosome loss. No significant effect on DNA strand breaks (Comet assay), phosphorylation of H2AX histone and apoptosis.
De Iuliis et al. (2009)	Human spermatozoa exposed to 1800-MHz	Increased oxidative DNA damage and fragmentation (apoptosis) and reactive

	RFR; SAR 0.4 – 27.5 W/kg for 16 h	oxygen species; sperm motility and vitality were reduced.
*de Oliveira et al. (2017)	Human buccal cells from cell phone users; Averaged years of use 11.4 yrs; mean duration of daily use 2.8 min	Cells ipsilateral to cell phone use did not have a statistically significantly higher micronucleus frequency, compared to cells contralateral to exposure.
Del Re et al. (2019)	Human HeLa, BE2C and SH-SY5Y cells exposed to 900 MHz 217-Hz pulse-modulated RFR for 48 h; SAR 1 W/kg	Increased transcription of repetitive DNA, type of transcription depended on cell type. (Alteration of repetitive DNA transcription can be induced by environmental stress conditions, causing human pathological effects.)
Del Vecchio et al. (2009)	Murine SN56 cholinergic cell line (48 and 72 h) and rat primary cortical neurons (24, 72, 120 h) exposed to GSM-modulate 900 MHz RFR; SAR 1 W/kg	Increased expression of beta-thymosin (cytoskeleton regulating factor) m-RNA, and reduced neurite generation.
Demsia et al. (2004)	Rats exposed to 910-MHz RFR 2 h/day for 30 days; SAR 0.42 W/kg.	Increased of micronuclei in polychromatic polymorphonuclear cells in bone marrow smears. Effects less in female rats.
Deshmukh et al. (2013)	Male Fischer rats exposed to 900 MHz (0.0005953 W/kg), 1800 MHz (0.0005835 W/kg), and 2450 MHz (0.0006672 W/kg) RFR for 2 h/day, 5 days/week for 30 days.	Increased DNA single strand breaks (Comet assay) in brain tissues.
Deshmukh et al. (2015)	Male Fischer rats exposed to 900 MHz (0.0005953 W/kg), 1800 MHz (0.0005835 W/kg), and 2450 MHz (0.0006672 W/kg) RFR for 2 h/day, 5 days/week for 180 days.	Increased DNA single strand breaks (Comet assay) in brain tissues; elevated heat-shock protein-70 level.
Deshmukh et al. (2016)	Male Fischer rats exposed to 900 MHz (0.0005953 W/kg), 1800 MHz (0.0005835 W/kg), and 2450 MHz (0.0006672 W/kg) RFR for 2 h/day, 5 days/week	Increased DNA single strand breaks (Comet assay) in brain tissues; elevated heat-shock protein-70 level.

	for 90 days.	
Diem et al.(2005)	Human diploid fibroblasts and cultured rat granulosa cells exposed to 1800 MHz intermittent (5 min On/10 min Off) or continuous –wave; SAR 1.2 or 2 W/kg	Increased in DNA single and double strand breaks (Comet assay) in both cell types after 16 h exposure. Intermittent wave showed a higher effect than continuous wave.
Duan et al (2015)	Mouse spermatocyte-derived GC-2 cells exposed to intermittent (5 min On/10 min Off) 1800 MHz RFR (from a GSM cell phone in talk mode) for 24 h; SAR 1. 2 , or 4 W/kg	Increased oxidative DNA damage a 4 W/kg; no significant with Comet assay.
*Durdik et al. (2019)	Umbilical cord blood (UCB) cells exposed to a GSM900 (1-17 h, 0.004 or 0.04 W/kg) or UMTS-1947.4 MHz (3 h, 0.04 /kg) cell phone signals fed to a TEM cell	No changes in DNA single and double strand breaks (Comet assay), and apoptosis; increased reactive oxygen species was observed.
Eker et al. (2018)	Female Wistar-albino rats exposed to 1800-MHz RFR for 2h/day for 8 weeks; SAR 0.06 W/kg	Caspase-3 and p38MAPK gene expressions increased in eye tissues.
Engelmann et al. (2008)	Cell suspension cultures of Arabidopsis thaliana exposed to 1900 MHz UMTS-modulated RFR for 24 h; SAR peak 2 W/kg, average 0.75 W/kg	Significant changes in transcription of 10 genes.
Esmekaya et al. (2011)	Human peripheral blood lymphocytes exposed to 1800 MHz GSM- (217 HZ) modulated RFR for 6, 8, 24, or 48 h; SAR 0.21 W/kg	Chromatin changes and increase in sister chromatin exchange.
*Falzone et al. (2010)	Human spermatozoa exposed to pulse-modulated 900-MHz RFR for 1 h; SAR: 2.0 and 5.7 W/kg	No significant effects on DNA fragmentation, reactive oxygen species, and capase-3 activity.

Ferreira et al. (2006)	Pregnant rats exposed to a cell phone at 834 MHz for 8.5 h/day from conception to birth; SAR 0.55-1.23 W/kg	Increased erythrocyte micronucleus frequency but no significant effects in oxidative parameters in blood and liver of newborn pups.
Figueiredo et al. (2004)	Human whole blood exposed to 2.5 GHz RFR (from a microwave oven) for 40 sec (SAR 626.67 W/kg) or 10.5 GHz RFR for 5 min (SAR 0.25 W/kg)	No chromosomal aberrations observed in lymphocytes; no alteration in radiosensitivity to gamma radiation; cell mortality increased markedly after RFR exposure.
*Finnie et al. (2006)	Pregnant mice exposed to 900-MHz RFR (modulated at 217 Hz with pulse-width of 0.6 ms) for 60 min per day from day 1-19 of gestation; SAR 4 W/kg	No significant effect on c-fos expression in brain of offspring.
Fragopoulou et al. (2018)	C57BL/6 adult male mice exposed to 2 hr to GSM 1800-MHz RFR (from a phone) for 2 h at an average power density of 0.0049-0.081 mW/cm^2	In the hippocampus, the expression of 178 genes changed significantly, revealing an impact on genes involved in critical biological processes, such as cell cycle, DNA replication and repair, cell death, cell signaling, nervous system development and function, immune system response, lipid metabolism, and carcinogenesis.
Franchini et al. (2018a)	Human fetal and adult fibroblasts exposed to 25 GHz RFR for 20 min; SAR 20W/kg	Increased total number of micronuclei and centromere positive micronuclei in exposed samples. No significant effect on DNA single strand break (Comet assay).
Franchini et al. (2018b)	Human adult fibroblasts exposed to 0.15 THz (150 GHz) RFR (4 µs pulses at 25 Hz) for 20 min; SAR 15-20 W/kg	Increased centromere-positive micronuclei frequencies and chromosomal nondisjunction events, indicating induction of aneuploidy and not by DNA breakage.
Franzellitti et al. (2008)	Human trohoblastes HTR-8/SVneo exposed to 1800 MHz continuous-wave, GSM-217-Hz, and GSM-Talk signals for 4-24 h, time averaged SAR 2 W/kg	Levels of the inducible HSP70C transcript were significantly enhanced after 24 h exposure to GSM-217Hz signals and reduced after 4 and 16 h exposure to GSM-Talk signals. No effect on inducible HSP70A, HSP70B and the constitutive HSC70 transcripts.
Franzellitti et al. (2010)	Human trophoblast HTR-8/SVneo cells exposed to1800 MHz	GSM signals increased DNA single strand breaks (Comet assay) after 16 and 24 h exposure; recovered within 2 h post-

	continuous –wave. GSM (217 Hz modulated) and GSM intermittent (5 min on/10 min off) RFR for 4. 16, or 24 h: SAR 2 W/kg	exposure; continuous-wave RFR was without effect.
*Fritze et al. (1997)	Rats expose to GSM 90 MHz RFR for 4 h, brain average SAR 0.3- 1.5 W/kg	No effect on C-jun and GFAP expression in brain.
Fucic et al. (1992)	Lymphocytes from humans occupationally exposed to RFR; 1250-1350 MHz, 10 $\mu W/cm^2$-20 mW/cm^2	Showed preferentially clastogenic effect measured by micronucleus. Effect on genetic material similar to both of a chemical agent and of ionizing radiation.
Furtado-Filho et al. (2014)	Rats of different ages (0-30 days) exposed 950 MHz RFR for 0.5 h/day for 51 days (21 days of gestation and 6-30 days old): SAR pregnant rat 0.01-0.03 W/kg; neonate 0.88 W/kg, 6-day old 0.51 W/kg, 15-day old 0.18 W/kg, 30-day old 0.06 W/kg.	Decreased DNA single strand breaks (Comet assay) in liver of 15-day old and increased breaks in 30-day old rats, no oxidative stress detected.
*Furtado-Filho et al. (2015)	At exposed to 950 MHz RFR. 0.5 h/day to 27 days (throughout pregnancy and 6 days postnatal); SAR 0.44-0.35 W/kg, neonatal rat 1.32 W/kg, 6-day old 1.14 W/kg	Right cerebral cortex showed an increase in DNA single strand breaks (Comet assay), but no significant effect in the left cerebral cortex in RFR-exposed 6-day old rats. No oxidative effects observed.
Gadhia et al. (2003)	Blood samples of cell phone and non-cell phone users	Increased dicentric chromosomes and sister chromatid exchange in lymphocytes of cell phone users.
Gajski and Garaj-Vrhovac (2009)	Blood samples from Wistar rats exposed to GSM-modulated 915 MHz RFR for 30 min, SAR 0.6 W/kg	Increased basal (single strand) and oxidative DNA damage (Comet assay) in lymphocytes.
Gandhi and Anita (2005)	Blood from cell phone users (most for 2-5 yrs)	Increased DNA single strand breaks (Comet assay) and micronucleus found in cell phone users.
Gandhi and Singh	Blood and buccal cells	Increased micronucleated buccal cells and

(2005)	from cell phone users (3-4,5 yrs); controls never used cell phone	chromosomal aberration in peripheral lymphocytes.
Gandhi et al. (2015)	People lived within 300 m of a cell phone base station (average power density= 1.149 mW/cm^2) for an average of 7.45 yrs, controls average power density = 0.0045 mW/cm^2.	Increased DNA single strand breaks (Comet assay) in peripheral blood leukocytes. Daily cell phone usage, location of residence, and power density are significant predictor of DNA damage.
Gapeyev et al. (2014)	Mouse blood samples exposed to 1-Hz pulse-modulated 42.2 GHz RFR for 20 min, SAR 1.5 W/kg; and x-rays	Pre-exposure to pulse-modulated RFR (not continuous-wave) reduced x-ray-induced DNA single strand breaks (Comet assay) in lymphocytes Effect may be related induction of reactive oxygen species by RFR.
Garaj-Vrhovac et al. (1990)	V79 Chinese hamster cells exposed to 7.7 GHz RFR for 15, 30, or 60 min; power density 30 mW/cm^2	Inhibited [^{3}H]thymidine into DNA with stoppage of cell cycle at S phase; chromosome aberration observed.
Garaj-Vrhovac et al. (1991)	V79 Chinese hamster fibroblast cells exposed to 7.7 GHz RFR for 15, 30, or 60 min; power density 0.5 mW/cm^2	Increased chromosome aberration (dicentric and ring chromosomes) and micronucleus.
Garaj-Vrhovac et al. (1992)	Human whole blood samples exposed to 7.7 GHz RFR for 10, 30, or 60 min; power density 0.5, 10, or 30 mW/cm^2	Increased chromosome aberration (dicentric and ring chromosomes) and micronucleus in lymphocytes.
Garaj-Vrhovac and Fucic (1993)	Air traffic controllers who did repair on radar devices two days ago and exposed to 1250-1350 MHz RFR of unknown intensity (pulse power 100 kW). (presumably higher than normal exposure of 10 $\mu W/cm^2$-20 mW/cm^2)	Lymphocytes showed increased number of chromosome breaks, acentric fragments, dicentric and polycentric chromosomes with accompanying fragments, ring chromosomes and chromatid interchange. Most aberrations returned to normal after 30 weeks, except dicentrics and ring chromosomes.
Garaj-Vrhovac. (1999)	Peripheral blood lymphocytes of workers on radar equipment and antenna system service, 1250-1350 MHz; power	Exposed subjects shows an increase in the number of micronucleus and number of micronucleus per cell; disturbance of cells in the cell cycle.

	density 10 μW/cm^2 -20 mW/cm^2; average employment duration 13.3 yrs	
Garaj-Vrhovac and Orescanin (2009)	Peripheral blood lymphocytes of workers on radar equipment and antenna system service, 1250-1350 MHz; power density 10 μW/cm^2 -20 mW/cm^2; average employment duration 13.3 yrs	Increased DNA single strand breaks (Comet assay) and bleomycin-induced chromatid breakage.
Garaj-Vrhovac et al. (2009)	Wistar rats exposed to 915 MHz RFR 1 h/day for two weeks, SAR 0.6 W/kg	Increased basal DNA single strand break and oxidative DNA damages (Comet assay) in blood leukocytes.
Garaj-Vrhovac et al. (2011)	Workers occupationally exposed to marine radar pulsed RFR (3, 5.5, and 9.4 GHz)	Increased DNA single strand break (Comet assay) and micronucleus in blood lymphocytes; increased oxidative stress.
*Garson et al. (1991)	Blood samples of radio-linemen occupationally exposed to 400 kHz – 20 GHz	No increase in chromosomal damage in lymphocytes.
Ghatei et al. (2017)	Mice exposed pre- and post-natally to radiation from a cellular phone jammer (900 and 1800 MHz)	At 8-10 weeks old, in the cerebellum, no effect on expression level of bcl-2 and p53 genes, but gene expression level of *bax* was decreased and gene expression level of *p21* was increased.
*Glaser et al. (2016)	Human hematopoietic stem cells and leukemia HL-60 cells exposed to GSM (900 MHz), UMTS (1,950 MHz) and LTE (2,535 MHz) for 4, 20 or 66 h;SAR 0-4 W/kg	No effect on apoptosis, oxidative stress, cell cycle, DNA damage (DNA single strand breaks (Comet assay)) and DNA repair. A significant decrease in DNA breaks was found in hematopoietic stem cells exposed for 4 h to GSM signal.
Gökçek-Saraç et al. (2020)	Rats exposed to UMTS 2100 MHz RFR 2h/day for 7 days; whole body average SAR 0.47or 2.17 W/kg	Decreased RNA expressions of acetylcholinesterase (AChE), choline acetyltransferase (ChAT), and vesicular acetylcholine transporter (VAChT) in the hippocampus; deficit in object location and Y-maze tests.
*Görlitz et al. (2005)	B6C3F1 mice exposed to GSM900 or DCS 1800 signals for 2 h/day for 1	No effect on micronucleus frequency in erythrocytes of the bone marrow or peripheral blood, in keratinocytes, or in

	week (SAR 0-33.2 W/kg) or 6 weeks (SAR 0-24.9 W/kg)	spleen lymphocytes.
Gorpinchenko et al. (2014)	Human sperms exposed to a cell phone in stand-by/talk mode for 5 h	Increased DNA fragmentation (apoptosis) and decreased motility in spermatozoa.
Gulati et al. (2016)	Blood and buccal cells of people lived close (<400 meters) to a cell tower; 1800 MHz, Maximum power density (at 150 meters) 1.22 $\mu W/cm^2$, some subjects lived in the area for more than 9 yrs	Inceased DNA single strand breaks (Comet assay) in lymphocytes and micronucleus in buccal cells. Female subjects had significantly higher effects than males.
Gulati et al. (2018)	Blood samples from subjects lived 400 m from cell towers for 8-9 years, power density 0.037-12.20 mW/cm^2	A significant association of genetic polymorphism of antioxidant genes (for MnSOD and CAT) with oxidative damage has been observed in human population exposed to radiations emitted from mobile towers. Decreased MnSOD and CAT activities and increased lipid peroxidaton observed in blood serum.
Gulati et al. (2020)	Human lymphocytes exposed to UMTS signals at 1923, 1947.47, and 1977 MHz for 1 or 3 hr; SAR 40 mW/kg	Observed DNA damage (Comet assay) depending on UMTS frequency wth maximal effect at 1977 MHz; no effects on ROS, apoptosis, preleukemic fusion genes, and mutations in TP53 gene.
Guler et al (2010)	Pregnant and non-pregnant New Zealand white rabbit exposed to GSM 1800-MHz RFR for 15 min/day for 7 days (15^{th} to 22^{nd} days of gestation); power density 0.052 mW/cm^2	Increased oxidative DNA damage and lipid peroxidation in brain tissues in adult rabbits, no significant effect in newborn rats
Guler et al. (2012)	New Zealand white rabbits exposed to GSM 180-MHz RFR for 15 min/day in utero between 15^{th} to 22^{nd} days of gestation and at 1-month old 15 min/day 7 days for female and 14 days for male; SAR 1.8 W/kg	Increased DNA oxidative damage in liver of female rabbits (not in male) and increased lipid peroxidation in liver of both male and female rabbits.
*Gurbuz et al. (2010)	Female Wistar rats	No significant effect on micronucleus

	exposed to GSM 1800-MHz RFR 20 min/day, 5 days/week for 1 month; power density 0.0054 mW/cm^2	frequency in bladder cells.
*Gurbuz et al. (2014)	Male Wistar rats exposed to 1800- or 2100-MHz RFR 30 min/day, 6 days/week for 1 or 2 months; SAR 0.23 W/kg	No significant effect on micronucleus frequency in bladder cells.
*Gurbuz et al. (2015)	Normal and diabetic rats exposed to a 2100-MHz RFR 30 min/day, 5 days/week for 1 month; SAR 0.24 W/kg	No effect on micronucleus frequency in exfoliated bladder cells in both normal rats and rats with chronic disorder.
*Gurisik et al. (2006)	Two human cell lines (neuronal SK-N-SH) and monocytoid U937) exposed to a GSM 900-MHz RFR for 2 h; SAR 0.2W/kg	No significant effects on gene expression, heat shock protein level, and cell cycle distribution in SK-N-SH cells; and no effects on cell viability and cell cycle in U937 cells.
Gürler (2014)	Wistar rats exposed to 2450 MHz RFR 1 h/day for 30 consecutive days; power density 0.0036 mW/cm^2	Increased oxidative DNA damage in brain and blood, and oxidative protein products in blood.
Gustavino et al. (2016)	Secondary roots of Vicia faba (broad bean) seedlings exposed to continuous-wave 915-MHz RFR for 2 h; SAR 0.4-1.5 W/kg	Increased micronucleus frequency up to 7-fold.
Habauzit et al. (2014)	Human keratinocytes exposed to 60.4 GHz RFR for 3 hr, incident power density of 20 mW/cm^2: SAR 594 W/kg (average), 1233 M/kg (peak)	7 gene expressions showed specific electromagnetic effect under hyperthermia condition (i.e., not mimicked by heat-shock controls).
* Habauzit et al. (2020)	Male hairless rats exposed to 94 GHz RFR 3 h/day, 3 days/week for 5 months, incident power density 10 mW/cm2	No significant modification of gene expression in skin cells.
Haider et al. (1994)	Plant cutting bearing young flower buds	Increased micronucleus was found in all conditions (compared to lab controls).

	exposed for 30 h to short-wave 10-21 MHz RFR on both sides of a slewable curtain antenna (0.424-7.67 mW/cm^2), at 15 m (2.15 mW/cm^2) and 30 m (1.3 mW/cm^2) from a cage antenna; and 200 m from a broadcasting station (0.00027-0.0024 mW/cm^2)	
Hanci et al. (2013)	Pregnant rats exposed 1 h/day on days 13-21 of pregnancy to 900-MHz RFR at power density 0.0265 mW/cm^2.	Testicular tissue of 21-day old offspring showed increased DNA oxidative damage, apoptotic index, and lipid peroxidation.
*Hansteen et al. (2009a)	Human lymphocytes exposed to18 GHz or pulsed 16.5 GHz RFR for 53 h	No significant effect on chromosomal aberration frequency.
*Hansteen et al. (2009b)	Human lymphocytes exposed to 2.3 GHz continuous-wave or pulsed (200 Hz, 50% duty cycle) RFR	No significant effect on chromosomal aberration frequency.
Hao et al. (2010)	Murine N9 microglial cells were exposed to pulsed 2450-MHz RFR for 20 min, SAR 6.2 W/kg	Significant induced phosphorylation of STAT3, increased transcription levels of the inflammation-associated genes, iNOS and TNF-alpha, which are reported to contain STAT-binding elements in their promoter region. (STAT3 is a transcription activator that mediates the expression of a variety of genes in response to cell stimuli, and thus plays a key role in many cellular processes such as cell growth and apoptosis.)
He et al. (2016)	Mouse bone marrow stromal cells exposed to a 900 MHz RFR 3 h/day for 5 days; peak and average SAR 4.1 x 10^{-4} and 2.5 x 10^{-4} W/kg	Increased expression of PARP-1 mRNA. (PARP-1 involved in DNA repair, genomic stability and apoptosis and is activated by DNA single strand breaks.)
He et al. (2017)	Mouse bone marrow stromal cells exposed to a 900 MHz RFR 3 h/day for 5 days; peak and average SAR 4.1 x 10^{-4}	Induced PARP-1. Cells exposed to RFR and gamma ray showed significantly decreased genetic damage (DNA single strand break (Comet assay)) as well as faster kinetics of repair compared with those exposed to GR

	and 2.5 x 10^{-4} W/kg, some cells were challenged with one dose of gamma ray.	alone.
Hekmat et al. (2013)	Calf thymus exposed to 940 MHz RFR for 45 min; SAR 0.04 W/kg	Altered DNA structure at 0 and 2 h after exposure; conformational changes and disaggregation caused by increment in surface charge and size of DNA.
*Hintzsche and Stopper (2010)	Oral cavity mucosa cells from human subjects who used cell phones for different durations weekly (0, <3 h, and > 3h)	No significant change in micronucleus frequency in mucosa cells with cell phone use.
*Hintzsche et al. (2012a)	Human HaCaT cells and A(L) human-hamster hybrid cells exposed to continuous-wave or GSM-modulated 900 MHz RFR for 30 min or 22 h; power density 0.0066-2.15 mW/cm^2	No significant effect on micronucleus frequency.
*Hintzsche et al. (2012b)	Human keratinocytes (HaCaT) and human dermal fibroblasts (HDF) exposed to 0.106 THz (106 GHz) RFR for 2, 8, 24 h; 0.88 -2 mw/cm^2 (2mw/cm^2 gave a SAR of 13.34 W/kg)	No effect on micronucleus frequency and DNA single strand breaks (Comet assay).
*Hirose et al. (2006)	Human glioblastoma A172 cells exposed to 2.1425 GHz W-CDMA radiation at SARs of 0.08, 0.25, and 0.8 W/kg, and continuous-wave radiation at 0.08 W/kg for 24 or 48 h; and human IMR-90 fibroblasts from fetal lungs exposed to both W-CDMA and continuous-wave RFR at a SAR of 0.08 W/kg for 28 h	No significant changes in induction of p53-dependent apoptosis, DNA damage, or other stress response
*Hirose et al. (2007)	Human glioblastoma	No significant induction of phosphorylation

	A172 cells were exposed to W-CDMA radiation at SARs of 0.08 and 0.8 W/kg for 2-48 h, and continuous-wave 2.1425 GHz RFR at 0.08 W/kg for 24 h, and human IMR-90 fibroblasts from fetal lungs were exposed to W-CDMA at 0.08 and 0.8 W/kg for 2 or 28 h, and continuous-wave at 0.08 mW/kg for 28 h.	of hsp27 or expression of heat shock protein gene family.
*Hook et al. (2004)	Human Molt-4 T lymphoblastoid cells exposed to 847.74 MHz code-division multiple-access (CDMA) (SAR 3.2 W/kg), 835.62 MHz frequency-division multiple-access (FDMA) (3.2 W/kg), 813.56 MHz iDEN(R) (iDEN) (0.0024 or 0.024 W/KG), and 836.55 MHz time-division multiple-access (TDMA) (0.0026 or 0.026 W/kg) for up to 24 h	No significant changes in DNA single strand breaks (Comet assay) and apoptosis.
*Hou et al. (2015)	Mouse embryonic fibroblasts (NIH/3T3) exposed to intermittent (5 min on/10 min off) 1800-MHz GSM-talk mode RFR from 0.5 to 8 h; SAR 2 W/kg.	No effect on γH2AX foci frequency (Increased reactive oxygen species and late apoptotic cells).
Houston et al. (2019)	Male mice exposed to 906 MHz RFR for 12 h/day for 1, 3, or 5 weeks; SAR 2.2 W/kg	Increased DNA oxidative and fragmentation (Comet assay) in spermatozoa across all exposure periods, increased mitochondrial reactive oxygen species.
*Huang et al. (2008a)	Jurkat human T lymphoma cells exposed for 24 h to 1763 MHz RFR; SAR 10 W/kg	Alterations in cell proliferation, cell cycle progression, DNA integrity (Comet assay) or global gene expression were not detected.
*Huang et al. (2008b)	HEI-OC1 immortalized mouse auditory hair cells	No significant effects on cycle distribution, DNA damage (Comet assay), stress response

	exposed to 1763 MHz (CDMA) RFR for 24 or 48 h; SAR 20 W/kg	and gene expression.
*Jeong et al. (2018)	14-month old C57BL/6 mice exposed to 1950 MHz RFR for 2 h/day, 5 day/wk, 8 months; SAR 5 W/kg	No significant effects on levels of oxidative stress, oxidative DNA damage, apoptosis, astrocyte, or microglia markers in brain tissues.
Jeong et al. (2020)	2 and 12-month old C57BL/6 mice exposed to 1950-MHz RFR 2h/day, 5 day/wk for 8 months; SAR 5 W/kg	Increased expression of Epha8 and Wnt6 genes in the hippocampi at 20 months after exposure, although 13 additional genes showed no significant changes. Cognitive enhancement detected in 1-month mice after exposure may be associated with increases in neurogenesis-related signals.
Ji et al (2004)	Human subjects used cell phones for 4 h.	DNA single strand breaks (Comet assay) increased in peripheral blood cells (T-cells, B-cells, granulocytes).
Ji et al. (2016)	Mouse bone-marrow stromal cells (BMSC) exposed to 900-MHz RFR for 4 h/day for 5 days; power density 0.12 mW/cm^2; some cells were also irradiated with 1.5 Gy γ-radiation after RFR exposure	RFR followed by γ-radiation exposure significantly decreased number of DNA strand breaks (Comet assay) and resulted in faster kinetics of repair of DNA strand breaks compared to γ-radiation alone. Thus, data suggest that RFR preexposure protected cells from damage induced by γ-radiation.
Jiang et al. (2012)	Mice were pre-exposed to a 900-MHz RFR for 4 h/day for 1, 3, 5, 7, and 14 days; power density 0.12 mW/cm2 and then subjected to an acute dose of 3 Gy γ-radiation	DNA single strand breaks (Comet assay) in blood leukocytes from mice pre-exposed to RFR for 3, 5, 7, and 14 days showed progressively decreased damage and was significantly different from those exposed to γ-radiation alone.
Jiang et al. (2013)	Mice exposed to a 900-MHz RFR 4/day for 7 days, SAR 0.548 W/kg and also γ-radiation	Pre-exposure to RFR decreased micronucleus frequency induced by γ-radiation in immature erythrocytes in peripheral blood and bone marrow.
*Juutilainen et al. (2007)	Female CBA/S mice were exposed for 78 weeks (1.5 h/day, 5 day/week) to either a continuous 902.5-MHz signal similar to that emitted by analog NMT (Nordic Mobile	No significant effects of RFR on micronucleus frequency in polychromatic or normochromatic erythrocytes.

	Telephone) phones at a whole-body SAR of 1.5 W/kg, or to a pulsed 902.4-MHz signal similar to that of digital GSM phones at 0.35 W/kg and also 4 Gy of X-ray on the first three weeks; female transgenic mice (line K2) and their nontransgenic littermates were exposed for 52 weeks (1.5 h/day, 5 day/week) to two digital mobile phone signals, GSM and DAMPS at SAR 0.5 W/kg, and repeated ultraviolet radiation	
Karaca et al. (2012)	Mouse brain cells exposed to a 10.715 GHz RFR for 6 h/day for three days, SAR 0.725 W/kg	Increased micronucleus apoptosis and necrosis, and decreased expression of the STAT3 genes.
*Kerbacher et sl. (1990)	Chinese Hamster Ovary cells exposed for 2 h to pulsed 2450 MHz RFR; SAR 33.8 W/kg	No significant effect on chromosome aberration; no interactions with Mitomycin C and Adriamycin.
Kesari and Behari (2009)	Male Wistar rats exposed to 50-GHz RFR 2 h/day for 45 days; SAR 0.0008 W/kg	Increased in brain tissue DNA double strand breaks (Comet assay); decreased antioxidant enzymes superoxides dismutase and glutathione peroxidase, and increased catalase activity.
Kesari et al. (2010)	Male Wistar rats exposed to 2.45-GHz RFR 2 h/day for 35 days; SAR 0.11 W/kg	Increased in brain tissue DNA double strand breaks (Comet assay); decreased antioxidant enzymes superoxides dismutase and glutathione peroxidase, and increased catalase activity.
Kesari et al. (2011)	Male Wistar rats exposed to 900 MHz-GSM signal 2 h/day for 35 days; SAR 0.9 W/kg	Decreased micronucleus frequency, change in cell cycle and increased oxidative stress in sperm cells.
Kesari et al. (2014)	Male Wistar rats exposed to a 3D cell phone. 2h/day for 60 days; SAR 0.26 W/kg	Increased DNA double strand breaks (comet assay), micronuclei, Caspase 3 and apoptosis in brain cells; activation of hsp27/p38MAPK stress pathway.
*Khalil et al (2011)	Mice exposed to 900	No effects on plasma, brain, and spleen 8-

	MHz-GSM signal 30 min/day for 30 days; SAR 1 W/kg	oxo-7, 8-dihydro-2'- deoxyguanosine and oxidative stress.
Khalil et al. (2012)	Male Sprague-Dawley rats exposed for 2 h to 1800-MHz GSM signal, SAR 1 W/kg	Urine samples collected 0.5, 1, 2, and 4 h from the beginning of exposure showed elevated 8-oxo-7, 8-dihydro-2'-deoxyguanosine (from repair of oxidative DNA damage) level.
*Khalil et al. (2014)	Saliva of cellular phone users collected before as well as after 15 and 30 min use of phones.	No change in 8-oxo-7,8-dihydro-2'-deoxyguanosine (8-Oxo-dG). There was no relationship between cell phone use and changes in the salivary oxidant/antioxidant profile.
Kim et al. (2008)	Mouse lymphoma cells and Chinese hamster lung cells exposed to 835-MHz RFR for 48 h; SAR 4W/kg	RFR increased clastogens-induced DNA single strand breaks (Comet assay).
*Komatsubara et al. (2005)	Mouse m5S cells exposed for 2 h to 2450 MHz CW RFR (SAR 5,10, 20, 50 and 100 W/kg) or pulsed RFR (SAR mean 100W/kg, peak 900 W/kg)	No chromosomal aberration observed.
Korenstein-Ilan et al (2008)	Human dividing lymphocytes exposed to 0.1 THz RFR (0.031 mW/cm^2) for 1, 2, or 24 h	Change in chromosomes number in chromosoms11 and 17 were most vulnerable (about 30% increase in aneuploidy after 2 and 24 h of exposure), while chromosomes 1 and 10 were not affected, and in the asynchronous mode of replication of centromeres 11, 17 and 1 (by 40%) after 2 h of exposure. 0.1 THz radiation induces genomic instability. It is speculated that these effects are caused by radiation-induced low-frequency collective vibration modes of proteins and DNA.
Koyama et al. (2003)	Chinese hamster ovary (CHO)-K1 cells exposed to 2450 MHz RFR for 18 h:SAR 13-100 W/kg	Higher micronucleus frequency after exposure at 78 W/kg and higher. Synergistic with bleomycin in microbnucleus formation.
Koyama et al. (2004)	Chinese hamster ovary K1 cells exposed to 2450 MHz RFR for 2h; SAR5-200 W/kg	Increased micronucleus formation above 50 W/kg (May be related to temperature rise).

*Koyama et al. (2016a)	Human corneal epithelial (HCE-T) cells exposed to 0.12 THz radiation at 5 mW/cm² for 24 h	No effect on micronucleus formation, morphological change and hest shock protein expression (Hsp27, Hsp70, and Hsp90α).
*Koyama et al. (2016b)	Human corneal epithelial (HCE-T) and human lens epithelial (SRA01/04) cells exposed to 60 gigahertz (GHz) RFR for 24 h; 1 mW/cm2	No effect on micronucleus formation DNA single strand breaks (Comet assay) and heat shock protein expression.
Kumar A. et al. (2020)	Allim cepa (onion) root meristematic cells exposed to 900- (0.0902 W/kg) and 1800-MHz (0.169 W/kg) RFR for 0.5, 1, 2, and 4 h	Increased chromosomal aberrations and increased DNA single strand breaks (Comet assay).
*Kumar G. et al. (2011)	Long bone (femur and tibia) of male Sprague – Dawley rats exposed to 900-MHz continuous-wave RFR for 30 min; SAR 2 W/kg	No significant effect on DNA single-strand breaks (Comet assay) in bone marrow lymphocytes.(Assayed at 72 h after exposure.)
*Kumar G. et al. (2015)	Long bone (femur and tibia) of male Sprague – Dawley rats exposed to 900 and 1800 MHz continuous-wave and pulsed RFR; 900-MHz CW at 2 and 10 W/kg for 90 min and 1800-MHz CW and PW at 2.5 and 12.4 W/kg for 120 min	No significant effect on DNA single-strand breaks (Comet assay) in bone marrow lymphoblasts. (Assayed at 1 h after exposure.)
Kumar R. et al. (2020)	male Wistar rats exposed to 900 MHz, 1800 MHz and 2450 MHz RFR at a specific absorption rate (SAR) of 5.84 × 10^{4} W/kg, 5.94 × 10^{-4} W/kg and 6.4 × 10^{-4} W/kg, respectively for 2 h per day for 1-month, 3-month and 6-month periods.	RFR exposure caused significant epigenetic modulations (DNA and histone methylation) which alter gene expression in the hippocampus.
Kumar S. et al. (2010)	Male Wistar rats exposed to 10-GHz RFR 2 h a day for 45 days, SAR	Increased micronucleus and reactive oxygen species in blood cells.

	0.014 W/kg	
Kumar S. et al. (2013)	Male Wistar rats exposed to a 10 GHz RFR 2h/day for 45 days; SAR 0.014 W/kg	Increased micronucleus frequency in blood lymphocytes and increased single strand breaks (Comet assay) in spermatozoa. Decreased testosterone and testicular size.
Kumar S. et al. (2014)	Male Wistar rats exposed to 1910.6 MHz RFR from a cell phone in "talk mode" for 60 days (2 h/day, 6 days a week); SAR 0.28 (Max.) and 0.0226 (Min.)	Increased DNA single strand breaks (Comet assay) an lipid peroxidation in spermatozoa,
*Lagroye et al. (2004a)	Sprague-Dawley rats exposed to pulsed 2450-MHz RFR for 2 h; SAR 1.2 W/kg	No significant change in DNA single strand breaks (Comet assay) (with or without proteinase-k treatment of samples-for detection of DNA-protein crosslinks) in brain cells.
*Lagroye et al. (2004b)	Clonal mouse embryo C3H 10T(1/2) cells exposed 2450-MHz continuous-wave RFR for 2 h; SAR 1.9 W/kg	No significant change in DNA single strand breaks (Comet assay) (with or without proteinase-k treatment of samples.)
Lai and Singh (1995)	Male Sprague-Dawley rats exposed to pulsed or continuous-wave 2450-MHz RFR for 2 h; SAR 0.6 and 1.2 W/kg	Increased DNA single strand breaks (Comet assay) in brain cells was observed at 4 h after exposure to pulsed RFR and at 0 and 4 h after continuous-wave exposure.
Lai and Singh (1996)	Male Sprague-Dawley rats exposed to pulsed or continuous-wave 2450-MHz RFR for 2 h; SAR 1.2 W/kg	Increased DNA single- and double-strand breaks (Comet assay) in brain cells was observed at 4 h after exposure to pulsed or continuous-wave RFR.
Lai and Singh (1997)	Male Sprague-Dawley rats exposed to pulsed 2450-MHz RFR for 2 h; SAR 1.2 W/kg	Increased DNA single- and double-strand breaks (Comet assay) in brain cells at 4 h after exposure. Effects blocked by melatonin or the spin-trap compound N-tert-butyl-alpha-phenylnitrone. (Free radicals are involved in the effects).
Lai and Singh (2005)	Male Sprague-Dawley rats exposed to continuous-wave 2450-MHz RFR for 2 h; SAR 0.6 W/kg	Increased DNA single- and double-strand breaks (Comet assay) in brain cells at 4 h after exposure. Effects blocked by a temporally incoherent magnetic field.
Lai et al. (1997)	Male Sprague-Dawley rats exposed to pulsed 2450-MHz RFR for 2 h;	Increased DNA double-strand breaks (Comet assay) in brain cells at 4 h after exposure. Effect blocked by naltrexone. (Involvement

	SAR 1.2 W/kg	of endogenous opioids in the effects).
Lakshmi et al. (2010)	Human subjects professionally using VDTs	No effect on DNA single strand break (comet assay) and micronucleus frequency in blood cells of subjects exposed for 2 years; increased in long-term (>10 years) users.
Lameth et al. (2020)	Healthy rats, rats undergoing an acute neuroinflammation triggered by a lipopolysaccharide (LPS) treatment, and transgenic hSOD1^{G93A} rats that modeled a presymptomatic phase of human amyotrophic lateral sclerosis (ALS) exposed head only to a GSM-1800 MHz RFR for 2 h, SAR 3.22 W/kg.	Cortical cell gene modulations triggered by GSM-RFR in the course of an acute neuroinflammation and indicate that GSM-induced gene responses can differ according to pathologies affecting the CNS.
*Lamkowski et al. (2018)	Human peripheral blood cells exposed to 900 MHz RFR for 30, 60, and 90 min; SAR 9.3 W/kg	No significant effect on gene expression.
Le Quément et al. (2012)	Primary human skin cells exposed to a 60.4-GHz RFR for 1, 6, or 24 h, SAR 42.4 W/kg.	Expression of 130 transcripts was found to be potentially modulated. PCR confirmed 5 genes as differentially expressed after 6 h of exposure.
*Lerchl et al. (2020)	Pregnant mice exposed to UMTS ~1960 MHz RFR from day 7 post-conception (p.c.) at SAR 0.04 and 0.4 W/kg (24 h/day, 7 days/week);at day 14 p.c., injected with ethylnitrosoures(ENU)	No DNA adenyl adduct formation was observed in the brain of fetuses at 24, 36, and 72 h after ENU inection.
Lee et al. (2005)	Human HL-60 cells exposed to a pulsed 2450 MHz RFR for 2 or 6 h; SAR 10 W/kg	Many genes apoptosis-related genes were affected. Apoptosis- related genes were among the upregulated ones and the cell cycle genes among the downregulated ones.
*Li et al. (2001)	Murine C3H 10T(1/2) fibroblasts exposed to 847.74 MHz code-division multiple access (CDMA) and 835.62 frequency-division	No significant effect on DNA single strand breaks (Comet assay).

	multiple access (FDMA) RFR for 2, 4, or 24 h; SAR 3.2 - 5.1 W/kg	
Li et al. (2018)	Mouse spermatocyte-derived cells (GC-2) were exposed to 1800-MHz RFR for 24 h, SAR 1, 2 or 4 W/kg	No effect on DNA double strand streak, increased DNA single strand breaks (Comet assay); free radicals involved.
Li et al. (2020)	Pregnant female rats exposed to 1800 (1 mW/cm^2) and 2400 (0.1 mW/cm^2) MHz RFR during the 21st day of pregnancy (8 pm- 8 am). Offspring tested from 3-9 weeks postnatal	Up- and down-regulation expressions of different forms (NR1, NR2A, NR2B, NR2C, NR2D, NR3A, NR3B) of methyl-D-aspartate receptors (NMDARs) in the hippocampus were obsersed; animals showed behavioral and cognitive development effects which may be associated with altered mRNA expression of NMDARs.
Lin et al. (2016)	Budding yeast exposed to 2-GHz RFR for 96 h, SAR 0.12 W/kg	Upregulation of the expression of genes involved in glucose transportation and the tricarboxylic acid (TCA) cycle.
Liu et al. (2013a)	Mouse spermatocyte-derived GC-2 cell line exposed to 1800-MHz Global System for Mobile Communication (GSM) signals (5 min on and 10 min off) for 24 h; SAR 1, 2, or 4 W/kg	Increased DNA single strand breaks (comet assay) and DNA adduct 8-oxoguanine at SAR of 4 W/kg; increased reactive oxygen species generation.
Liu et al. (2013b)	Mouse spermatocyte-derived GC-2 cell line was exposed to a commercial mobile phone handset once every 20 minutes in standby, listen, dialed or dialing modes for 24 h; power density 0.0059-0.0122 mW/cm^2	Increased DNA single strand breaks (Comet assay) (attenuated by melatonin).
Lixia et al. (2006)	Human lens epithelial cells exposed to GSM-1.8 GHz RFR for 2 h, SAR 1, 2, 3 W/kg	Increased DNA single strand breaks (comet assay) at 3 W/kg at o and 30 min post-exposure; Increased mRNA and protein expression of Hsp70.
López-Martín et al. (2009)	Picrotoxin-pretreated male Sprague-Dawley rats exposed to 900-MHz GSM-modulated or unmodulated RFR for 2	Increased c-fos expression in brain areas.

	h, SAR modulated RFR 0.03 W/kg average–peak 0.14 W/kg in brain; unmodulated RFR average 0.26 W/kg- peak 1.4 w/kg in brain	
Luukkonen et al. (2009)	Human SH-SY5Y neuroblastoma cells exposed to 872-MHz (CW and GSM) RFR for 1 h; SAR 5 W/kg	CW RFR increased DNA single strand breaks (Comet assay) and reactive oxygen species in cells treated with menadione (a chemical that induces intracellular ROS production and DNA damage) compared to cells treated with menadione alone. GSM-modulated RFR had no significant effect.
*Luukkonen et al. (2010)	Human SH-SY5Y neuroblastoma cells exposed to 872-MHz (CW and GSM) RFR for 3 h (DNA damage) and 1 h (reactive oxygen species) ; SAR 5 W/kg	CW and modulated RFR had no significant effect on DNA single strand breaks (Comet assay) and reactive oxygen species production in cells treated with ferrous chloride,
Maes et al (1993)	Human peripheral blood lymphocytes exposed to pulsed2450-MHz RFR for 30 or 120 min, SAR 75 W/kg	Increase in the frequency of chromosome aberrations (including dicentric chromosomes and acentric fragments) and micronuclei.
Maes et al (1996)	Human whole blood samples exposed to GSM 954- MHz emitting antenna for 2 h, SAR 1.5 W/kg, some samples also incubated with mitomycin C after exposure	Synergistic effect between RFR and mitomycin C was observed the frequencies of sister chromatid exchanges in metaphase figures.
Maes et al. (1995)	Human whole blood cells exposed to 954 MHz RFR from an antenna for 2 h; SAR 1.5 W/kg. Blood from maintenance workers of transmission antenna (450, 900 MHz) exposed at least 1 h/day for a year.	Increased chromosome aberration (dicenric chromosome) in lymphocytes. No effect found in blood of antenna maintenance workers.
*Maes et al. (1997)	Human whole blood cells exposed to 935.2 MHz RFR alone and in	No significant effects of RFR on chromosome aberration, sister chromatid exchange, and DNA single strand breaks

	combination with mitomycin C for 2 h; SAR 0.3-0.4 W/kg	(comet assay). No synergistic effect with mitomycin C.
*Maes et al (2000)	Human lymphocytes exposed to 455.7 MHz RFR from antenna of a car phone for 2 h; SAR 6.5 W/kg	No significant effects of RFR on chromosome aberration and sister chromatid exchange. No synergistic effect with mitomycin C.
*Maes et al (2001)	Human lymphocytes exposed to 900-MHz RFR for 2 h, SAR 0-10 W/kg	No significant effects of RFR on chromosome aberration and sister chromatid exchange. No synergistic effect with mitomycin C.
*Maes et al (2006)	Peripheral blood lymphocytes from subjects who were professionally exposed to cell phone RFR	No evidence of RFR-induced genetic effects: DNA single strand breaks (Comet assay), chromosome aberration, and sister chromatid exchange.
*Malini (2017)	Blood and semen samples from subjects who used cellular phones for 1-5. 6-10, and >10h/day.	No DNA damages (ladder assay) and oxidative changes observed.
*Malyapa et al. (1997a)	U87MG and C3H 10T1/2 cells exposed to 2450-MHz continuous-wave RFR for 2 h; SAR 0.7 and 1.9 W/kg	No significant effects on DNA single strand breaks (Comet assay).
*Malyapa et al. (1997b)	Mouse C3H 10T1/2 fibroblasts and human glioblastoma U87MG cells exposed to 835.62 MHz (FMCW) and 847.74 MHz (CDMA) RFR up to 24 h; SAR 0.6 W/kg	No significant effects on DNA single strand breaks (Comet assay).
*Malyapa et al. (1998)	Male Sprague-Dawley rats exposed to 2450 MHz continuous-wave (CW) RFR for 2 h; SAR 1.2 W/kg	No significant effects on DNA single strand breaks (Comet assay) in cerebral cortex or hippocampus.
Manti et al. (2017)	Four days-old adult female flies (Drosophila melanogaster) exposed to GSM-1800 talk mode RFR emitted by a commercial cellular	168 genes were differentially expressed associated with multiple and critical biological processes, such as basic metabolism and cellular subroutines related to stress response and apoptotic death. Free radicals may be involved.

	phone for 30 min; SAR 0.15 W/kg	
Manti et al. (2008)	Human peripheral blood lymphocytes exposed a UMTS 1.95 GHz signal for 24 h; SAR 0.5 and 2.0 W/kg; some samples also exposed to x-ray	X-ray induced chromosome exchange per cell was increased by RFR exposure. (RFR may either influence the repair of X-ray-induced DNA breaks or alter the cell death pathways of the damage response.)
Marinelli et al. (2004)	acute T-lymphoblastoid leukemia cells exposed to 900 MHz RFR for 2-48 h, SAR 0.0035 W/kg	Increased DNA damage (DNA ladder) and activation genes involved in pro-survival signaling.
Markova et al. (2005)	Human lymphocytes exposed to 905 and 915 MHz GSM signals for 1 h. SAR 0.037 W/kg	RFR from GSM cell phone affected chromatin conformation and 53BP1/gamma-H2AX foci similar to heat shock. No significant difference between lymphocytes from healthy and electro-hypersensitive subjects.
Markova et al. (2010)	Human diploid VH-10 fibroblasts and human adipose-tissue derived mesenchymal stem cells exposed to GSM (905 MHz or 915 MHz) or UMTS (1947.4 MHz, middle channel) RFR for 1, 2, or 3 hr; SAR 0.037-0.039 W/kg	915 MHz and 1947.4 MHz signals inhibited tumor suppressor TP53 binding protein 1 (53BP1) foci that are typically formed at the sites of DNA double strand break location in both cell types. 905 MHz RFR did not inhibit 53BP1 foci in differentiated cells but in stem cells. (Inability to form DNA repair foci has been correlated to radiosensitivity, genomic instability, and other repair deficits.)
Martin et al. (2020)	Human neonatal foreskin keratinocytes (HEK-3N, HEK-1N, and NHEK-3N) and human skin keratinocyets HeCAT exposed to a 60-GHZ RFR for 3 h, Average SAR 513 W/kg and peak SAR 1233 W/kg	Different cell types showed different patterns of expreson of ADAMTS6, IL7R, and NOG genes.
Mashevich et al. (2003)	Human peripheral blood lymphocytes exposed to830 MHz RFR for 72 hr, SAR 1.6-8.8 W/kg	A linear increase in chromosome 17 aneuploidy (loss and gain of chromosome) and abnormal chromosome-17 replication were observed as a function of the SAR value, demonstrating that this radiation has a genotoxic effect.
Mazor et al. (2008)	Human lymphocytes exposed to continuous-wave800 MHz for 72 hr;	Increased levels of aneuploidy depending on the chromosome studied as well as on the level of exposure. In chromosomes 1 and 10,

	SAR 2,9 and 4,1 W/kg	there was increased aneuploidy at the higher SAR, while for chromosomes 11 and 17, the increases were observed only for the lower SAR.
*McNamee et al. (2002a)	Human blood cultures exposed to continuous-wave 1900 MHz RFR for 2 h; SAR 0-10 W/kg	No effect on DNA single strand breaks (Comet assay) in leukocytes.
*McNamee et al. (2002b)	Human blood cultures exposed to pulsed 1900 MHz RFR for 2 h; SAR 0-10 W/kg	No effect on DNA single strand breaks (Comet assay) and micronucleus formation in leukocytes.
*McNamee et al. (2003)	Human blood cultures exposed to continuous-wave or pulsed 1900 MHz RFR for 24 h; SAR 0-10 W/kg	No effect on DNA single strand breaks (Comet assay) and micronucleus formation in leukocytes.
*McNamee et al. (2016)	Male C57BL/6 mice exposed to pulse-modulated or continuous-wave 1900 MHz RFR for 4 h/day for 5 consecutive days; whole body average SAR ~0.2 W/kg and ~1.4 W/kg.	No differentially expressed gene expressions were identified in various regions of the brain.
Meena et al. (2014)	Wistar rats exposed to 2.45 MHz RFR 2 h/day for 45 days; SAR 0.14 W/kg. Rats also treated with melatonin.	Increased in DNA single strand breaks (Comet assay) and oxidative stress in testicular tissue. Effects attenuated by melatonin.
Megha et al. (2015a)	Fischer rats exposed to 900 and 1800 MHz RFR for 30 days (2 h/day, 5 days/week); SAR 0.00059 and 0.00058 W/kg	Reduced levels of neurotransmitters dopamine, norepinephrine, epinephrine, and serotonin, and downregulation of mRNA of tyrosine hydroxylase and tryptophan hydroxylase (synthesizing enzymes for the transmitters) in the hippocampus.
Megha et al. (2015b)	Fischer rats exposed to 900, 1800, and 2450 MHz RFR for 60 days (2 h/day, 5 days/week); SAR 0.00059, 0.00058, and 0.00066 W/kg	Increased DNA single-strand breaks (Comet assay) in hippocampus, increased oxidative stress and pro-inflammatory cytokines (IL-2, IL-6, TNF-α, and IFN-γ)
*Meltz et al. (1990)	Mouse leukemic cells exposed to pulsed 2450	No evidence in any mutagenic action by the RFR exposure alone or interaction with

	MHz RFR for 4 h, SAR 40 W/kg	proflavin, a DNA-intercalating drug.
Mildažienė et al. (2019)	Sunflower seeds exposed to 5.28 MHz RFR for 5, 10, 15 min, 12.7 kV/m	RFR exposure induced a long-term effect on gene expression in leaves, mostly stimulating expression of proteins involved in photosynthetic processes and their regulation.
Millenbaugh et al. (2008)	Rats exposed to 35 GHz RFR at 75 mW/cm^2 untik colonic temperature reached 41-41°C, skin was assayed	Changes were detected in 56 genes at 6 h and 58 genes at 24 h post-exposure. Genes associated with regulation of transcription, protein folding, oxidative stress, immune response, and tissue matrix turnover were affected at both times. At 24 h, more genes related to extracellular matrix structure and chemokine activity were altered.
*Miyakoshi et al. (2002)	Human brain tumor derived M)54 cells exposed to 2450 MHz RFR for 2 h; SAR 50 or 100 W/kg	No effect on DNA single strand breaks (Comet assay) observed.
*Mizuno et al. (2015)	WI38VA13 subcloned 2RA human fibroblast cells exposed to wireless power transfer (WPT) 12.5 MHz resonant frequency for 48, 96, or 144 h; SAR 21 W/kg	No effects on cell growth, cell cycle distribution, DNA single strand breaks (Comet assay), micronucleus formation, and hypoxanthine-guanine phosphoribosyltransferase (HPRT) gene mutation.
*Nakatani-Enomoto et al. (2016)	Human spermatozoa exposed to to 1950 MHz Wideband Code Division Multiple Access (W-CDMA)-like RFR for 1 h; SAR 2.0 or 6.0 W/kg	No effect on percentage of 8-hydroxy-2'-deoxyguanosine positive spermatozoa.
Narasimhan and Huh (1991)	Lambdaphage DNA exposed to short pulses of RFR	Observed conformational anomolies in DNA probably resulting from single strand breaks and localized strand separations induced by RFR.
Nikolova et al. (2005)	Mouse embryonic neural progenitor stem cells exposed to 1710-MHz GSM RFR for 6 or 48 h; SAR 1.5 W/kg	Exposure for 6 h, but not for 48 h, resulted in a low and transient increase of DNA double-strand breaks and the transcript level of genes related to apoptosis and cell cycle control..
Nittby et al. (2008)	Fischer 344 rats exposed to 1800 MHz GSM RFR	Expression in cortex and hippocampus of genes connected with membrane functions.

	for 6 h; SAR whole body average 0.013 W/kg, head 0.03 W/kg	
Nylund and Leszczynski (2006)	Human endothelial cell line: EA.hy926 and EA.hy926v1exposed to 900-MHz GSM RFR for 1 h; SAR 2.8 W/kg	Gene and protein expression were altered dependent on the cell type.
Odaci et al. (2016)	Pregnant Sprague - Dawley rats exposed to 900 MHz RFR 1 h each day during days 13 - 21 of pregnancy; SAR whole body average 0.024 W/kg	Testis and epididymis of offspring showed higher DNA oxidation and lipid peroxidation at 60 days postnatal.
Ohtani et al. (2016)	Sprague-Dawley rats exposed to wideband code division multiple access 2140 MHz RFR for 6 h or 3 or 6 h/day for 4 days, SAR 4 or 0.4 W/kg	Exposure at 4 W/kg (at 6 h/day) increased core temperature and upregulation of some stress markers, heat-shock proteins and heat-shock transcription factors family, in the cerebral cortex and cerebellum.
*Ohtani et al. (2019)	Mice exposed to 85 kHz (for charging electrical vehicles) EMF at 25.3 mT, 1 h/day for 10 days	No significant change in gene transcriptional expression in brain and liver.
*Ono et al. (2004)	Pregnant lacZ-transgenic mice exposed intermittently (10 sec On, 50 sec OFF) 16 h/day to 2450-MHz RFR from embryonic days of 0 to 15; SAR whole body average 0.71 W/kg	No significant effects on mutation frequencies at the lacZ gene in spleen, liver, brain, and testis in offspring. The RFR is not mutagenic in utero.
Ozgur et al. (2014)	Hepatocarcinoma cells exposed to intermittent (15 min ON, 15 min OFF) GSM 900- and 1800-MHz RFR for 1, 2, 3, or 4 h; SAR 2 W/kg	Cells showed irregular nuclei pattern and DNA damage (apoptosis).
Pacini et al. (2002)	Human skin fibroblasts exposed to GSM 904.2-MHz RFR for 1 h (from a cell phone); SAR 0.6 W/kg	Increased the expression of mitogenic signal transduction genes (e.g., MAP kinase kinase 3, G2/mitotic-specific cyclin G1), cell growth inhibitors (e.g., transforming growth factor-beta), and genes controlling apoptosis (e.g., bax).

Panagopoulos et al. (2007)	Flies (Drosophila melanogaster) exposed to either GSM 900-MHz or DCS 1800-MHz signals from a digital cell phone, for few minutes per day during the first 6 days of their adult life.	Degeneration of large numbers of egg chambers after DNA fragmentation (apoptosis) of their constituent cells, induced by both types of mobile telephony radiation.
Panagopoulos (2019)	Human peripheral blood lymphocytes exposed to UMTS signal (1900-2200 MHz) using a cell phone for 15 min	Chromatid-type aberrations (gaps and breaks) observed.
Panagopoulos (2020)	Human lymphocytes (in G2/M phase) exposed to UMTS (3G) 1920-1960 MHz RFR entted from a smart phone on talk mode for 15 min; peak power density 92 $\pm$27 $\mu W/cm^2$; averaged over 6 min 29 $\pm$ 14 $\mu W/cm^2$	Chromatid-type aberrations were observed. Effect synergistic with caffeine.
Pandey et al. (2017)	Swiss albino mice exposed to 900-MHz RFR for 4 or 8 h per day for 35 days; SAR 0.0054-0.0516 W/kg	RFR exposure-induced oxidative stress causes DNA single-strand breaks (Comet assay) in germ cells, with altered cell cycle progression leading to low sperm count in mice (depolarization of mitochondrial membranes resulting in destabilized cellular redox homeostasis). Larger effect with longer exposure time, and recovery at 35 days post-exposure.
Pandey and Giri (2018)	Swiss albino mice exposed to GSM 900-MHz RFR 3h twice/day for 35 days, SAR 0.0516-0.0054W/kg	Increased DNA single strand breaks (Comet assay) and free radicals in testis and germ cells, effects attenuated by melatonin.
*Paparini et al. (2008)	Mice exposed to GSM 1800-MHz signal for 1 h; SAR whole body average 1.1 W/kg, brain 0.2 W/kg	No significant modulation in gene expression in whole brain.
Paulraj and Behari (2006)	35-day old male Wistar rats exposed 2 h/day for 35 days to 2450 MHz or 16.6 GHz RFR; SAR 1.0 and 2.01 W/kg,	Increased in DNA single strand breaks (Comet assay) in brain cells for both frequencies.

	respectively.	
Pesnya and Romanovsky (2013)	Onion (Allium cepa) exposed to GSM 900-MHz RFR from a cell phone for 1 h/day or 9 h/day for 3 days; incident power density 0.05 μW/cm^2	Increased the mitotic index, the frequency of mitotic and chromosome abnormalities, and the micronucleus frequency in an exposure-duration manner.
Phillips et al. (1998)	Human Molt-4 T-lymphoblastoid cells exposed to pulsed signals at cellular telephone frequencies of 813.5625 MHz (iDEN signal) and 836.55 MHz (TDMA signal) for 2or 21 h. SAR 0.0024 and 0.024 W/Kg for iDEN and 0.0026 and 0.026 W/kg for TDMA)	Changes in DNA single strand breaks (increase and decrease depending on exposure parameters) (Comet assay) were observed.
*Port et al. (2003)	Human leukaemia cells (HL-60) exposed to pulsed (1 Hz) 400 MHz RFR for 6 min;50 kV/m-25 times higher than the ICNIRP reference levels for occupational exposure	No significant effects on apoptosis, micronucleation, abnormal morphologies and gene expression assayed at 9, 24, 48, and 72 h post-exposure.
Qin et al. (2018)	Male mice exposed to 1800-MHz RFR 2 h/day for 32 days, SAR 0.0553 W/kg	Inhibition of testosterone synthesis might be mediated through CaMKI/RORα signaling pathway.
Qin et al. (2019)	Mouse Leydig cells exposed to a 1800-MHz RFR for 1, 2 or 4 h, SAR 0.116 W/kg	Cells showed downregulated of testosterone synthase genes (*Star, Cyp11a1*, and *Hsd-3β*) and clock genes (*Clock, Bmal1*, and *Rorα*), also reduced level of testosterone and increased oxidative stress.
*Qutob et al. (2006)	Human U87MG glioblastoma cells exposed to pulse-modulated 1900 MHz RFR for 4 h; SAR 0.1, 1.0, and10 W/kg	No significant effect on gene expression.
Racuciu (2009)	Zea mays root tips exposed to continuous-	Increased mitotic index and chromosomal aberration frequency linear with increased

	wave 900 MHz RFR for 1 – 36 h; SAR < 1 W/kg)	exposure time.
Rago et al. (2013)	Human subjects with different daily durations of cell phone use (no use, < 2 h, 2-4 h, > 4 h) and "trouser users" and "shirt users"	>4 h daily use and "trouser users" had higher sperm DNA fragmentations.
Rammal et al. (2014)	Lycospersicon esculentum (tomato) exposed to 1250 MHz RFR for 10 days at 0.0095 mW/cm^2	Increased expression of proteinase inhibitor (Pin II) and Lycospersicon esculentum basic leucine Zipper1 (lebZIP1), two wound-plants genes.
*Regalbuto et al. (2020)	Human fibroblasts exposed to 2450 MHz continuous-wave or pulsed (1 ms square oulses, 50% duty cycle) RFR; SAR 0.7W/kg	No significant effect on γ-H2AX/53BP1 foci, differential gene expression, micronucleus formation, and cell cycle.
Remondini et al. (2006)	Six human cell types exposed to 900 and 1800 MHz RFR; three exposure systems were used, exposure time 1, 24, or 44 h, SAR 1 - 2.5 W/kg (Details in Table 1 of paper.)	Some but not all human cells reacted to RFR with an increase in expression of genes encoding ribosomal proteins and therefore up-regulating the cellular metabolism.
Romano-Spica et al. (2000)	Human hemopoietic and testicular cell types exposed to 50 MHz RFR modulated (80%) with a 16-Hz frequency for 0.5-24 h; the exposure system generates a 0.2 microT magnetic field parallel to the ground and a 60 V/m electric field orthogonal to the earth's magnetic field.	Overexpression of the proto-oncogene ets1 mRNA in Jurkat T-lymphoblastoid and Leydig TM3 cell lines only in the presence of the 16-Hz modulation.
*Ros-Lior et al. (2012)	Cells collected from cheeks of human subjects	Comparing control area with the side cell phone was placed; no significant genotoxic effect was found (DNA damage and cytokinetic defects, proliferative potential, and cell death).

*Roti-Roti et al (2001)	C3H 10T(1/2) cells exposed to 835.62 MHz FDMA or 847.74 MHz CDMA for 7 days and then one-dose X-ray followed by RFR for 42 days; SAR 0.6 W/kg	No significant effect of RFR on neoplastic transformation (induced by X-ray) was observed.
Roux et al. (2006)	Tomato plants exposed to a 900-MHz RFR for 2-10 min at 0.0066 mW/cm^2	Increased stress-related transcripts (calmodulin, protease inhibitor and chloroplast mRNA-binding protein) in leaves. (Increased at 15 min after the end of electromagnetic stimulation, dropped to close to initial levels by 30 min, and then increased again at 60 min.)
Roux et al. (2008)	Tomato plants exposed to a 900-MHz RFR for 10 min at 0.0066 mW/cm^2	Induction of stress gene expression; similar to wound responses suggesting that the radiation is perceived by plants as an injurious stimulus.
Sagripanti and Swicord (1986)	Purified DNA solution exposed to 2.55-GHz RFR for 20min; SAR_{min} and SAR_{max} ranges: 0, 2-8-5 and 21-85 W/kg,	Structural changes in DNA suggested that exposure to RFR can cause single as well as double-strand breaks in DNA in solution.
Sagripanti et al. (1987)	Purified plasmid DNA exposed to RFR in the frequency range from 2.00 to 8.75 GHz for 20 min; SAR 0, 8.5, or 85 W/kg	Induced dose- and exposure-duration-dependent DNA single and double strand beaks depends on the presence of small amounts of cuprous ions.
Sahin et al. (2016)	Rats exposed to 3-G 2100 MH RFR 6 h/day for 10 or 40 days	Oxidative DNA damage (8-hydroxy-2'deoxyguanosine) in brain increased after 10-day exposure but decreased after 40 day exposure.
Said-Salman et al. (2019)	Escherichia coli K-12 DH5α exposed to 2.4 GHz RFR for 5 h	Expression of 101 genes was differentially affects (up- and down-regulation).
*Sakuma et al. (2006)	Human glioblastoma A172 cells exposed to W-CDMA 2.1426 GHz radiation at SARs of 80, 250, and 800 mW/kg and CW radiation at 0.08 W/kg for 2 and 24 h; normal human IMR-90 fibroblasts from fetal lungs exposed to W-	No significant effect on DNA single strand breaks (Comet assay).

	CDMA and CW radiations at a SAR of 0.08 W/kg for 2 and 24 h.	
*Sakurai et al. (2011)	Human glial cell line, SVGp12, exposed to continuous-wave 2450 MHz RFR for 1, 4, and 24 h; SAR 1, 5, and 10 W/kg	No evidence of effect on gene expression.
*Salmen et al. (2018)	*S. aureus*, *S. epidermidis*, and *P. aeruginosa*. Exposed to exposed to 900 and 1800 MHz RFR for 2 h using a cell phone	No significant effects on DNA, growth rate and antibiotic susceptibility.
*Sannino et al. (2006)	Human blood leukocytes exposed to UMTS-1950 MHz signal for 24 h; SAR 0.5 or 2 W/kg	No effect on DNA single strand breaks (Comet assay) and cell viability.
*Sannino et al. (2009a)	Human dermal fibroblasts from a healthy subject and from a subject affected by Turner's syndrome exposed to GSM 900 MHz.RFR for 24 h; SAR 1 W/kg	No significant effect on DNA single strand breaks (Comet assay)
*Sannino et al. (2009b)	Human dermal fibroblasts from one subject exposed to 900 MHz RFR for 24 h; SAR 1 W/kg	No significant effect on DNA single strand breaks (Comet assay) and micronucleus frequency.
Sannino et al. (2011)	Phytohemagglutinin activated human blood lymphocytes exposed to a 900-MHz RFR for 20 h; SAR 1.25 W/kg, and then to mitomycin C	RFR attenuated micronucleus induced by mitomycin c at S-phase, and not at G(0)- and G(1)-phases of the cell cycle. (Adaptive response)
Sannino et al. (2014)	Phytohemagglutinin activated human blood lymphocytes exposed to a 900-MHz RFR for 20 h; SAR 0.3 W/kg, and then to x-ray	RFR attenuated micronucleus induced by x-ray.
Sannino et al. (2017)	Chinese hamster lung fibroblasts exposed to 1950 MHz, Universal	Increased micronucleus frequency at 0.15 and 0.3 W/kg, no effect at 0.6 and 1.25 W/kg; attenuated micronucleus induced by

	Mobile Telecommunication System signal for 20 h; SAR 0.15 – 1.25 W/kg	mitomycin-C at 1.25 W/kg.
Sarimov et al. (2004)	Human lymphocytes exposed to GSM 895-915 MHz signals for 30 min; SAR 0.0054 W/kg	Condensation of chromatin was observed. (Stronger effect at 1 h exposure.)
Sarkar et al. (1994)	Mice exposed to 2450 MHz RFR 2 h/day for 120, 150, and 200 days; SAR 1.18 W/kg	Rearrangements of DNA segments were observed in brain and testis.
Scarfi et al (1996)	Bovine lymphocytes exposed to 9 GHz RFR for 10 min, SAR 70 W/kg	Increased micronucleus frequency.
*Scarfi et al. (2003)	Human peripheral blood lymphocytes exposed to pulsed 120-130 GHz (pulse rate 2 Hz, pulsed duration 4 μs) field for 20 min; delivered energy 1.2 and 0.72 J for the two frequencies, respectively.	No effect on micronucleus frequency and cell proliferation.
*Scarfi et al (2006)	Human lymphocytes exposed to GSM 900 MHz RFR for 24 h, SAR 1, 5, and 10 W/kg).	The results provided no evidence for the existence of genotoxic (micronucleus) or cytotoxic effects
* Schuermann et al. (2020)	Human MRC-5 lung fibroblasts, human osteosarcoma cells, HTR-8/SVneo human trophoblasts, and GFP-tagged XRcc1 cells exposed to intermittent (5/10 min ON/FF) or continuous 1950 MHz, 2450 MHz (GSM or unmodulated) RFR for 1-24 h; SAR 0.5-4.9 W/kg.	No significant effect on DNA single strand breaks (Comet assay).
Schwarz et al. (2008)	Human fibroblasts and lymphocytes exposed to UMTS 1950 MHz RFR for 4-48 h; SAR 0.05 to 2.0 W/kg	Increased DNA single strand breaks (comet assay) and micronuleus were observed in fibroblasts but not in lymphocytes either unstimulated or stimulated with phytohemegglutinin.

Sekeroğlu et al. (2012)	Immature (2 week old) and mature (10 weeks old) Wistar rats exposed to continuous–wave 1800 MHz RFR for 2 h/days for 45 days; SAR 0.38-0.78 W/kg (immature rats), 0.31-0.52 W/kg (mature rats)	Bone marrow cells showed chromosome aberrations, micronucleus frequency, mitotic index and ratio of polychromatic erythrocytes (PCEs) in all exposed groups. Immature group showed more effect and less recovery at day 15 post-exposure. The cytogenotoxic damage in immature rats was statistically higher than the mature rats.
Sekeroglu et al. (2013)	Immature and mature rats exposed to 900 MHz RFR for 2 h/days for 45 days; SAR immature rats, 0.38-0.78 W/kg; mature rats 0.31-0.52 W/kg	Bone marrow cells showed chromosome aberrations, increases in micronucleus frequency, mitotic index, and ratio of polychromatic erythrocytes. Effects persisted for 15 days after exposure.
*Sekijima et al. (2010)	Human A172 (glioblastoma), H4 (neuroglioma), and IMR-90 (fibroblasts from normal fetal lung) cells exposed to continuous-wave and W-CDMA 2.1425 GHz RFR up to 96 h; SAR 0.08, 0.25, 0.8 W/kg	No significant effects on gene expression and cell proliferation.
Semin et al. (1995)	DNA in glycine and formaldehyde exposed to 10 different 4 to 8 GHz RFR 25 ms pulses, 1-6-Hz repetition rate, 0.4 to 0.7 mW/cm^2 peak power density	3 or 4 Hz pulses and 0.6 mW/cm^2 peak power increased the accumulated damage to the DNA secondary structure. However, changing the pulse repetition rate to 1, 5, 6 Hz, as well as changing the peak power to 0.4 or 0.7 mW/cm^2 had no effect (“window effect”).
*Senturk et al. (2019)	Lymphocytes from patients received radiofrequency treatment on inferior turbinate as they were diagnosed with inferior turbinate hypertrophy	No significant effect on DNA single strand breaks (Comet assay) on Day 15 post-treatment. Increase in oxidative stress was observed.
Shah et al. (2015)	Human blood samples exposed to 916-MHz RFR at two power densities and 1-8 hr using an antenna	Chromosomal damage observed in lymphocytes at higher power density and longer exposure duration.

Shahin et al. (2013)	Female mice (*Mus musculus*) exposed to continuous-wave 2.45 GHz RFR 2 h/day for 45v days; SAR 0.023 W/kg	Increased DNA strand breaks (Comet assay) observed in the brain. Changes in oxidative mechanisms and oxidative stress were observed in liver, kidney and ovary. Increased embryo implantation/resorption and abnormal pregnancy were observed.
Shahin et al. (2019)	Male Wistar rats exposed to 900 MHz RFR for 2 h/day for 8 weeks, SAR 1.075 W/kg	Increased DNA single strand breaks (Comet assay) in testis and increased oxidative stress.
Sharma ad Shukla (2020)	Male Wistar rats exposed to 900 MHz RFR for 1, 2, or 4 h/day for 90 days; SAR brain 0.231 W/kg	Increased DNA single strand breaks (Comet assay) and increased oxidative stress in brain.
Shckorbatov et al. (2009)	Human buccal epithelium cells exposed to 35 GHz RFR for 10 sec; SAR 0.75 W/kg	Caused condensation of chromatin. Left circularly polarised radiation induced less effect than linearly polarised radiation. Cell membrane damage observed.
Shckorbatov et al. (2010)	Human fibroblasts exposed to 36.65 GHz RFR at incident power densities of 1, 10, 30 and 100 microW/cm^2 for 10 sec	Chromosome condensation observed at 10 and 100 μW/cm^2 exposure. Right-handed elliptically polarized radiation was more biological activity than the left-handed polarized one.
*Shi et al (2014)	Cultured human lens epithelial cells (HLECs) exposed to 90 kHz magnetic field for 2 and 4 h; 93.36 μT	No significant effects on DNA single strand break (comet assay) and double strand breaks.
*Silva et al. (2016)	Human primary thyroid cells exposed to 895 and 900 MHz RFR for 3-65 h, SAR 0.082-0.170 W/kg	No effect on expressions of Ki-67 (involved in cell proliferation) p53 (tumor suppression) HSP-70 (stress biomarker), and reactive oxygen species.
Smith-Roe et al. (2020)	Male and female Hsd:Sprague Dawley rats and B6C3F1/N mice exposed from Gestation day 5 or Postnatal day 35, respectively, to code division multiple access (CDMA) or global system for mobile modulations over 18 hr/day, at 10-min	Significant increases in DNA single strand breaks (Comet assay) observed in the frontal cortex of male mice (both modulations), leukocytes of female mice (CDMA only), and hippocampus of male rats (CDMA only). No significant increases in micronucleated red blood cells were observed in rats or mice.

	intervals for 19 (rats) or 14 (mice) weeks; SAR 1.5, 3, or 6 W/kg (rats, 900 MHz) or 2.5, 5, or 10 W/kg (mice, 1,900 MHz).	
Sokolovic et al. (2015)	Wistar rats exposed to RFR (4 h/day, for 20, 40, and 60 days) from a Nokia 3110 cell phone:SAR 0.043-0.135 W/kg; some rats treated with melatonin (2 mg/kg, ip)	Melatonin reduced DNA fragmentation in testicular tissues also reversed oxidative changes caused by RFR (malondialdehyde, xanthine oxidase, and acid-DNase)
Soubere Mahamoud et al. (2016)	Human keratinocyte exposed to a 60.4-GHz RFR at an incident power density of 20 mW/cm^2 for 3 hours	No keratinocyte transcriptome modifications were observed. Co-treatment with a glycolysis inhibitor slightly alter the transcriptome of 6 genes encoding transcription factors or inhibitors of cytokine pathways. Thus, the RFR exposure may affect metabolically stressed cells
Souza et al. (2014)	Exfoliated cells from the oral epithelium from human subjects who spent different time using cell phones (group I, t > 5 h; group II, t > 1 h and ≤ 5 h; and group III, t ≤ 1 h).	Structures that may be associated with gene amplification were significantly greater in the individuals in group I. No significant effects on micronucleus frequency and apoptosis and necrosis were observed.
*Speit et al. (2007)	Human fibroblasts (ES1 cells) and Chinese hamster cells (V79) exposed to intermittent (5 min ON/10 min OFF)1800-MHz for 1, 4, 24 h; RFR; SAR 2 W/kg	No significant effects on DNA single strand break (Comet assay) and micronucleus frequency.
*Speit et al. (2013)	Human HL-60 exposed to intermittent (5 min ON/10 min OFF) 1800 MHz RFR for 24 r; SAR 1.3 W.kg	No significant effects on DNA single strand break (Comet assay) and micronucleus frequency.
*Stronati et al. (2006)	Human blood samples exposed to GSM 935-MHz signal for 24h; SAR 1 and 2 W/kg	Lymphocytes showed no changes in DNA single strand breaks (Comet assay), chromosomal aberrations, sister chromatid exchanges, micronuclei frequency and cell cycle. No significant interaction with x-ray.
*Su et al (2017)	Neurogenic A172, U251, and SH-SY5Y cells	No significant DNA damage (γH2AX foci)

	exposed to an intermittently (5 min ON/10 min OFF) 1800 MHz RFR at SAR of 4.0 W/kg for 1, 6, or 24 h.	
*Su et al. (2018)	Primary cultured astrocytes, microglia and cortical neurons were exposed to intermittent (5 min ON/10 min OFF) GSM 1800 MHz RFR for 1, 6 or 24 h; SAR 4.0 W/kg.	The RFR did not elicit DNA double strand breaks (γH2AX foci) but inhibited the phagocytic ability of microglia and the axon branch length and branch number of cortical neurons.
Sun C. et al. (2016)	Mouse embryonic fibroblasts (MEFs) with proficient ($Atm^{+/+}$) or deficient ($Atm^{-/-}$) ataxia telangiectasia mutated, which is critical to initiation of DNA repair, to GSM 1800-MHz RFR for 1, 12, 24, or 36 h; SAR 4 W/kg.	Increased DNA single-strand breaks (SSBs) (Comet assay) and activated the SSB repair mechanism. This effect reduced the DNA damage to less than that of the background level after 36 hours of exposure. In the $Atm^{-/-}$ MEFs, the same RF-EMF exposure for 12 h induced both DNA single and double-strand breaks (Comet assay) and activated the two repair processes, which also reduced the DNA damage to less than the control level after prolonged exposure. (compensatory effects) (Conclusion from interpretation f different results from ($Atm^{+/+}$) and ($Atm^{-/-}$) cells.
Sun, LX et al. (2006a)	Human lens epithelial cells exposed to 217 Hz-modulated 1800 MHz RFR for 2 h; SAR 1, 2, 3, 4 W/kg	No or repairable DNA single strand breaks (Comet assay) was observed after 2 hour irradiation of 1.8 GHz microwave on LECs when SAR </= 3 W/kg. The DNA damages caused by 4 W/kg irradiation were irreversible.
Sun, LX et al. (2006b)	Human lens epithelial cells exposed to 217 Hz-modulated 1800 MHz RFR for 2 h; SAR 1, 2, 3, 4 W/kg	No DNA single strand breaks (comet assay) was induced using comet assay after 2 hours irradiation of 1. 8 GHz microwave on hLECs at the dose SAR < or = 3.0 W/kg. 4.0 W/kg irradiation caused significantly DNA damage and inhibition of hLECs proliferation.
Sun Y. et al. (2017)	HL-60 cells from human leukemia exposed to a 900-MHz RFR for 4 h/day for 5 days, Peak and average SAR 4.1x	Increased oxidative DNA damage, decreased mitochondrial transcription, and increased oxidative stress.

	10^{-4} and 2.5 x 10^{-4} W/kg	
Sykes et al. (2001)	pKZ1 mice exposed daily for 30 min to 217-Hz modulated 900 MHz RFR 1, 5, or 25 days; SAR 4 W/kg	After 25 days of exposure, RFR could lead to a perturbation in recombination frequency which may have implications for recombination repair of DNA.
*Takahashi et al. (2002)	Male Big Blue mice (BBM) exposed to 1.5 GHz RFR in the head region for 90 min/day, 5 days/week, for 4 weeks; SAR 0.67 and 2 W/kg	There was no significant variation in the frequency of independent mutations of the lacItrans gene and deletion mutation in the brain.
Tice et al. (2002)	Human blood leukocytes and lymphocytes exposed to voice modulated 837 MHz produced by an analog signal generator or by a time division multiple access (TDMA) cellular telephone, 837 MHz generated by a code division multiple access (CDMA) cellular telephone (not voice modulated), and voice modulated 1909.8 MHz generated by a global system of mobile communication (GSM)-type personal communication systems (PCS) cellular telephone for 3 or 24 h, SAR 1-10 W/kg	No significant effect on DNA single strand break (Comet assay). Exposure to each of the four RF signal technologies for 24 h at an average SAR of 5.0 or 10.0 W/kg resulted in a significant and reproducible increase in the frequency of micronucleated lymphocytes.
Tiwari et al. (2008)	Blood samples from male human subjects exposed to a CDMA cell phone for 1 h	In vitro exposure to RFR induces reversible DNA single strand breaks (Comet assay) in synergism with aphidicolin, a DNA repair inhibitor,
Tkalec et al. (2009)	Allium cepa L root meristematic cells from seeds exposed to 400 and 900 MHz RFR for 2 h, power density 10, 23, 41 and 120 V/m).	Lagging chromosomes, vagrants, disturbed anaphases and chromosome stickiness were observed.

Tkalec et al. (2013)	Earthworm (Eisenia fetida) exposed to continuous-wave and AM-modulated 900-MHz RFR for 2 - 4 h; SAR 0.00013, 0.00035, 0.0011, and 0.00933 W/kg	Increased DNA single strand breaks (Comet assay) in earthworms coelomocytes and oxidative stress (lipid and protein oxidation)
Tohidi et al. (2020)	Male BALB/c mice exposed to RFR from a cell phone jammer that emits 900- and 1800 MHz CDMA and GSM signals) for 0.5, 1, 2, or 4 h twice a day for 30 days.	Apoptotic genes Bax and Bc12 expression in the hippocampus were upregulated for 1- and 2-h exposures and down-regulated with longer exposure.
*Tomruk et al. (2010)	Nonpregnant and pregnant New Zealand White rabbits exposed to GSM 1800 MHz RFR 15 min/day for a week	No oxidative damage in liver of exposed adult and offspring, increased lipid peroxidation.
Trivino Pardo et al (2012)	T-lymphoblastoid leukemia cells exposed to 900 MHz RFR for 2 or 48 h; SAR 9.0035 W/kg	Changes in gene expressions (e.g., an early activation of genes involved in DNA double- and single-strand breaks repair).
Trosic (2001)	Rats exposed to 2450 MHz RFR for 2, 8, 13 and 22 irradiation treatments of two hours each; power density 5-15 mW/cm^2, SAR 20 W/kg	Increased multinucleated alveolar macrophages- the elevation of the number of nuclei per cell was exposure time- and dose-dependent.
Trosic and Busljeta (2005)	Wistar rats exposed to continuous-wave 2450 MHz RFR 2 h/day 7 days /week for a total of 4, 16, 30, and 60 h. power density 5-10 mW/cm^2 SAR 1-2 W/kg	The frequency of micronucleated bone marrow erythrocytes was significantly increased after 15 irradiation treatments. No effect after 2, 8, and 30 exposure treatments.
Trosic and Busljeta (2006)	Rats exposed to 2450 MHz RFR 2 h/day, 7 days/week; SAR 1.24 W/kg	Bone marrow cell micronucleus frequency increased on experimental day 15, and micronucleated polychromatic erythrocytes in peripheral blood increased on day 8.
Trosic et al. (2002)	Male Wistar rats exposed for 2 h/day, 7 days a week for up to 30 days to continuous-wave 2450	Increased micronuclei in peripheral blood polychromatic erythrocytes on the 2nd, 8th, and 15th day of exposure. It is likely that an adaptive mechanism, both in

	MHz RFR; power density 5-10 mW/cm^2 SAR 1-2 W/kg	erythrocytopoiesis and genotoxicity occurred.
Trosic et al. (2004)	Male Wistar rats exposed for 2 h/day, 7 days/week for 4, 16, 30, and 60 h to continuous-wave 2450 MHz RFR; power density 5-10 mW/cm^2 SAR 1.25 W/kg	The frequency of micronucleated polychromatic erythrocytes in bone marrow was significantly increased on experimental day 15, but not on 2, 8, and 30 days.
Trosic et al. (2011)	Male Wistar rats exposed to GSM 915 MHz RFR for 1 h /day 7 days/week for 2 weeks; SAR 0.6 W/kg	Increased DNA single strand breaks (Comet assay) in brain, renal, and liver cells.
Tsybulin et al. (2013)	Japanese Quail embryos exposed in ovo to GSM 900 MHz signal from a cell phone intermittently (48 sec ON/12 sec OFF) during initial 38 h of brooding or for 158 h (120 h before brooding plus initial 38 h of brooding): SAR 0.000003 W/kg	The lower duration of exposure led to a significant decrease in DNA single strand breaks (Comet assay) in cells of 38-h embryos, while the higher duration of exposure resulted in a significant increase in DNA damage.
Usikalu et al., (2013)	Sprague-Dawley rats exposed to 2450 MHz RFR for 10 min: SAR 0-4.3 W/kg	Increased DNA single strand breaks (Comet assay) found in ovary and testis.
Vafaei et al. (2020)	Pregnant mice exposed to 2400 MHz RFR from a D-link Wi-Fi router from 5 days after mating to 1 day before delivery for 2-4 h/day, head SAR at 30 cm from router 0.09 W/kg	Placenta tissue showed increased superoxide dismutase mRNA, CDKN1A, and Gadd 45a expression. (CDKN1A, and Gadd 45a are involved in DNA repair, cell cycle arrest, apoptosis, and cellular responses to environmental stressors.) Also, increased BAX mRNA and decreased Bcl-2 mRNA leads to apoptosis.
*Valbonesi et al. (2008)	Human trophoblast cell line HTR-8/SVneo exposed to pulsed 1817 MHz RFR or 1 h; SAR 2 W/kg	No significant change in either HSP70 or HSC70 protein or gene expression, or DNA single strand breaks (Comet assay).
Valbonesi et al. (2014)	Rat PC12 cells exposed to continuous-wave 1.8 GHz RFR or GSM-	After PC12 cells exposure to the GSM-217 Hz signal for 16 or 24 h, HSP70 mRNA transcription significantly increased, whereas

	217Hz and GSM-Talk signals for 4, 6, or24 h, SAR 2W/kg	no effect was observed in cells exposed to the CW or GSM-Talk signals.
*Valbonesi et al. (2016)	Rat PC12 cells exposed to 1.8 GHz 217-GSM signal for 24 h. SAR 2 W/kg	Acetylcholine esterase transcriptional or translational pathways not affected, whereas acetylcholine esterase enzymatic activity increased.
Vanishree et al. (2018)	Buccal cells from low and high cellular phone users	There was a significant increase in micronucleus counts in subject who use the phone longer. There was highly significant difference in the mean micronucleus count of participants using (code division multiple access) CDMA than (global system for mobiles) GSM cellular phones.
Varghese et al. (2018)	Female Sprague-Dawley rats exposure 2450 MHz RFR, 4/day. For 45 days; SAR 0.23W/kg	Increased caspase-3 gene expression in brain tissues; decreased antioxidant enzymes and increased lipid preoxidation. Rat showed lowering of learning and memory and expression of anxiety behavior.
Veerachari and Vasan (2012)	Human elected semen exposed to a 900-GSM cellular phone in talk mode for 1 h; power density 1-40 $\mu W/cm^2$ at 2.5 cm from antenna.	Increased DNA fragmentation index and reactive oxygen species, and decreased sperm motility and viability.
*Verschaeve et al. (2006)	Female rats exposed to RF fields for 2 h per day, 5 days per week for 2 years; SAR 0.3 or 0.9 W/kg. the mutagen and carcinogen 3-chloro-4-(dichloromethyl)-5-hydroxy-2(5H)-furanone (MX) was given in the drinking water. at a concentration of 19 mug/ml.	No significant genotoxic activity of MX in blood and liver cells measured by micronucleus and DNA single strand breaks (comet assay). However, MX induced DNA damage in rat brain. Co-exposures to MX and RF radiation did not significantly increase the response of blood, liver and brain cells. (no data on RFR alone.)
Vian et al. (2006)	Tomato plants exposed to a 900-MHz RFR for 10 min at 0.0066 mW/cm^2	Induction of mRNA encoding the stress-related bZIP transcription factor.(3.5 folds at 5-15 min post-exposure)
Vijayalaxmi et al. (1997a)	C3H/HeJ mice exposed to for 20 h/day, 7 day to continuous-wave 2450 MHz RFR MHz for 20 h/day. 7 days/week, over	Significant increases in micronucleus formation in peripheral blood and bone marrow cells were observed.

	18 months: SAR 1.0 W/kg	
Vijayalaxmi et al. (1997b)	Human peripheral blood exposed to 2450 MHz RFR either continuously for 90 min or intermittently (30 min on and 30 min off, repeated three times); SAR 12.46 W/kg	No effect on several genotoxic indexes including chromosome damage, exchange aberrations, and micronucleus frequency.
*Vijayalaxmi et al. (1999)	CF-1 male mice exposed to ultra-wideband electromagnetic radiation (UWBR) for 15 min; SAR 0.037 W/kg	No significant effects on micronucleus frequency and polychromatic erythrocytes in peripheral blood and bone marrow cells at 16 and 24 h post-exposure.
*Vijayalaxmi et al. (2000)	3 human peripheral blood samples exposed to pulsed 2450-MHz RFR for 2 h; SAR 2.135 W/kg	No significant effect on DNA single strand breaks (Comet assay) was observed in lymphocytes immediately and at 4 h post-exposure.
*Vijayalaxmi et al. (2001a)	4 human peripheral blood samples exposed to835.62 MHz (FDMA) RFR for 24 h, SAR 4.4 or 5.0 W/kg	Lymphocytes were stimulated with a mitogen, phytohemagglutinin. No significant effects at 48 and 72 h post=exposure in mitotic indices, incidence of exchange aberrations, excess fragments, binucleate cells, and micronucleus frequency.
*Vijayalaxmi et al. (2001b)	Male Sprague-Dawley rats exposed to continuous-wave 2450 MHz RFR for 24 h; SAR 12 W/kg	Peripheral blood and bone marrow smears showed no effects on frequency of micronuclei in polychromatic erythrocytes at 24 h post-exposure. .
*Vijayalaxmi et al. (2001c)	4 human peripheral blood samples exposed to continuous-wave 847.74 MHz (CDMA) RFR for 24 h; SAR 4.9 or 5.5 W/kg	No significant effects on mitotic indices, frequencies of exchange aberrations, excess fragments, binucleate cells, and micronuclei in lymphocytes at 48 and 72 h post-exposure.
*Vijayalaxmi et al. (2003)	Timed-pregnant Fischer 344 rats (from nineteenth day of gestation) and their nursing offspring (until weaning) exposed to a far-field 1.6 GHz Iridium wireless communication signal for 2 h/day, 7 days/week	No significant effects on micronuclei in polychromatic erythrocytes in bone marrow.

	for 2 years; SAR 0.036 to 0.077 W/kg	
*Vijayalaxmi et al. (2004)	Mice exposed to 42.2 GHz RFR applied to the nasal region 30 min/day for 3 days; peak SAR 622 W/kg	No effect on micronucleus frequency in polychromatic erythrocytes of peripheral blood and bone marrow cells collected 24 h after exposure.
*Vijayalaxmi et al. (2006)	Human peripheral blood samples exposed to 2.45 GHz or 8.2 GHz pulsed-wave RFR for 2 h; SAR 2.13 W/kg (245 MHz) or 20.71 W/kg (8.2 GHz),	No significant effects on chromosomal aberrations and micronuclei in lymphocytes.
Vilic et al. (2017)	Honey bee (Apis mellifera) larvae exposed to 900 MHz at field levels of 10, 23, 41 and 120 V m^{-1} for 2 h. At a field level of 23 V m^{-1} the effect of 80% AM 1 kHz sinusoidal and 217 Hz modulation was investigated as well.	DNA single strand break (Comet assay) increased significantly in honey bee larvae exposed to modulated (80% AM 1 kHz sinus) field at 23 V m^{-1}. Oxidative changes also observed. Modulated RF-EMF produced more negative effects than the corresponding unmodulated field.
*Waldmann et al. (2013)	Human peripheral blood samples exposed to GSM 1800 MHz RFR for 28 h; SAR 0.2, 2, and 10 W/kg	No significant effects on lymphocytes on chromosome aberration, micronucleus frequency, sister chromatid exchange and DNA single strand break (comet assay).
Wang et al. (2015)	Neuro-2a (mouse neuroblastoma) cells exposed to GSM 900 MHz RFR for 24 h; SAR 0.5, 1 or 2 W/kg	Increased DNA oxidative damage (comet assay) and reactive oxygen species. OGG1(a base excision DNA repair enzyme) may be involved.
Wu et al. (2008)	Human lens epithelial cells exposed to 1800 MHz mobile phone radiation for 24 h; SAR 4 W/kg	Increased DNA single strand breaks (Comet assay) and reactive oxygen species.
Xu et al. (2010)	Sprague-Dawley rat primary cultured cortical neurons exposed to intermittent (5 min ON/10 min OFF) 217-Hz pulsed 1800 MHz RFR for 24 h; SAR 2 W/kg	Increased in the levels of 8-hydroxyguanine, a common biomarker of DNA oxidative damage, in the mitochondria of neurons, levels of mitochondrial RNA (mtRNA) transcripts showed a reduction.
Xu et al. (2013)	Six different types of cells intermittently (5	RFR induced DNA damage (γH2AX foci and alkaline and neutral comet assay) in a

	min ON/10 min OFF) exposed to pulsed GSM 1800 MHz RFR for 1 or 24 h: SAR 3.0 W/kg	cell type-dependent manner.
Yadav and Shama (2008)	Buccal-mucosa cells from 85 regular cell phone users (exposed) and 24 non-users (controls)	A positive correlation between 0-1, 1-2, 2-3 and 3-4 years of exposure and the frequency of micronucleated cells and_total micronuclei.
Yakymenko et al. (2018)	Quail embryos exposed to GSM 1800 GHz signal from a smart phone (48 s ON/12 s OFF) for5 days before and 14 days during incubation , power density 0.00032 mW/cm^2	Increased DNA single sand breaks (comet assay), oxidative DNA damage, reactive oxygen species, and mortality.
Yan et al. (2008)	Adult Sprague-Dawley rats exposed to a cell phones 1.9 GHz (PCE CDMA) for 6 h per day for 126 days (18 weeks).	Significant mRNA up-regulation of injury-related proteins in the brain of rats exposed to cell phone radiation
Yao et al. (2004)	Rabbit lens epithelial cells exposed to continuous-wave 2450-MHz RFR for 8 h, power densities 0.10, 0.25, 0.50, 1.00, and 2.00 mW/cm^2	The RFR higher than 0.50 mW/cm^2 can inhibit lens epithelial cell proliferation, and increase the expression of P27Kip1.
Yao et al. (2008)	Human lens epithelial cells intermittently (5 min ON/10 min OFF) exposed to GSM 1.8 GHz RFR for 2 h; SAR 1, 2, 3, and 4 W/kg	Increased DNA single strand breaks (Comet assay), no change in double strand breaks (γH2AX foci), and increased reactive oxygen species.
Ye et al. (2016)	Chicken embryos exposed to GSM 900 MHz RFR from cell phones 3 h/day from day 2 to day 21 of incubation	Increased DNA single strand breaks (Comet assay) from blood cells and mortality.
*Yildirim et al. (2010)	People who lived around cell phone base stations and healthy controls	There was no significant difference in micronucleus frequency and chromosomal aberrations in blood lymphocytes between the two study groups
Zalata et al. (2015)	Human semen samples exposed to 850-MHz	Significant increase in sperm DNA fragmentation percent, clusterin gene

	RFR from a cell phone for 1 h; SAR 1.46 W/kg at 10 cm	expression and clusterin protein (associated with clearance of cellular debris and apoptosis) levels in the exposed semen samples.
*Zeni et al. (2003)	Human peripheral blood exposed to continuous wave 925 MHz RFR or GSM 925 MHz (6 min ON/ 3 h OFF for 44h (SAR 1.6 W/kg); or GSM signal 1 h/day for 3 days (SAR 0.2 W/kg).	No statistically significant differences were detected in micronucleus frequency in lymphocytes.
*Zeni et al. (2005)	Human peripheral blood lymphocytes exposed to GSM 900 MHz signal for 2 h; SAR 0.3 and 1 W/kg	No significant effects on DNA single strand breaks (Comet assay), chromosome aberration, or sister chromatid exchange.
*Zeni et al. (2007)	Human whole blood samples exposed to 120 GHz (SAR 0.4 W/kg) and 130 GHz (SAR 0.24, 1.4, or 2 W/kg) RFR for 20 min.	No effects in leukocytes on micronucleus frequency and DNA single strand breaks (comet assay).
*Zeni et al. (2008)	Human peripheral blood exposed intermittently (6 min ON/2 h OFF) to 1945 MHz RFR for 24 – 68 h; SAR 2.2 W/kg	No significant effects on DNA single strand breaks (Comet assay) and micronucleus frequency in leukocytes.
Zeni et al. (2012a)	Human peripheral blood lymphocytes exposed to 1950-MHz RFR UMTS (universal mobile telecommunication system) signal for 20 h; SAR 1.25, 0.6, 0.3, or 0.15 W/kg. and then tomitomycin C	Cells pre-exposed to RFR at 0.3W/kg (less consistent at the other SARs) and then treated with MMC showed a significant reduction in the frequency of micronucleus, compared with the cells treated with MMC alone
*Zeni et al. (2012b)	Rat neuron-like pheochromocytoma (PC12) cells exposed to 1950-MHz 3G Universal Mobile Telecommunications System (UMTS) signal for 24 h; SAR 10 W/kg	No effect on DNA single strand break (Comet assay), cell viability, and apoptosis.

Zhang et al. (2006)	Chinese hamster lung cells exposed intermittently (5 min ON/10 min OFF) to GSM 1800 MHz RFR for 1 or 24 h; SAR 3 W/kg	Cells exposed for 24 h showed increased DNA double strand breaks (γH2AX foci).
Zhang et al. (2002)	Human whole blood exposed to 2450 MHz RFR for 2 h; Power density 5 mW/cm^2	2450-MHz RFR cannot induce DNA and chromosome damage, but can increase DNA single strand breaks (Comet assay) induced by mitomycin C .
Zhang et al. (2008)	Primary culture of rat neurons exposed to a 1.8 GHz RFR for 24 h; SAR 2 W/kg.	Changes (up- and down-regulation) of many genes transcription (involving cytoskeleton, signal transduction pathway, metabolism, etc.) were observed.
Zhao J. et al. (2020)	Escherichia coli exposed to 3.1 THz RFR for 8 h at 33 mW/cm2 and 10 Hz repetition frequency	Plasmid copy number, protein expression and fluorescence intensity of bacteria from the irradiated area were 3.8-, 2.7-, and 3.3 times higher than in bacteria from the un-irradiated area, respectively.
Zhao R. et al. (2007)	Rat neurons exposed to pulsed 217-Hz modulated 1800 MHz RFR for 24 h; SAR 2 W/kg	up- and down-regulation of genes transcriptions were observed.
Zhao TY. et al. (2007)	Primary cultured neurons and astrocytes exposed to a GSM 1900 MHz cell phone for 2 h;	Up-regulation of caspase-2, caspase-6 and Asc (apoptosis associated speck-like protein containing a card) gene expression in neurons and astrocytes. Additionally, astrocytes showed up-regulation of the Bax gene. Neurons appeared to be more sensitive to this effect than astrocytes.
*Zhijian et al. (2009)	Leukocytes from four young healthy donors exposed intermittent (5 min ON/10 min OFF) to 1800 MHz RFR for 24 h; SAR 2 W/kg; Cell also exposed x-ray	No significant effect on DNA single strand breaks (Comet assay) and no synergistic effect with x-ray.
*Zhijian et al. (2010)	Human B-cell lymphoblastoid cells exposed to 1800 GHz RFR for 2 h; SAR 2 W/kg	RFR did not directly induce DNA single strand breaks (Comet assay)
*Ziemann et al. (2009)	Peripheral blood erythrocytes of B6C3F1	No significant effect on micronucleus frequency.

	mice exposed to GSM 900 or DCS 1747 MHz RFR 2 h/day, 5 days /week for 2 years; SAR 0.4, 1.3 and 4 W/kg	
Zong et al. (2015)	Mice exposed to 900 MHz RFR 4 h/day for 7 days; SAR 0.05 W/kg	RFR alone had no effect on DNA single strand breaks (Comet assay) and oxidative damage in blood leukocytes. It attenuated bleomycin-induced DNA breaks and repair, and oxidative damage.
Zothansiama et al. (2017)	Blood samples from people lived closed to cell phone base station	The exposed group, residing within a perimeter of 80 m of mobile base stations, showed significantly higher frequency of micronuclei in lymphocytes when compared to the control group, residing 300 m away from the mobile base stations.
Zotti-Martelli et al. (2000)	Human peripheral blood lymphocytes exposed to 2.45 and 7.7 GHz RFR for 15, 30, or 60 min; power density 10, 20, or 30 mW/cm^2	Increased micronucleus frequency at a power density of 30mW/cm^2 and after an exposure of 30 and 60 min.
Zotti-Martelli et al. (2005)	Human whole blood samples exposed to continuous-wave 1800 MHz RFR for 60, 120 and 180 min; power density 5, 10, or 20 mW/cm^2	A statistically significant increase of micronucleus was observed in lymphocytes dependent on exposure time and applied power density.
*Zuo et al. (2015)	Sprague-Dawley rat spiral ganglion neurons exposed intermittently (5 min ON/10 min OFF) to GSM 1800 MHz RFR for 24 h; SAR 2 and 4 W/kg	The RFR could not directly induce DNA single strand breaks (Comet assay) in normal spiral ganglion neurons, but it could cause the changes of cellular ultrastructure at SAR 4.0 W/kg when cells are in fragile or micro-damaged condition.

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Supplement 2

Genetic effects of static and ELF EMF (*study with no effect observed) Study reported effect =168 (79%); study reported no effect = 45 (21%). (literature up to January 2021)

	Exposure conditions	**Results**
Agliassa et al. (2018)	Arabidopsis thaliana (thale cress) exposed to 0.00004 mT static magnetic field for 38 days after sowing.	Changes in gene expression in leaf and floral meristem (cryptochrome-related gene involved); delayed flowering time and a significant reduction of leaf area index and flowering stem length, with respect to controls under geomagnetic field.
Ahuja et al. (1999)	Human peripheral blood samples exposed to 50 Hz EMF at 2, 3, 5, 7, or 10 mT	Increased DNA single strand breaks (Comet assay) in lymphocytes.(Damage levels higher in female than in male subjects.)
*Albert et al. (2009)	Human subjects exposed to exposed to 60-Hz magnetic field at 0.2 mT for 4 h	No significant effect on DNA single strand breaks (Comet assay) and micronucleus frequency in lymphocytes.
Alcaraz et al. (2013)	Swiss mice exposed to 50-Hz magnetic field at 0.2 mT for 7, 14, 21, or 28 days	Increased micronucleus frequency in bone marrow. Effect not affected by antioxidants.
Al-Huqail and Abdelhaliem (2015)	Maize seedlings exposed to 50-Hz electric field at 6 kV/m for 1, 3, or 5 days	Increased DNA single strand breaks (comet assay)
Amara et al. (2006)	Male rats exposed to a static magnetic field at 128 mT, I h/day for 30 days	Increased 8-oxo-dG concentration and oxidative damage in testis.
Amara et al. (2007a)	Human monocytic leukemia THP-1 cells exposed to static magnetic field at 250 mT for 1, 2, or 3 h	Lower level of DNA single strand breaks (Comet assay) at 3 h of exposure, no effect on oxidative damages and enzymes and oxidative DNA damage.
Amara et al. (2007b)	Rats exposed to a static magnetic field at 128 mT, 1 h/day for 30 days	Increased 8-oxo-7,8-dihydro-2'-desoxyguanosine in kidney but not in liver. Also decreased anti-oxidative enzymes and increased lipid peroxidation. Zinc supplementation attenuated DNA oxidation induced by static magnetic field in kidney to the control level.

*Amara et al. (2009)	Rats exposed to a static magnetic field at 128 mT, 1 h/day for 30 days	No significant effect on 8-oxo-7,8-dihydro-2'-deoxyguanosine in frontal cortex and oxidative stress induced. However, there was an increase in metallothioneins level which might have protected DNA from oxidative damage.
*Amara et al. (2011)	Rats exposed to a static magnetic field at 128 mT, 1 h/day for 30 days, also treated with cadmium (Cd)	Magnetic field had no interaction on Cd-induced increase in 8-oxo-7,8-dihydro-2-desoxyguanosine in the frontal cortex and hippocampus. However, static magnetic field enhanced Cd-induced increase in oxidative damage in the rat brain.
Arruda-Neto et al. (2009)	*Microcystis panniformis*, the eukaryote *Candida albicans* and human MRC5 lung cells exposed to gamma radiation and then to static electric field for 2-20 h at 20- 1250 V/cm	Static electric field caused suppression of DNA repair in *C. albicans*. It decreased cell growth in *M. panniformis* when compared with gamma radiation alone. The electric field increased number of nuclei with γ-H2AX foci in the irradiated MRC5 cells. Electric field interferes mostly in the DNA repair mechanisms.
Ashta et al. (2020)	Human glioblastoma cells (A172) exposed to 10 Hz or static magnetic field at 5 mT, up to 96 h	Increased p52 gene expression, cytotoxicty and free radical formation; effects enhanced by Temozolomide.
Back et al. (2019)	Mouse embryonic stem cells exposed to hypomagnetic field (<0.005 mT) up to 12 days	Induced abnormal DNA methylation through the dysregulation of DNA methyltransferase3b (Dnmt3b) expression, eventually resulting in incomplete DNA methylation during differentiation.
Bagheri Hosseinabadi et al. (2019)	Blood samples from 102 thermal power plant workers as the exposure group and 136 subjects as the unexposed group.	Increased DNA single strand breaks (Comet assay) in lymphocytes of exposed subjects.
Bagheri Hosseinabadi et al. (2020)	Blood samples from thermal power plant workers; mean levels of exposure to ELF magnetic and electric fields were .0165 mT (±6.46) and 22.5 V/m (±5.38), respectively,	DNA single strand breaks (Comet assay) in lymphocytes decreased by antioxidants.

Balamuralikrishnan et al. (2012)	Blood from electrical workers exposed to ELF EMF occupationally	Increased chromosome aberrations and micronucleus in lymphocytes.
Baraúna et al. (2015)	Chromobacterium violaceum bacteria cultures exposed to ELF-EMFfor 7 h at 0.00066 mT	Five differentially expressed proteins detected including the DNA-binding stress protein, which may help to prevent physical damage to DNA.
Belyaev et al. (2005)	Human lymphocytes exposed to 50 Hz magnetic field at 0.015 mT (peak) for 2 h (measurements made at 24 and 48 h after exposure).	Induced chromatin conformation changes and decreased background 53BP1 (protein co-localized with DNA double strand breaks and involves in DNA damage signaling pathway.)
Bertea et al. (2015)	Arabidopsis thaliana (thale cress) exposed to artificially reversed geomagnetic field conditions for 10 days at .0419 mT	Significant effects on plant growth and gene expression observed. This supports the hypothesis that GMF reversal contributes to inducing changes in plant development that might justify a higher selective pressure, eventually leading to plant evolution.
Borhani et al. (2011)	Female NMRI mice exposed to a 50-Hz EMF at 0.5 mT for 4 h/day, 6 days/week for 2 weeks. Mated on day 8 after exposure, on day 4, blastocysts were obtained by flushing the uterus horns.	DNA fragmentation index increased and decrease in blastocytes in exposed group.
*Brix t al. (2020)	Young volunteers allocated to three study arms were exposed to [^{18}F] fluoro-D-glucose alone, to a 3-T SMF alone or to both combined over 60 min at a PET/CT or a PET/MRI system.	No significant change in lymphocyte DNA double strand breaks (γH2AX) to static magnetic field or interaction with [^{18}F] fluoro-D-glucose.
Buddak et al. (2012)	Murine AT478 carcinoma cells cultured with cisplatin exposed to 50-Hz EMF for 16 min at 1 mT	Exposure to ELF-EMF alone resulted in an increase in DNA single strand breaks (Comet assay) compared to control cells. ELF-EMF lessened the effects of oxidative stress and DNA damage that were induced by cisplatin;

		however, ELF-EMF alone was a mild oxidative stressor and DNA damage inducer. The addition of ELF-EMF exposure to cisplatin treatment resulted in decreased ROS levels and antioxidant enzyme activity.
Burgos-Molina et al (2020)	DNA double strand breaks were induced in Saccharomyces cerevisiae yeast and exposed to a 50-Hz magnetic field for 21 days at 2.45 mT	Long-term magnetic field exposure increased the DNA repair activity.
Calabro et al. (2011)	Human neuronal-like cells exposed to static (2 mT) and 50 Hz (1 mT) for 3 h.	Fourier self deconvolution spectroscopic analysis showed alteration in DNA/RNA and increased beta-sheet.
Calabro et al. (2020)	Human Neuronal-like cells and roots of Allium sativum and Vicia faba exposed to a static and 50 Hz magnetic fields at intensities ranging from 1 mT to 0.8 T	Exposure to both low- and high-intensity magnetic fields in typical human and plant cells induces uncoiling and unpackaging of chromatin constituents, followed by chromosome alignment towards the direction of applied magnetic field, providing further demonstration that magnetic fields can induce the orientation of organic macromolecules even at low-intensity values.
*Cantoni et al.(1996)	Cultured mammalian cells exposed to 50 Hz electric (0.2 - 20 kV/m), magnetic (0.0002-0.2 mT), or combined electric and magnetic fields.	Repair of DNA single strand breaks (Comet assay) induced by the carcinogens methylmethane sulphonate (MMS), chromate, and 254 U.V. radiation not affected by ELF EMF exposure.
Celikler et al. (2009)	Workers from transfrormer and distribution line stations. The electric field was in the range from 130–8310 V/m and from 300–15,000 V/m, the magnetic field was between 0.5 and 1.7 A/m and 0.25–17 A/m around and inside transformer buildings. Average time of exposure was 19 years.	Increased chromosomal aberrations and micronucleus in peripheral lymphocytes. The frequency of chromosomal aberration in exposed groups correlated with the years of exposure.

*Cellini et al. (2008)	Escherichia coli ATCC 700926 exposed to 50-Hz EMF (0.1, 0.5, 1.0 mT); 20-120 min	No changes among DNA finger-printings. Other measurements indicates 50 Hz EMF acts as a stressing factor on bacteria
*Chahal et al. (1993)	Escherichia coli strain AB1157 exposed to a frequency of 1 Hz with field strengths of 1 or 3 kV m-1	Low frequency electromagnetic fields do not increase spontaneous mutation, induce DNA repair or increase the mutagenic effects of UV or mitomycin C.
Chen GD et al. (2008)	Human MCF-7 breast cancer cells exposed to a 50-Hz magnetic fields for 24 h at 0.4 mT	Identified three 50 Hz MF responsive genes in MCF-7 cells.
*Chen G et al. (2012)	*Saccharomyces cerevisiae* yeast cells exposed to a 50-Hz magnetic field at 0.4 mT for 6 h	Yeast cells did not alter gene expression in response to 50 Hz magnetic field.
Chan J. et al. (2020)	Human choriocarcinoma cells exposed to DC electric field (150 mV/mm) for 8 h	Increased gene expressions of ErbB and HIF-1 signaling pathways involved in cell migration/motility, cell cycle progression and proliferation.
Chen WF et al. (2010)	Human myelogenous leukemia K562 cells exposed to static magnetic field at 8.8 mT with or without cisplatin	Static magnetic field exposure induced DNA to become thicker than controls, and enhanced DNA breakage (Comet assay) induced by cisplatin.
Cho S et al. (2014)	Human lymphocytes exposed to 60-Hz EMF at 0.8 mT for 12-72 h with or without gadolinium.	ELF-EMF increased cell death, micronucleus frequency, DNA single strand break (Comet assay), and apoptosis induced by gadolinium.
Cho YH et al. (2007)	Human fibroblasts exposed to 60-HZ EMF at 0.8 mT plus bleomycin for 28, 88, and 240 h	The co-exposure of cells to bleomycin and EMF led to a significant increase in the frequencies of micronucleus and aneuploidy compared to the cells treated with bleomycin alone.
Chow and Tung (2000a)	Escherichia coli strain XL-1 Blue exposed a 50-HZ magnetic field at 0.1-1.2 mT for 1 h	This result was indicative that the efficiency of DNA repair had been improved. The improvement was found to be mediated by the induced overproduction of heat shock proteins DnaK/J (Hsp70/40).
Chow and Tung (2000b)	Escherichia coli strain XL-1 Blue (transformed by plasmid pUC8 that had been mutagenized by	Improved efficiency of DNA repair mediated by the induced overproduction of heat shock proteins DnaK/J (Hsp70/40).

	hydroxylamine exposed a 50-HZ magnetic field at 0.1-1.2 mT for 1 h	
Collard et al. (2013)	Epidermis cultures harvested from human abdominoplasty exposed to ELF electric fields (a biphasic, asymmetric, charge-balanced current stimuli, with a repetition frequency of4 0 Hz modulated by a fundamental frequency of 0.125 Hz.The exposure was repeated during 4 s followed by a 4 s break for 40 min/day for 11 days	Observed a significant change in genes expression after 4 days and change in expression in another group of genes at day 4 and 7. Genes are involved in cell proliferation or differentiation, mitosis, cell cycle or in the DNA replication transcription and translation.
Consales et al. (2018)	Human SH-SY5Y neuroblastoma cells and mouse primary cortical neurons exposed to a 50-Hz magnetic field at 1 mT for 4-72 h	Expressions of microRNA miR-34b/c that caused mitochondrial oxidative stress, also altered α-synuclein expression involved in synaptic functions. These effects may be related to neuro-degeneration.
Cuccurazzu et al. (2010)	Mice exposed to 50 Hz EMF at 1 mT for 1-7 h/day for 7 days	Induced increases in the transcription of pro-neuronal genes (Mash1, NeuroD2, Hes1) and genes encoding Ca(v)1.2 channel α(1C) subunits in the hippocampus. Generation of new granule cells in the dentate gyrus.
Del Re et al. (2006)	Escherichia coli exposed to sinusoidal or pulsed square wave 50-Hz magnetic field at 1 mT for 40 min	Sinusoidal magnetic field exposure induced a significantly higher level of DnaK and GroEL, whereas a lower level was observed after pulsed magnetic field exposure. When bacterial cells were exposed to heat shock (HS) after ELF-magnetic field exposure: again sinusoidal and pulsed fields resulted in an increase and in a reduction of HSP amount.
Delimaris et al. (2006)	Human lymphocytes exposed to 50-Hz pulsed electric fields (10-Hz carrier frequency) at 4 x 10^5 V/m for 120 min	Increased in DNA single strand breaks (Comet assay).
Di Campli et al. (2010)	Helicobacter pylori biofilm exposed to 50-	No changes in DNA patterns were recorded, whereas a modulation in amiA gene

	Hz EMF at 1 mT for 2 days	expression was detected; phenotypic changes induced.
Dominici et al. (2011)	Lymphocytes from welders (average magnetic field exposure from personal dosimeters 0.00781 mT (general environmental level 0.00003 mT)	Higher micronucleus frequency correlated with EMF exposure levels; decreased in sister chromatid exchange frequency.
Dong et al. (2019)	Human pre-osteoclast RAW264.7 cells exposed to a 16 T static magnetic field for 2-4 days	HiSMF markedly blocked the expression of osteoclast-associated transcription factors and osteoclast marker genes and inhibited iron absorption and iron storage-related protein expression. Mitochondrial concentration and oxidative stress levels in osteoclasts were decreased under magnetic field exposure.
Du et al. (2008)	Cultured human lens epithelial cells exposed 50-Hz magnetic field at 0.4 mT for 2 h, 6 h, 12 h, 24 h and 48 h	Increased DNA doubled strand breaks (γ–H2AX foci) after 24 h exposure.
Duan et al. (2015)	A mouse spermatocyte-derived GC-2 cell line intermittently (5 min on and 10 min off) exposed to a 50 Hz EMF at 1, 2 or 3 mT for 24 h	Increased DNA strand breaks (Comet assay and γ–H2AX foci) at 3 mT exposure.
El-Bialy and Rageh (2013)	Mice with Ehrlich tumors exposed to a 50-Hz magnetic field 1 h/day for 2 weeks at 10 mT	Exposure cause DNA single strand breaks (Comet assay) in tumor cells and increased micronucleus frequency in bone marrow cells. ELF-MF enhanced the effects of cisplatin.
Erdal et al. (2007)	Wistar rats exposed to 50 Hz magnetic field at 1 mT for 4 h or 4h/day for 45 days	Micronucleus frequency higher in bone marrow cells of long-term exposed rat. Mitotic index decreased in both exposed groups.
*Fairbairn and O'Neill (1994)	Human cells exposed to ELF-EMF	No significant effect on DNA single strand breaks (Comet assay)
Fan et al. (2005)	Rat bone marrow derived-mesenchymal stem cells exposed to a 50-Hz EMF at 1 mT for 4 h/day for 3 days	Increased cell viability, DNA synthesis and proportion of cells in S phase and up-regulated the expressions of hematopoietic growth factors.

Fan et al. (2018)	*Enterococcus faecalis* (isolated from dental infection) exposed to a static magnetic field at 170 mT for 24 or 72 h.	Static magnetic field up-regulated the expression of stress gene (dnaK) and virulence genes (efaA and ace). Synergistic with alkaline pH induced by calcium hydroxide (a major dental antimicrobial) in antimicrobial action and up-regulation of stress and virulence genes.
Fatigoni et al. (2005)	Tradescantia (a perennial wildflower) exposed to a 50-Hz magnetic field at 1 mT for 6 or 24 h	Caused a time-dependent increase in micronucleus frequency.
Fedrowitz and Loscher (2012)	Female F344 and Lewis rats exposed to a 50-Hz magnetic field at 0.1 mT 24 h/day for two weeks	F344 breast tissue showed alterations in gene expression, which were absent in Lewis rats, particularly, α-amylase, a stress marker.
*Fiorani et al. (1992)	Human immortalized myelogenous leukemia K562 cells exposed to50-Hz electric (0.2-20 kV/m) or magnetic (0.0002-.2 mT) or combination of electric and magnetic fields, for 24 h	No detectable DNA lesions (measured by filter elution technique).
Focke et al. (2010)	Human fibroblasts exposed to intermittent (5 min ON/10 min OFF) 50-Hz EMF at 1 mT for 15 h	Increased DNA single strand breaks (Comet assay) caused by magnetic and not electric field, No oxidative DNA damage. Could be caused by minor disturbances in S-phase processes and occasional triggering of apoptosis rather than by the generation of DNA damage.
*Frahm et al. (2006)	Mouse macrophages exposed to a 50-Hz magnetic field for 45 min, 12, 24, or 48 h; 0.05 – 1 mT	No genotoxic effect (micronucleus formation); increased phagocytic activity, free radicals, and IL-1 beta production.
*Frazier et al. (1990)	Human lymphocytes induced with DNA damage with ionizing radiation were exposed to 60-Hz magnetic field at 1 mT, electric field at 1 or 20V/m, or combinations of magnetic and electric	EMF exposure did not affect repair of DNA single strand breaks (Comet assay).

	fields (0.2 V/m and 0.05 mT, 6 V/m and 0.6 mT, or 20 V/m and 1 mT) up to 180 min	
Frisch et al. (2013)	Transfected rat primary fibroblast (RAT1) cells exposed to 10 Hz electric fields at 20-500 V/m for 2 h	Induced HSP70 heat shock expression, with peak responses obtained at 8 h following exposure.
Giorgi et al. (2011)	Two Escherichia coli model systems were exposed to sinusoidal or pulsed-square wave magnetic fields of various frequencies (20, 50, 75 Hz) and for different exposure times (15 and 90 min). at 1 mT	ELF-MF exposure affected transposition activity (transposon (Tn) mobility) and the effects critically depended on the wave shape of the field, but not on the frequency and the exposure time.
*Giorgi et al. (2014)	Human neuroblastoma BE(2)C cells treated with hydrogen peroxide exposed to 50-Hz pulsed magnetic field at 1 mT for 1-72 h	Pulsed magnetic field exposure did not interfere with genotoxicity (DNA double strand breaks measured by γ-H2AX foci) and cytotoxicity induced by oxidative stress.
Giorgi et al. (2017)	Human neural cells (BE(2)C) exposed to pulsed 50-Hz magnetic field at 1 mT for 24 and 48 h in combination with oxidative stress (hydrogen peroxide)	Pulsed magnetic field and oxidative stress induced weak decreases and increases of DNA methylation levels; combined exposure led to significant transient decrease of DNA methylation levels at different genome loci.
Heredia-Rojas et al. (2010)	Human non-small cell lung cancer cells (INER-37) and mouse lymphoma cells (RMA E7) (transfected with a plasmid with hsp70 expression when exposed to magnetic field and contains the reporter for the luciferases gene) exposed to a 60-Hz magnetic field at 0.008 and 0.00008 mT for 20 min.	An increased in luciferase gene expression was observed in INER-37 cells exposed to magnetic field, but similar exposure had no effect on the RMA E7 cell line.

Hong et al. (2005)	Mice exposed to a 50-Hz EMF at 0.2 or 6.4 mT for 4 weeks	EMF induced DNA single strand breaks (Comet assay) in testicular cells and chromatin condensation in spermatozoa.
*Huwiter et al. (2012)	Escherichia coli K-12 MG1655 exposed at 50-Hz magnetic fields generated by three signal types (sinusoidal continuous, sinusoidal intermittent, and power line intermittent) at 1 mT for 8 min, 2.5 h, or 15 h	No effect on transcription of 4358 gene studied.
Ivancsits et al. (2002)	Human diploid fibroblasts exposed to continuous or intermittent (5 min ON/10 min OFF) 50-Hz EMF at 1 mT for 24 h	Intermittent exposure induced DNA single and double strand breaks (Comet assay).
Ivancsits et al. (2003a)	Human diploid fibroblasts exposed to intermittent (5 min ON/10 min OFF)50-Hz EMF at 0.02- 1 mT for 1-24 h	DNA Single and double strand breaks (Comet assay) observed at 0.035 mT at 15 h; recovered within 9 h.
Ivancsits et al.(2003b)	Fibroblasts from human subjects of different ages exposed to intermittent (5 min ON/10 min OFF) 50-Hz EMF at 1 mT for 1-24 h	Increased DNA Single and double strand breaks (Comet assay) at 15 h; more pronounced in cells from older donors
Ivancsits et al. (2005)	Various cell types exposed to intermittent (5 min ON/10 min OFF) 50-Hz EMF at 1 mT for 1-24 h	Effects on DNA Single and double strand breaks (Comet assay) showed three responder (human fibroblasts, human melanocytes, rat granulosa cells) and three non-responder cell types (human lymphocytes, human monocytes, human skeletal muscle cells).
Jajte et al. (2001)	Rat peripheral blood lymphocytes exposed to a 50-Hz magnetic field at 7 mT for 3 h	Increased DNA single strand breaks (Comet assay) in cells treated with ferrous chloride; melatonin attenuated the effect.
*Jin H. et al. (2015)	Non-tumorigenic human lung epithelial L132 cells exposed to a 60-Hz magnetic field at 1 or 2 mT for 9 h	No G2/M arrest or aneuploidy nor interaction with gamma radiation and H_2O_2

*Jin et al, (2012)	Mouse embryonic fibroblast NIH3T3 cells and human lung fibroblast WI-38 cells exposed to a 60 Hz magnetic field at 1 mT for 4 h	No significant effect on micronucleus frequency and interaction with ionizing radiation, H_2O_2, or c-Myc activation.
*Jin et al, (2014)	NIH3T3 mouse fibroblast cells, WI-38 human lung fibroblast cells, L132 human lung epithelial cells, and MCF10A human mammary gland epithelial cells exposed to a 60-Hz magnetic field at 1 mT for 4 or 16 h	No significant effect on DMA single strand breaks (Comet assay), and interaction with ionizing radiation, H_2O_2, or c-Myc activation.
Jin et al. (2019)	Arabidopsis young seedlings exposed to a static magnetic field at 600 mT	Increased auxin (a plant growth hormone) from expression of PIN3 and AUX1 genes in root tips; cryptochromes (cry1 and cry 2) are also involved. Root growth enhanced. Effects occurred when static magnetic field was parallel and perpendicular not opposite, to geomagnetic field.
Jouni et al. (2012)	*Vicia faba* (broad bean) culture in soil with high background radioactivity and exposed to static magnetic field at 15 mT for 8h/day for 8 days	Increased chromosomal aberration and DNA damage in root tip cells with lowering of antioxidant defense; soil radioactivity enhanced the effects.
Kesari et al. (2015)	Human neuroblastoma SH-SY5Y cells exposed to a 50-Hz 100 μT magnetic field for 24 h.	Micronucleus formation was observed at 15 and 30 days postexposure. Effect not related to oxidative changes.
Kesari et al. (2016)	Human glioblastoma SH-SY5Y and rat glioma C6 cells exposed to a 50-Hz magnetic field at 0.01 and 0.03 mT for 24 h with menadione as a cofactor	Micronuclei were significantly increased in SH-SY5Y cells at 0.03 mT Increased cytosolic and mitochondrial superoxide levels were observed in C6 cells. The results indicate that the threshold for biological effects of ELF magnetic field is 0.01 mT or less.
Khalil and Qassem (1991)	Human lymphocytes exposed to a pulsing 50-Hz EMF at 1.05 mT for 24, 48 and 72 h	Suppression of mitotic activity and a higher incidence of chromosomal aberrations. Delay in cell proliferation index and an increase in the baseline frequency of sister-chromatid

		exchanges occurred only after 72 h f exposure.
Ki et al. (2020)	Human hair follicle dermal papilla cells, a type of cells involved in hair growth, exposed to a 70 Hz EMF at intensities ranging from 0.5 to 10 mT over four days	Increased the expression of anagen-related molecules, including collagen IV, laminin, ALP, and versican, and increased β-catenin and Wnt3α expression and GSK-3β/ERK/Akt phosphorylation. Cell proliferation enhanced.
Kim HJ. et al. (2013)	Bone marrow derived mesenchymal stem cells (BM-MSCs) were subjected to a 50-Hz EMF	Increased levels of neuronal differentiation marker (MAP2), while early neuronal marker (Nestin) was down-regulated; increased differentially expression of 8 proteins; notably, a significantly increased expression of the ferritin light chain.
Kim J. et al. (2010)	IMR90 (human lung fibroblast) primary cells and HeLa (human cervical carcinoma) cells exposed to a time-varying (rotating) 60-Hz magnetic field at 6 mT for 60 min or 30 min/day for 3 days	Repeated exposure showed DNA double strand breaks (γ-H2AX foci) and decreased cell viability and increased apoptosis through p38 activation.
Kim J. et al. (2012)	Human primary fibroblast and cervical cancer cells exposed to a time-varying 60-Hz magnetic field at 7 mT for 10-60 min	DNA double strand breaks (γ-H2AX foci and Comet assay) detected (intracellular reactive oxygen species not affected).
Kimsa-Dudek et al. (2018)	Normal human dermal fibroblasts exposed to static magnetic field at 0.65 T for 24 h and sodium fluoride	Static magnetic field attenuated expression of antioxidant defense genes (SOD1, PLK3, CLN8, XPA, HAO1) induced by sodium fluoride.
Kimsa-Dudek et al. (2020)	Normal human dermal fibroblasts exposed to static magnetic field at 0.45, 0.55 and 0.5 T for 24 h and sodium fluoride	The field reduced fluoride-induced apoptosis and affected apoptosis gene expression; reduced fluoride-induced increases in reactive oxygen species and lipid peroxidation and decrease in antioxidant enzymes.
Kimura et al. (2008)	*Caenorhabditis elegans* exposed to 2, 3, or 5 T static magnetic field for 4-24 h	Genes involved in motor activity, actin binding, cell adhesion, and cuticles are transiently and specifically induced; also hsp (heat shock protein) 12 and 16 family genes.

Kindzelskii and Petty (2000)	Human neutrophils exposed to pulsed square-wave (20 msec) DC electric field at 0.2 V/m for 30, 45, 60 min	Increased DNA single strand breaks (Comet assay).
*Kirschenlohr et al. (2012)	Male human subjects exposed to 50-Hz EMF at 0.062 mT for 2 h (Exposure repeated two more times.)	No genes or gene sets in blood samples showed consistent response profiles to repeated ELF-EMF exposures (including immediate early genes, stress response, cell proliferation and apoptotic genes).
Koyama et al. (2008)	Human glioma A172 cells exposed to a 60-Hz magnetic field at 5 mT for2, 4, 8, 16, 24 h	The number of apurinic/apyrimidinic sites induced by gentoxic agents methyl methane sulfonate and H_2O_2 was enhanced by exposure to ELF magnetic fields. (Apurinic/apyrimidinic sites are common DNA lesions arise from spontaneous depurination or by base excision repair of oxidized, deaminated or alkylated bases.)
Kubinyi et al. (2010)	Human lymphocytes exposed to an inhomogeneous static magnetic field with a lateral magnetic flux density gradient of 47.7, 1.2, or 0.3 T/m by 10 mm lateral periodicity, or a homogeneous SMF of 159.2 mT magnetic flux density for a time period of 0.5 min, 1, 2, 4, 6, 18, 20, or 24 h.	Increased DNA single strand breaks (Comet assay); affected DNA repair induced by gamma ray when exposure occurred after ionizing radiation treatment.
Kumari et al. (2017)	Mice exposed continuously for 5 weeks to 7.5 KHz MF at 120 μT	Expression of the pro-inflammatory cytokine tumor necrosis factor alpha mRNA was significantly increased in the hippocampal region; impairment of memory observed.
*Lacy-Hulbert et al. (1995)	Human leukemic cells (HL60) exposed to a 60-Hz EMF for 20 min at 0.00057, 0.0057, or 0.057 mT	No change in MYC and beta-actin gene expression observed.
Lagroye and Poncy (1997)	Rat tracheal epithelial cell lines were first exposed to gamma rays and then cultured in a 50-Hz magnetic field at 0.1 mT for 24 h.	Increased binucleated cells with micronuclei in cells exposed to gamma rays and magnetic field, compared with gamma irradiation alone. Magnetic field alone had no significant effect on micronucleus frequency.

Lai and Singh (1997a)	Male Sprague-Dawley rats exposed to a 60-Hz magnetic field at 0.1, 0.25, or 0.5 mT for 2 h	Increased DNA single and double strand break (Comet assay) in brain cells.
Lai and Singh (1997b)	Male Sprague-Dawley rats exposed to a 60-Hz magnetic field at 0.5 mT for 2 h	Increased DNA single and double strand break (Comet assay) in brain cells. Effects blocked by melatonin and a spin-trap compound.
Lai and Singh (2004)	Male Sprague-Dawley rats exposed to a 60-Hz magnetic field at 0.01 mT for 24 or 48 h	Increased DNA single and double strand break (Comet assay) in brain cells. More effect with 48-h than 24-h exposure. Effects blocked by Trolox (a vitamin E analog) and 7-nitroindazole (a nitric oxide synthase inhibitor).
Laramee et al. (2014)	Transfected rat primary fibroblast (RAT1) cells exposed to static magnetic fields of 1 to 440 mT for 16, 24, or 48 h starting at 24 and 48 h post transfection	Induction of heat shock protein (HSP70) expression showed a dependency on flux density, exposure duration, and start time post transfection.
Lee et al. (2010)	*Caenorhabditis elegans* exposed to exposed to a static magnetic field at 200 mT	Expression of genes involved in development and aging. Accelerated development and shorten lifespan.
Lee et al. (2016)	MCF10A, MCF7, Jurkat, and NIH3T3 cells exposed to a 60 Hz magnetic field at 1 mT for 4 or 16 h	MCF10A and MCF7 cells showed consistent and significant decreases in cell number, cell viability, and DNA synthesis rates (cell cycle delay), whereas Jurkat and NIH3T3 cells showed no effect. MCF7 cells (2 mT for 16 h) showed up-regulation of PMAIP1 gene (involved in apoptosis).
Lee et al. (2011)	Human lymphocytes exposed to EMF generated during MRI scanning (clinical routine brain examination protocols: three-channel head coil) for 22, 45, 67, and 89 min	Significant increases in DNA single-strand breaks (Comet assay), and frequencies of both chromosome aberrations and micronuclei in a time-dependent manner.
Leone et al. (2014)	Neural stem cells isolated from hippocampi of newborn mice exposed to a 50-Hz EMF at 1 mT for 10 days	Histone acetylation-related chromatin remodeling leading to enhanced proliferation and neuronal differentiation.

Li and Chow (2001)	E. coli XL-1 Blue transformed with plasmid pUC18 and DNA samples exposed to a 50-Hz magnetic field at 1.2 mT for 1-5 h, with heat shock response suppressed	Without the protection of the heat shock response, magnetic field exposure induced DNA degradation, which could be attenuated by the presence of an antioxidant,
*Li L. et al (2015)	Workers from a power supply bureau (inspection workers vs. logistic staff); The average time-weighted average was 0.0073 mT (0.00156-0.02633 mT) and the subjects were subgrouped by cumulative ELF-magnetic field exposure dose: low (<0.0156 mT), middle (0.0156-0.073 mT) and high (> 0.073 mT)	No significant effect on the frequency of micronucleus lymphocytes or micronuclei frequency; no changes in antioxidant enzymes and cellular oxidative damage.
Li SS et al. (2013)	Male *Drosophila melanogaster* fruit flies exposed to a 50-HZ EMF at 3 mT for 72 or 312 h	Different sets of genes were up- and down-regulated after short- or long-term exposure. Short-term exposure may decrease the reproductive ability of males, whereas long-term exposures had no effect on reproductive ability.
Li Y. et al. (2014)	Fertilized embryos of zebra fish (*Danio rerio*) exposed to a 50-Hz magnetic field at 0.1 - 0.8 mT for 96 h	The transcription of apoptosis-related genes (caspase-3, caspase-9) was significantly up-regulated in exposed embryos. Delayed hatching and apoptosis observed.
Li, Y. et al. (2015)	Rat oligodendrocyte precursor cells exposed to DC electric field at 50, 100. Or 200 mV/mm for 1.5 h	Mitogen-activated protein kinase pathway that signals cell migration was significantly upregulated in cells treated with an EF of 200 mV/mm compared with control cells and downregulation of differentially expressed genes in chemotaxis.
Li Y. et al. (2019)	Dementia rats induced by streptozotocin (STZ) intracerebroventricular injection exposed to a 10 mT 20-Hz pulsed EMF,	Pulsed EMF increased expression of insulin growth factor 2 (IFG-2) in the hippocampus and improved the ability of learning and memory in STZ-treated rats.

	2 h/day, 10 days	
Lin et al. (2016)	Budding yeast exposed to a 50-Hz EMF at 6 mT for 96 h	The transcription levels of 28 genes were upregulated and those of four genes were downregulated. Exposure can upregulate the expression of genes involved in glucose transportation and the tricarboxylic acid (TCA) cycle, but not the glycolysis pathway.
Liu et al. (2015)	Mouse spermatocyte-derived GC-2 cell line exposed to an intermittent (5 min ON/10 min OFF) 50-Hz EMF at 1, 2, or 3 mT for 72 h	Exposure decreased genome-wide methylation at 1 mT, but global methylation was higher at 3 mT. Expression of DNMT1 and DNMT3b (DNA methyltransferases) was decreased at 1 mT, and increased at 3 mT.
*Lopucki et al. (2005)	Cotyledons dissected from placentas obtained immediately after physiological labors exposed to a 50-Hz magnetic field at 2 or 5 mT for 3 h	No significant effect on level of 8-hydroxy-2'-deoxyguanosine in DNA (oxidative DNA damage).
Lourencini da Silva et al. (2000)	SnCl2-treated pBR322 plasmids exposed to a 3400Hz square-wave EMF with peak power of 4V for 2 h	An EMF-dependent potentiation of DNA scission (i.e. the appearance of relaxed plasmids) was observed. The results indicate that the EMF, in the presence of a transition metal, is capable of causing DNA damage.
*Luceri et al. (2005)	Human peripheral blood lymphocytes and DBY747 *Saccharomyces cerevisiae* exposed to a50-Hz magnetic field at 0.001, 0.01or 0.1 mT for 18 h	No significant effects on DNA single strand breaks (Comet assay), oxidated DNA base, and gene expression.
Lupke et al (2006)	Human umbilical cord blood-derived monocytes exposed to a 50-Hz magnetic field at 1 mT for 45 min	Alteration of 986 genes involved in metabolism, cellular physiological processes, signal transduction and immune response.
Luukkonen et al. (2011)	Human SH-SY5Y neuroblastoma cells. Exposed to a 50-Hz magnetic field at 0.1 mT for 24 hours, followed by chemical (menadione) exposure for 3 h	Magnetic field enhanced menadione-induced DNA damage, DNA repair rate, and micronucleus formation. No effects were observed after magnetic field exposure alone.

Luukkonen et al. (2014)	Human SH-SY5Y neuroblastoma cells. Exposed to a 50-Hz magnetic field at 0.1 mT for 24 hours, followed by menadione exposure for 3 h	Persistently elevated levels of micronuclei were found in the progeny of magnetic field (alone)-exposed cells at 8 and 15 days after exposure, indicating induction of genomic instability. (No magnetic field x menadione interaction effect). Magnetic field disturbed oxidative balance immediately after the exposure, which might explain the previous findings on MF altered cellular responses to menadione-induced DNA damage.
Luukkonen et al. (2017)	Human SH-SY5Y neuroblastoma cells. Exposed to a 50-Hz magnetic field at 0.1 mT for 24 hours, followed by menadione exposure for 1 or 3 h	Decreased p21 protein (a DNA damage response-related proteins) level after 1-h menadione treatment, as well as increased proportion of cells in the G1 phase and decreased proportion of S phase cells after 3-h menadione treatment. Magnetic field exposure decreased DNA single strand breaks (Comet assay) caused by I h treatment with menadione.
Ma et al. (2014)	Mouse embryonic neural stem cells exposed to a 50-Hz EMF at 2 mT for 3 days	Expression of genes regulating neuronal differentiation was altered.
Mahaki et al. (2019)	Rats exposed to a 50-Hz EMF at 0.001-2 mT for 2 h/day for 60 days	In the spleen, gene expression levels of RORα (retinoid-related orphan receptor alpha) and c-Maf (transcription factor Maf) were significantly down-regulated at 0.001 and 0.1 mT, while the expression of STAT6 (signal transducer and activator of transcription 6) was only significantly decreased at the density of 0.1 mT. No effect on thymus.
Mahmoudinasab and Saadat (2016)	Human MCF-7 cells exposed to a 50-Hz magnetic field at 0.25 and 0.5 mT (5 min ON/5 min OFF, 15 min ON/15 min OFF, or 30 min field-on continuously) for 30 min	Alterations in the *NQO1* and *NQO2* (NAD(P)H: quinone oxidoreductase) mRNA levels seen at the "5 min ON/5 min OFF" condition.
Mahmoudinasab and Saadat (2018a)	MCF-7 and SH-SY5Y cells exposed to 50-Hz EMF at 0.5 mT (15 min ON/ 15 min OFF), and treated with morphine and cisplatin.	EMF exposure could protect SH-SY5Y cells from the cytotoxicity of cisplatin and morphine, whereas it has no significant change in MCF-7 cells. Expression patterns of antioxidant genes are different in both cell lines.

Mahmoudinasab and Saadat (2018b)	SH-SY5Y cells exposed to 50-Hz EMF at 0.5 mT ("15 min ON/ 15 min OFF" and "30 min ON") for 30 min, and treated with morphine and beta-lapachone	NQO1 mRNA level decreased in the "15 min field-on/15 min field-off" condition, the expression level of NQO2 was increased. Morphine and EMF reduced the cytotoxicity of beta-lapachone.
Mahmoudinasab et al. (2016)	Human MCF-7 cells exposed to a 50-Hz magnetic field at 0.25 and 0.5 mT (5 min ON/5 min OFF, 15 min ON/15 min OFF, or 30 min field-on continuously) for 30 min	Significant changes in mRNA levels of seven antioxidant genes for "the 15 min field-on/15 min field-off condition".
Mairs et al. (2007)	UVW human glioma cells to a 50-Hz EMF at 1 mT for 12 h	Induced 0.011 mutations/locus/cell, which was equivalent to a 3.75-fold increase in mutation induction compared with unexposed controls. The field also potentiated the mutagenic capacity of gamma-irradiation.
Manzella et al. (2015)	Human dermal fibroblasts exposed to a 50 Hz magnetic field at 0.1 mT for 1 h	Changes in expression of clock genes.
Mariucci et al. (2010)	CD1 mice exposed to a 50-Hz magnetic field at 1 mT for 1 or 7 days (15 h/day)	Increased DNA single strand breaks (Comet assay) in brain areas detected immediately after 7-day exposure. No effect on HSP-70 expression.
Markkanen et al. (2008)	Murine L929 fibroblasts exposed to a 50-Hz magnetic field at 0.1 or 0.3 mT for 24 h, with or without ultraviolet B (UVB, wavelength 280-320 nm) radiation or menadione (MQ)	Pre-exposure to magnetic field can alter cellular responses to other agents, and indicate that magnetic field as low as 0.1 mT has measurable impacts on cancer-relevant cellular processes such as DNA-damage.
Mastrodonato et al. (2018)	Mice exposed to a 50 Hz, 1 mT EMF 3.5 h/day for 12 days	Increased Wnt3 (neurogenesis gene) mRNA expression and nuclear localization of its downstream target β-catenin in subventricular zone of the lateral ventricle. Mice showed enhanced olfactory memory at 30 days post-exposure.

*McNamee et al. (2002)	10-day-old mice exposed to a 60-Hz magnetic field at 1 mT for 2 h, cerebellum assayed at 0. 2, 4, and 24 h after exposure	DNA single strand breaks (Comet assay): "While increased DNA damage was detected by tail ratio at 2h after MF exposure, no supporting evidence of increased DNA damage was detected by the other parameters." "Taken together, these results do not support the hypothesis that acute MF exposure causes DNA damage in the cerebellums of immature mice." No change in apoptosis.
*McNamee et al. (2005)	Rodents (adult rats, adult mice, and immature mice) exposed to a 60-Hz magnetic field at 0.1, 1 or 2 mT for 2 h. Assayed at 0, 2 and 4 h after exposure	This study provided no evidence of magnetic-field-induced DNA single strand breaks (Comet assay) in the brain.
Mercado-Sáenz et al. (2019)	*Saccharomyces cerevisiae* wild type strain (WS8105-1C) exposed to sinusoidal magnetic field (2.45 mT, 50 Hz, continuous) or pulsed magnetic field (1.5 mT, 25 Hz, 8 h/day). Chronological aging was evaluated during 40 days	Decreased spontaneous frequency of mitochondrial mutation during aging was observed in pulsed magnetic field-treated samples.
*Miyakoshi et al. (1996a)	Chinese hamster ovary (CHO) cells exposed to a 60-Hz magnetic field at 5 mT for 130 h	No significant effect on c-myc expression and cell growth rate.
Miyakoshi et al. (1996b)	Human melanoma MeWo cells exposed to a 50-Hz magnetic field at 400 mT up to 20 h	Induced mutations in the hypoxanthine-guanine phosphoribosyl transferase gene, synergistic with X-ray. No significant increase in mutant frequency occurred when DNA replication was inhibited during magnetic field exposure. DNA replication error is suspected of causing the mutations produced by ELFMF exposure.
Miyakoshi et al. (1997)	Human melanoma MeWo cells exposed to a 50-Hz magnetic field at 400 mT for 2 h	Induced mutations in the hypoxanthine-guanine phosphoribosyl transferase gene, DNA replication errors and/or disturbance of the mismatch repair systems caused by exposure to ELF-MF may be involved in the

		mutagenic effect.
Miyakoshi et al. (1998)	Human osteosarcoma cells (Saos-LP-12), with deleted 53 gene, exposed to a 50-Hz magnetic field at 400 mT for 4 h	Induced mutations in the hypoxanthine-guanine phosphoribosyl transferase gene. Introduction of the wild-type (wt) p53 expression plasmid (pOPRSVp53) suppressed the magnetic induced mutation. The findings suggest that wt p53 has a function in suppression of DNA replication errors and/or in maintenance of genomic stability after high-density magnetic field exposure.
Miyakoshi et al. (1999)	Chinese hamster ovary K1 (CHO-K1) cells exposed to a 60-Hz magnetic field at 5 mT for up to 6 weeks	No effect on mutant frequency of the hypoxanthine-guanine phosphoribosyl transferase but enhanced the effect of x-ray.
Miyakoshi et al. (2000)	Human glioma MO54 cells exposed to a 50-Hz magnetic field at 55, 50, or 400 mT at 4^0C or on ice, for 30 min	Exposure to magnetic field at more than 50 mT potentiated X-ray-induced DNA single strand breaks (Comet assay).
*Mizuno et al. (2014)	Human fibroblast WI38VA13 subcloned 2RA and XP2OS(SV) cells exposed to a 60-Hz magnetic field at 5 mT for 24 h	Magnetic field exposure did not have modification effect on cell survival after UV-B irradiation and on repair process of DNA damage induced by UV-B irradiation.
Moraveli et al. (2016)	dermal papilla mesenchymal cells exposed to 50-Hz EMF at 1 mT for 5-14 days	Increased expression of MAP gene with decreased cell proliferation (cell differentiation occurred.) (MAP2 protein involves in neuritogenesis to stabilize microtubules.)
Moretti et al. (2005)	Jurkat cells exposed to a 50-Hz magnetic field at 1 mT for 1 h with added xenobiotics	Magnetic field exposure enhanced genotoxic effects (DNA single strand breaks (Comet assay)) of xenobiotics.
Mouhoub et al. (2017)	*Salmonella hadar* grown under static magnetic field of 200 mT for 3, 6, or 9 h	Increased expression of gene involved in the production of acdiolipin and phosphatidylethanolamine (both components of bacteria cell membrane).
Nakayama et al. (2016)	Macrophages stimulated with the bacterial endotoxin, lipopolysaccharide and	Increased DNA single strand breaks (Comet assay) and decreased viability.

	posed to a 50-Hz magnetic field at 0.5 mT for 24 h	
Nasrabadi et al. (2018)	Neonatal human retinal pigment epithelial cells exposed to pulsed 50-Hz EMF at 1 mT for 8 h daily for 3 days	Both gene and protein expressions of retinal progenitor cell markers were reduced.
Nikolova et al. (2005)	Mouse embryonic stem (ES) cells exposed to an intermittent (5 min ON/30 min OFF) 50-Hz EMF at 2 mT for 6 or 48 h	Significantly affected transcript levels of the apoptosis-related bcl-2, bax, and cell cycle regulatory "growth arrest DNA damage inducible" GADD45 genes, No effect on DNA single and double strand breaks (Comet assay).
*Okudan et al. (2010)	Swiss mice exposed to a 50-Hz EMF at 0.001 - 0.005 mT for 40 days	The results suggest that </=0.005 mT intensities of 50 Hz EMFs did not cause genotoxic effect in the mouse.(However, The number of micronucleus per peripheral blood lymphocytes in the 0.004 and 0.005 mT-exposure groups were significantly higher than those of the lower intensity exposure groups. The males in 0.004 mT-exposure group displayed the highest micronucleus number per lymphocyte).
Panagopoulos et al. (2013)	Newly eclosed *Drosophila melanogaster* exposed to 50-Hz magnetic field (0.1, 1.1, and 2.1 mT) continuously during the first 5 days of their adult lives	Severe DNA damage (DNA fragmentation by TUNEL assay) and consequent cell death induction in the reproductive cells.
Pesqueira et al. (2017)	Human tendon-derived cells exposed to a 2 Hz magnetic field at 350 mT for 4 or 8 h, or 8 h every 24 or 48 h up to 14 days	8-h exposure significantly upregulated the expression of tendon-associated genes SCX, COL1A1, TNC and DCN. 8 h every 24 h exposure significantly upregulated COL1A1, COL3A1 and TNC at day 14.
Pilger et al. (2004)	Human fibroblasts exposed to an intermittent (5 min ON/10 min OFF) 50-Hz EMF at 1 mT for 15 h	Exposure resulted in an increase in DNA single strand breaks (Comet assay) unlikely to be caused by intracellular changes that affect intracellular [Ca2+] or mitochondrial membrane potential.
Potenza et al. (2004a)	*E. coli* XL-1Blue exposed to static	Increased cell proliferation and changes in gene expression observed. The field

	magnetic field at 300 mT up to 50 h	magnetic field may stimulate transposition activity.
Potenza et al. (2004b)	Escherichia coli DNA, plasmid, and amplification products of different lengths exposed to static magnetic field at 200-150 mT for 5 h	The in vitro assays displayed interactions between the magnetic field and DNA, revealing principally that magnetic field exposure induces DNA alterations in terms of point mutations.. This genotoxic effect of the magnetic field, however, is minimized in living organisms due to the presence of protective cellular responses.
Rageh et al. (2012)	Newborn rats (10 days after delivery) exposed continuously to a 50 Hz magnetic field at 0.5 mT for 30 days	Increased DNA single strand breaks (Comet assay) in brain cells and micronucleus frequency in bone cells. Changes in anti-oxidative enzymes and increased lipid peroxidation.
*Reese et al. (1998)	Chinese hamster ovary (CHO) cells exposed to 60-Hz magnetic fields (0.1 or 2 mT), electric fields (1 or 38 V/m), or combined magnetic and electric fields (2 mT and 38 V/m, respectively) for 1 h	No significant effect on DNA single strand breaks (Comet assay) from exposures.
Reyes-Guerrero et al. (2010)	Adult male and female Wistar rats exposed to a 60-Hz magnetic field at 1 mT for 2 h/day for 9 days	ELF EMF modulates estrogen receptor- beta gene expression in the olfactory bulb of female adult rats but not in males.
Robison et al. (2002)	HL-60, HL-60R, and Raji cell lines exposed to a 60-Hz EMG at 0.15 mT for 24 h	EMF exposure offers significant protection from apoptosis (DNA double strand breaks (Comet assay)) and significantly decreased DNA repair rates in HL-60 and HL-60R cell lines but not in the Raji cell line.
*Ross et al. (2018)	Human mesenchymal stromal cell exposed to a 5-Hz EMF at 0.4 mT for 20 min/day, 3 times a week for 2 weeks	No chromosome breaks, viability and proliferation rate detected.
*Ruiz-Gómez et al. (2010)	Wild type (wt) and radiation sensitive mutant yeast strains (Saccharomyces cerevisiae) exposed to a	The exposure did not induce alterations in cell cycle and cause DNA damage.

	50 Hz magnetic field at 2.45 mT for 96 h	
Sadri et al. (2017)	Human mesenchymal stem cells derived from human newborn cords exposed to a static magnetic field of 12, 18, or 24 mT for 2 h	Induced differentiation and decreased expression of Sox-2, Nanong, and Oct-4 genes (These genes are involved in embryonic orgen development, maintenance of multipentency and self renewal of undifferentiated embryonic stem cell.)
Sanie-Jahromi et al. (2016)	Human breast adenocarcinoma MCF-7 and neuroblastoma SH-SY5Y cells exposed to 50-Hz EMF at 0.25 and 0.5 mT (5 min ON/5min OFF; 15 min ON/15min OFF, or 30 ON continuously) for 30 min	mRNA levels of seven genes involved in DNA repair pathways down regulated in MCF-7 cells. Synergistic with cisplatin in MCF-7 and SH-SY5Y cells.
Sanie-Jahromi and Saadat (2017)	MCF-7 and SH-SY5Y cells exposed to an intermittent (15 min OF/15-min OFF) 50-Hz EMF at 0.5 mT for 30 min. Cells were also treated with cisplastin and bleomycin	EMF exposed MCF-7 cells treated with cisplastin and bleomycin showed more effects on some DNA repair gene expression compared with "cisplastin and bleomycin" treatment alone, while SH-SY5Y susceptibility was not changed between the two treatments.
Sanie-Jahromi and Saadat (2018)	MCF-7 and SH-SY5Y cells were treated with 5.0 μM morphine and exposed to an intermittent (15 min ON/15 min OFF) 50-Hz EMF at 0.50 mT for 30 min	Morphine treatment showed significant down-regulation of expression of genes involved in DNA repair pathways, while in "Morphine + EMF" treatment, the genes were not significantly changed.
Sarimov et al. (2011)	Human lymphocytes exposed to 50-Hz magnetic field at 0.005-0.02 mT for 15-180 min	Magnetic field condensed relaxed chromatin and relaxed condensed chromatin.
*Scarfi et al (2005)	Human diploid fibroblasts exposed to an intermittent (5 min ON/10 min OFF) 50-Hz EMF or a 50-Hz field plus its harmonics for 24 h (1,2,4-BT) also studied	No significant effects on DNA single strand breaks (Comet assay) and micronucleus frequency.

Scassellati Sforzolini et al. (2004)	Cells exposed to a 50-Hz magnetic field at 5 mT; co-genotoxic effects with N-methyl-N'-nitro-N-nitrosoguanidine (MNNG), 4-nitroquinoline N-oxide (4NQO), benzene, 1,4-benzenediol (1,4-BD), or 1,2,4-benzenetriol	Magnetic field showed genotoxic (micronucleus test) and co-genotoxic (comet assay) capabilities.
Schmitz et al. (2004)	Male adult mice exposed to a 50-Hz magnetic field at 1.5 mT for 8 weeks	A significant increase in both unscheduled DNA synthesis and in situ nick translation was only found for epithelial cells of the choroid plexus. Mitochondrial DNA synthesis was exclusively increased in renal epithelial cells of distal convoluted tubules.
Seong et al. (2014)	Human bone marrow-mesenchymal stem cells exposed to a 50 Hz EMF at 1 mT for 8 days	Increased expression of early growth response protein 1 (Egr1).
*Shen et al. (2016)	Chinese Hamster Lung cells exposed to a 50-Hz EMF at 0.4mT for 30 min or 24 h	Increase in LC3-II expression and increased autophagosome formation; no significant effect on γH2AX foci.(EMF-induced autophagy may balance the cellular homeostasis to protect the cells from severe adverse biological consequences.)
Shokrollahi et al. (2018)	Soybean plants exposed to static magnetic field at 20 and 30 mT for 5 h/day for 5 days	Exposure to 20 mT decreased gene expression of Fe transporter, ferrous and H_2O_2 contents and gene expression, content and activity of ferritin and catalase. Opposite responses were observed at 30 mT exposure. Tertiary structures of ferritin, apoferritin and catalase altered by static magnetic field.
Singh and Lai (1998)	Rats exposed to a 60-Hz magnetic field at 0.5 mT for 2 h	Data suggested that both DNA-protein and DNA-DNA crosslinks (Comet assay) were formed in brain cells.
Skyberg et al. (2001)	Blood samples from high voltage laboratory workers exposed to electromagnetic fields and mineral oil	In inhibited (hydroxyurea-inhibits DNA synthese, and caffeine-inhibits DNA repair) lymphocyte cultures, there were indications that electromagnetic fields in combination with mineral oil exposure may produce chromosomal aberrations. No effect on un-inhibited cells.

Solek et al. (2017)	Mouse spermatogenic cell lines (GC-1 spg and GC-2 spd) exposed to pulsed (1sec on/off) or continuous-wave 2, 50, 120 Hz EMF at 2.5- 8 mT for 2 h	EMF activated oxidative and nitrosative stress-mediated DNA damage pathways, resulting in p53/p21-dependent cell cycle arrest and apoptosis
*Song et al. (2018)	HeLa and primary IMR-90 fibroblasts exposed to a 60-Hz EMF at 1, 3, 6, or 10 or mT continuously for up to 168 h or 30 min every 24h for 3 days	No effect on DNA damage (gamma-H2AX foci).; promoted cell proliferation (probably due to decreased reactive oxygen species).
Stankevičiūtė et al. (2019)	Rainbow trout (*Oncorhynchus mykiss*) exposed to a 50-Hz EMF at 1 mT for 40days; and the common ragworm (*Hediste diversicolor*) and the Baltic clam (*Limecola balthica*) for 12 days	Trout and ragworm erythrocytes and clam gill cells showed elevated micronucleus frequency, nuclear buds, nuclear buds on filament cells, and cells with blebbed nuclei.
*Stronati et al. (2004)	Human whole blood exposed to a 50-Hz magnetic field at 1 mT for 2 h	No significant effects on DNA single strand breaks (Comet assay), sister chromatid exchanges, chromosome aberrations, and micronucleus frequency in lymphocytes. A slight decrease in cell proliferation observed.
*Sun C et al. (2018)	ATM-proficient ($Atm^{+/+}$) and ATM-deficient ($Atm^{-/-}$) mouse embryonic fibroblasts exposed to a 50-Hz magnetic field at 2 mT for 15 min.(Ataxia telangiectasia mutated (ATM) plays a central role in DNA damage repair.)	No effect on γ-H2AX foci in both types of cells.
Sun L et al. (2019)	Irpex lacteus, a white-rot fungus, exposed to a 50-Hz magnetic field ay 3.5 mT for 3 h/day for 4 days	Global gene expression changes were observed.
Sun RG et al.(2012)	K562 human leukemia cells exposed to	The potency of the combination of SMF and paclitaxel was greater than that of SMF or

	paclitaxel in the presence or absence of 8.8 mT static magnetic field for 24 h	paclitaxel alone on K562 cells, and these effects were correlated with DNA single strand breaks (Comet assay).
Suzuki et al. (2001)	Mouse exposed to high intensity static magnetic fields (3.0 T for 48 and 72 h and 4.7 T for 24, 48 and 72 h).	Increased micronucleus frequency in bone marrow cells.
Svedenstal et al. (1999)	Brain cells of CBA mice exposed to a 50 Hz magnetic field at 0.5 mT 2 h, 5 days or 14 days	DNA single strand breaks (Comet assay) increased after 14 days of exposure,
*Szerencsi et al. (2013)	Peripheral blood samples from men exposed to EMF produced by 3T magnetic resonance imaging equipment for 0, 22, 45, 67, and 89 min during the scanning procedure	No significant effect on DNA single strand breaks (Comet assay) and DNA integrity in lymphocytes.
Teodori et al. (2014)	Human glioblastoma cells exposed to static magnetic field at 80 mT for 6,12, or 24 h, also in combination with X-ray	Increased in DNA single strand breaks (Comet assay) after 24 h of exposure; x-ray induced DNA strand breaks significantly reduced by post-irradiation exposure to static magnetic field. Further data suggested that static magnetic field modulated DNA damage and/or repair, possibly through a mechanism that affects mitochondria.
*Testa et al. (2004)	Human blood samples exposed to a 50-Hz magnetic field at 1 mT for 48 h	No significant effect on micronucleus frequency and proliferation of lymphocytes. No interaction with x-ray.
*Tiwari et al. (2015)	Blood samples of human subjects occupationally exposed to 132 kV high-voltage substations (mean duration on job 9.27 years, range 2-30 years).	No significant effect on DNA single strand breaks (Comet assay) in lymphocytes, increased oxidative stress observed.
Udroiu et al. (2006)	Liver and peripheral blood sampled from newborn mice exposed to a 50-Hz magnetic field of 0.65 mT during the	Data obtained in newborn mice showed a significant increase in micronuclei frequencies. No significant effect was recorded on exposed adults.

	whole intra-uterine life (21 days), and on bone marrow and peripheral blood from adult mice exposed to the same magnetic field for the same period	
Udroiu et al. (2015)	Mice exposed to 50-Hz, 0.065 mT magnetic field, 24 hours/day, for a total of 30 days, starting from 12 days post-conception	Magnetic field induced a slight genotoxic damage (micronucleus formation) and no interaction with x ray in erythrocytes, but modulate the response of male germ cells to X-rays with an impact on proliferation/differentiation processes. Magnetic field exposure decreased DNA single and double strand breaks (Comet assay) in germ cells at 42 days after birth.
*Verschaeve et al. (2011)	*Salmonella typhimurium* exposed to a 50-Hz magnetic field at 0.1 or 0.5 mT for 1 or 2 h	The magnetic field did not induce mutagenicity in S. typhimurium bacteria and did not show any synergetic effect when combined with chemical mutagens.
*Verschaeve et al. (2016)	*Salmonella typhimurium* exposed to50 Hz magnetic field at 0.1 mT for 1 h	The magnetic field did not damage DNA and had no influence on the DNA damaging capacity of several mutagens.
Villarini et al. (2006)	Human leukocytes exposed to a 50-Hz magnetic field at 3 mT for 30, 60, or 120 min and treated with mutagens	Magnetic field exposure increased N-methyl-N'-nitro-N-nitrosoguanidine and decreased 4-nitroquinoline N-oxide-induced DNA single strand breaks (Comet assay).
Villarini et al. (2013)	Male CD1 mice exposed to a 50-Hz magnetic field at 0.1, 0.2, 1 or 2 mT for 7 days (15 hours/day) and sacrificed either at the end of exposure or after 24 h	Magnetic field exposure induced DNA single strand breaks (Comet assay) and did not affect hsp70 expression in the brain.
Villarini et al. (2015)	Blood leukocytes from electric arc welders presumably exposed to 50-Hz EMF(mean 0.0078 mT; range: 0.00003-0.171 mT)	Decreased DNA single strand beaks (Comet assay), may be caused by DNA-protein crosslinks by metal exposure.
*Villarini et al. (2017)	SH-SY5Y and SK-N-BE-2 human neuroblastoma cells	or $AlCl_3$ alone induced DNA single strand breaks (Comet assay), changes in GSH/GSSG ratio or variations in Hsp70

	exposed to a 50-Hz magnetic field at 0.01. 0.1, or 1 mT for 1 h continuously or 5 h intermittently (15 min ON/15 min OFF), and also aluminum	expression. Co-exposure to ELF-MF and $AlCl_3$ did not have any synergic toxic effects.
Wahab et al. (2007)	Human peripheral blood lymphocytes exposed to 50 Hz sinusoidal (continuous or pulsed) or square (continuous or pulsed) magnetic fields at 0.001 or 1 mT for 72 h	A significant increase in the number of sister chromatid exchange /cell observed.
*Wang Y et al. (2019)	Human ventricular cardiomyocytes exposed to a 50-Hz magnetic field at 0.1 mT for 1 h continuously or 75 min intermittently (15 min ON/15 min OFF). Sprague-Dawley rats exposed to 50 Hz magnetic field at 0.1 mT for 15 h/day for 7 days	Magnetic field exposure did not cause DNA single strand breaks (Comet assay) in heart cells in both in vitro and in vivo experiments.
Wang Y. et al. (2020)	*Caenorhabditis elegans* exposed to 50-Hz, 3 mT EMF for 15 generations	Expression levels of the *r53.4, hpo-18, atp-5*, and *atp-3* genes encoding ATPase and *sod-1, sod-2,* and *sod-3* genes encoding superoxide dismutase (SOD) were significantly upregulated.
Wang Z et al. (2009)	Human embryoid body derived (hEBD) LVEC cell line exposed to 0.23-0.28 T static magnetic field for 24 h	Gene expression in cells showed nine signaling networks responded to static magnetic field
*Williams et al. (2006)	Salmonella bacteria cultures exposed to a 60-Hz intermittent magnetic field (5 min ON/10 min OFF) at 14.6 mT for 4 h	No significant increase in recombination events and DNA single and double strand breaks (assayed using a recombination event counter).However, magnetic field exposure induced protection from heat stress.
Wilson et al. (2015)	BALB/c×CBA/Ca F1 hybrid males exposed to 50Hz magnetic fields at 0.01, 0.1 or 0.3 mT for 2 or 15 h	There was a marginally significant increase in a non-dose-dependent mutation frequency in sperm, and not in blood cells.

Winker et al. (2005)	Human fibroblasts exposed to a 50-Hz intermittent (5 min ON/10 min OFF) EMF at 1 mT for 2-24 h	Increased micronucleus frequency and chromosomal aberration.
Wolf et sl. (2005)	HL-60 leukemia cells, Rat-1 fibroblasts, and WI-38 diploid fibroblasts exposed to a 50-Hz EMF at 0.5-1 mT for 24-72 h	Dose-dependent increases in DNA single strand breaks (Comet assay) and formation of 8-hydroxy-2'-deoxyguanosine adducts were observed in all cell lines. There were increases in cell proliferation and reactive oxygen species.
Yagci and Kesim (2016)	Human gingival fibroblasts exposed in vitro to static magnetic fields produced by dental magnetic attachments for 10-12 days. (The maximum magnetic flux densities measured at the magnet centers of 4 types of attachment were 95.6-148.1 mT and became almost zero at 10 mm away)	Increased micronucleus frequency.
Yaguchi et al. (1999)	Mouse embryonic skin m55 cells exposed to a 60-Hz magnetic field at 5, 50, or 400 mT for 42 h	Increase in sister chromatid exchanges after 400 mT exposure.
Yaguchi et al. (2000)	Mouse embryonic skin m55 cells exposed to 60-Hz (5 or 50 mT) or 50-Hz (400 mT) magnetic fields for 40 h. Some cells also treated with mitomycin C or X-ray	Increased chromosomal aberration, synergistic with mitomycin C and X-ray.
Yao et al. (2015)	Rat Schwann cells exposed to DC electric field for 36-72 h at 50, 100, or 200 mV/mm	Differentially expression of genes participate in multiple cellular signaling pathways involved in the regulation of cell migration, including pathways of regulation of actin cytoskeleton, focal adhesion, and PI3K-Akt cell cycle regulation).
Yin et al. (2016)	Primary cultured rat hippocampal neurons exposed to a 50-HZ EMF at mT for 90 min	Increase in DNA single strand breaks (Comet assay); free radicals involved.

Yokus et al. (2005)	Female Wistar rats exposed to a 50-Hz magnetic field at 0.97 mT for 3 h/day for 50 and 100 days	Increased 8-hydroxy-2'-deoxyguanosine in blood cells.
Yokus et al. (2008)	Male Sprague-Dawley rats exposed to a 50-Hz magnetic field at 0.1 or 0.5 mT for 2 h/day for 10 months	Increased DNA base modifications in leucocytes [8-hydroxyguanine (8-OH-Gua), 2,6-diamino-4-hydroxy-5-formamidopyrimidine (FapyGua), and 4,6-diamino-5-formamidopyrimidine (FapyAde)]
Yoon et al. (2014)	Human lung fibroblast WI38 cells and human lung epithelial L132 cells exposed to a 60-Hz magnetic field at 2 mT for 6 h	2 mT field induced increased γ-H2AX expression, as well as γ-H2AX foci production. Interacted with gamma radiation but not H_2O_2.
Yuan et al. (2020)	Tumor cell lines including lung cancer, gastric cancer, pancreatic cancer and nephroblastoma exposed to a 50-Hz EMF modulated by static MF with time-average intensity of 5.1 mT, for 2 h/day for 3 days	Induced DNA single strand breaks (Comet assay), gamma-H2AX and activation of DNA repair pathways, increased reactive oxygen species and ferroptosis, and decreased proliferation.
Zendehdel et al. (2019)	Peripheral blood cells of male power line workers in a power plant. The median value of the magnetic field at the working sites was 0.00085 mT	Increased in DNA single strand breaks (Comet assay).
Zhang H et al. (2016)	ICR mice exposed to a 50-Hz EMF at 8 mT for 4 h/day for 28 days	Declined DNA content and increased expression of apoptosis genes in spleen. Free radical may be involved.
Zhang Y et al. (2016)	Workers with or without exposure to ELF-EMF (50 Hz) of 110-420kV power lines	Significant increased urinary 8-isoprostane and 8-OHdG were observed in workers with EMF exposure. Free radical may be involved.
Zheng et al. (2018)	dental pulp stem cells exposed to a static magnetic field of 1,2, 4 mT for 15 min, 30 min, 1 h or 24 h	Increased expression of several growth factors (FGF-2, TGF-β, and VEGF), migration genes (MMP-1 and MMP-2), and upregulated the two YAP/TAZ-regulated genes, CTGF and ANKRD1. (YAP/TAZ are transcriptional activators particularly

		involved in cancer cell proliferation, therapy resistance and metastasis. Increased cell proliferation, osteo/odontogenesis and mineralization observed in the stem cells.
*Zhu et al. (2016)	Human lens epithelial cells exposed to a 50-Hz magnetic field at 0.4 mT for 2, 6, 12, 24, or 48 h	No effect on DNA single strand breaks (Comet assay) and gamma-H2AX foci.
Zmyslony et al. (2000)	Rat exposed to a static or 50-Hz magnetic field at 7 mT for 3 h	In combination with $FeCl_2$, increases in DNA single strand breaks (Comet assay) observed for both static and 50-Hz field exposure in lymphocytes.
Zmyslony et al. (2004)	Rat lymphocytes exposed first to ultraviolet radiation and then to a 50-Hz magnetic field at 0.04 mT for 5 or 60 min	60-min magnetic field exposure (plus UVA) caused an increase in DNA single strand breaks (Comet assay). MF may affect the radical pairs generated during the oxidative or enzymatic processes of DNA repair.

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Supplement 3

Gene expressions after RFR and static/ELF EMF exposure (literature up to January 2021)

RFR	***Exposure effects***
Akhavan-Sigari et al. (2014)	Increased risk for the mutant type of p53 gene expression in the peripheral zone of the glioblastoma, and that this increase was significantly correlated with shorter overall survival time.
Beaubois et al. (2007)	Accumulation of basic leucine-zipper transcription factor (bZIP) mRNA in the exposed terminal leaf of tomato plant.
Belyaev et al. (2006)	Expression of genes encode proteins with diverse functions including neurotransmitter regulation, blood-brain barrier (BBB), and melatonin production in rat brain.
Buttiglione et al. (2007)	Affected both Egr-1 gene expression and cell regulatory functions, involving apoptosis inhibitors like Bcl-2 and surviving in human neuroblastoma cells.
Cervellati et al. (2013)	Induced 17-β-estradiol modulates connexins and Integrins as well as estrogen recptor (ER-β) expression in trophoblast cells, suggesting an influence on cell differentiation and migration.
Chen et al. (2012)	Expression was limited to only a very small number of genes in yeast. (Expressions of structural maintenance of chromosomes 3 (SMC3) and aquaporin 2 (AQY2 (m)) while halotolerance protein 9 (HAL9), a kinase 1 (YAK1) and one function-unknown gene showed opposite changes in expression.
Del Vecchio et al. (2009)	Increased expression of beta-thymosin gene, a cytoskeleton regulating factor in murine cortical neurons, correlated to reduced number of neurites generated.
Deshmukh et al. (2015)	Increased heat shock protein 70 (HSP70) in rat brain.
Eker et al. (2018)	Caspase-3 and p38 mitogen-activated protein kinase (p38MAPK) (a kinase responsive to stress stimuli, and involved in cell differentiation, apoptosis and autophage) gene expressions were significantly up-regulated in the ocular tissues of rat.
Engelmann et al. (2008)	Significant changes in transcription of 10 genes in Arabidopsis thaliana (thale cress) cells.
Fragopoulou et al. (2018)	Expression of 178 genes changed significantly mouse hippocampus
Franzellitti et al. (2008)	Levels of the inducible HSP70C transcript were significantly enhanced after 24 h exposure to GSM-217Hz signals and reduced after 4 and 16 h exposure to GSM-Talk signals in human trophoblasts.
Ghatei et al. (2017)	No effect on expression level of bcl-2 and p53 genes, but gene expression level of *bax* decreased and gene expression level of *p21* increased in cerebellum of mice exposed pre-and postnatally to RFR.
Gökçek-Saraç et al. (2020)	Decreased RNA expressions of acetylcholinesterase (AChE), choline acetyltransferase (ChAT), and vesicular acetylcholine transporter (VAChT)

	in the hippocampus of rats exposed to 2100 MHz RFR.
Gulati et al. (2018)	A significant association of genetic polymorphism of antioxidant genes (for MnSOD and CAT) with oxidative damage has been observed in human population exposed to radiations emitted from mobile towers.
Habauzit et al. (2014)	7 genes were differentially expressed in human keratinocytes, associated to the cellular response to hyperthermia.
Hao et al. (2010)	Significant induced phosphorylation of STAT3, increased transcription levels of the inflammation-associated genes, iNOS and TNF-alpha murine N9 microglial cells. (Signal transducer and activator of transcription 3 (STAT3) is a transcription activator that mediates the expression of a variety of genes in response to cell stimuli, and thus plays a key role in many cellular processes such as cell growth and apoptosis.)
He et al. (2016)	Mouse bone marrow stromal cells showed increased PARP-1 mRNA expression.(PARP-1 involves in differentiation, tumor transformation and DNA repair.)
He et al. (2017)	Mouse bone marrow stromal cells showed increased PARP-1 mRNA expression. Gamma radiation decreased RFR-induced PARP-1 expression.
Karaca et al. (2012)	Decreased STAT3 expression in moue brain. (STAT3 acts as transcription activator).
Kumari et al. (2017)	Increased expression of the pro-inflammatory cytokine tumor necrosis factor alpha mRNA in the hippocampal region.
Kumar, R. (2020)	Altered expression of DNA (epigenetic) methylating enzymes, DNA methyltransferase1 (DNMT1) and histone methylating enzymes euchromatic histone methylthransferase1 (EHMT1) in hippocampus.
Jeong et al. (2020)	Increased expression of Epha8 and Wnt6 genes in the hippocampi of mice. (Both genes are involved in development, particularly, Epha8 coded protein mediates developmental events in the nervous system in axonal guidance).
Lameth et al. (2020)	Altered gene expressions in rat cerebral cortex in an acute neuroinflammation. Gene responses to RFR can differ according to pathologies affecting the CNS.
Le Quément et al.(2012)	Human skin cells showed differential expression of genes involved in functions such as cardiovascular development, facilitate pathogen recognition by macrophages, inhibition of angiogenesis, nonspecific ion channels, etc.
Lee et al. (2005)	Many genes were affected in human HL60 cells. Apoptosis-related genes were among the upregulated ones and the cell cycle genes among the downregulated ones.
Li et al. (2020)	Offspring of pregnant female rats exposed to RFR showed differential expression of methyl-D-aspartate receptors

	(NMDARs) genes in the hippocampus.
Lin et al. (2016)	Upregulated the expression of genes involved in glucose transportation and the tricarboxylic acid (TCA) cycle, but not the glycolysis pathway. Transcription levels of 29 genes were upregulated and 24 genes were downregulated.
López-Martín et al. (2009)	c-Fos expressions in brain of picrotoxin-treated and untreated rats.
Manta et al. (2017)	168 genes differentially expressed in the house fly Drosophila melanogaster), associated with multiple and critical biological processes, such as basic metabolism and cellular subroutines related to stress response and apoptotic death.
Martin et al. (2020)	Four different types of human keratinocytes showed different patterns of expression of ADAMTS6, IL7R, and NOG genes
Megha et al. (2015)	Downregulation in mRNA expression of enzymes involved in monoamine transmitter synthesis in rat hippocampus.
Mildažienė et al. (2019)	Leaves from exposed common sunflower (Helianthus annus L.) seeds showed gene expression mostly of proteins involved in photosynthetic processes and their regulation.
Millenbaugh et al. (2008)	Genes associated with regulation of transcription, protein folding, oxidative stress, immune response, and tissue matrix turnover were affected in rat skin.
Nittby et al. (2008)	Altered gene expression in both cortex and hippocampus of the rat: extracellular region, signal transducer activity, intrinsic to membrane, and integral to membrane.
Nylund and Leszczynski (2006)	Gene and protein expressions altered differentially in two human endothelial cell lines.
Ohtani et al. (2016)	Heat-shock proteins (Hsp) and heat-shock transcription factors (Hsf) gene expression levels were significantly upregulated in the cerebral cortex and cerebellum of the rat.
Ohtani et al. (2019)	No change in transcription gene expression in brain and liver of mice exposed to a 85-kHZ field.
Pacini et al. (2002)	Human skin fibroblasts showed increased expression of mitogenic signal transduction genes (e.g., MAP kinase kinase 3, G2/mitotic-specific cyclin G1), cell growth inhibitors (e.g., transforming growth factor-beta), and genes controlling apoptosis (e.g., bax).
Qin et al. (2018)	Altered the expression of genes involved in testosterone synthesis (*Star, P450scc, P450c17 and 3β-Hsd*) in mouse testicular tissue.
Qin et al. (2019)	Exposed Leydig cells showed downregulated of testosterone synthase genes (*Star, Cyp11a1*, and *Hsd-3β*) and clock genes

	(*Clock, Bmal1*, and *Rorα*),
Rammal et al. (2014)	Increased expression of two wound-plant gene in tomato.
Remondini et al. (2006)	Different human cell types responded differently in gene expression. Affected gene families did not point towards a stress response, but suggested upreglulating of cellular metabolism.
Romano-Spica et al. (2000)	Overexpression of the proto-oncogene ets1 mRNA in Jurkat T-lymphoblastoid and Leydig TM3 cell lines
Roux et al. (2006)	Leaves of tomato plants showed increased stress-related transcripts (calmodulin, protease inhibitor and chloroplast mRNA-binding protein).
Roux et al. (2008)	Tomato plant showed increase in stress-related mRNA (calmodulin, calcium-dependent protein kinase and proteinase inhibitor), similar to wound responses.
Said-Salman et al. (2019)	101 genes were differentially expressed in Escherichia coli. Up-regulated genes are involved in metabolic pathways, transposition, response to stimuli, motility, chemotaxis, and cell adhesion, while the down-regulated genes are associated with metabolic pathways and localization of ions and organic molecules.
Silva et al. (2016)	No effect on expressions of Ki-67 (involved in cell proliferation) p53 (tumor suppression) HSP-70 (stress biomarker), and reactive oxygen species in human thyroid cells.
Soubere Mahamoud et al. (2016)	Exposed human keratinocytes treated with the glycolysis inhibitor, 2-deoxyglucose showed changes in genes encode transcription factors or inhibitors of cytokine pathways,
Souza et al. (2014)	Cells from oral mucosa of individual used cellular phones more than 5 h/week high number of broken egg which may be associated with gene amplification.
Sun Y. et al. (2017)	Decreased gene expression in mitochondria of HL-60 human leukemia cells. Free radicals involved.
Tohidi et al. (2020)	Apoptotic genes Bax and Bc12 expression in the hippocampus were upregulated in mice exposed to RFR from a cell phone jammer for 1, 2, twice a day for 30 days and down-regulated with longer exposure schedule.
Trivino Pardo et al. (2012)	Gene expression affected in acute T-lymphoblastoid leukemia cells. Genes which act as sensors of DNA damage (*ATM, RAD17,RAD50, and PRKDC*) are activated. This over-expression could produce a signal cascade that causes the activation of the main DNA repair signaling. Some of the genes that were defined as essentials in double-strands repair

	(*BRCA1, LIG4, XRCC2*) and single-chain DNA repair process (*XPC, MSH5*) were found to over-express. More cells in S-phase.
Vafaei et al. (2020)	Increased superoxide dismutase, CDKN1A, GADD45a, Bax mRNA, and decreased Bcl-2 mRNA. (CDKN1A and GADD45a are involved in DNA repair and cellular responses to stressors.)
Valbonesi et al. (2014)	HSP70 transcription was significantly increased in rat neuronal-like PC12 cells.
Varghese et al. (2018)	Increased caspase-3 gene expression in brain tissues of rats exposed to 2450 MHz RFR
Vian et al. (2006)	Rapid induction of mRNA encoding the stress-related bZIP transcription factor in plants.
Yan et al. (2008)	Brain of exposed rat showed mRNA up-regulation of several injury-associated proteins. RFR exposure may result in cumulative injuries that could eventually lead to clinically significant neurological damage.
Yao et al. (2004)	Rabbit lens epithelial cells showed increased expression of P27kip1 protein, also G/G1 cell cycle arrest. (p27kip1 is a cyclin-dependent kinase inhibitor which binds to cyclinE/cdk2, blocking the G1/S transition.)
Zhang et al. (2008)	Primary culture neurons showed gene up- and down-regulation. Genes are associated with multiple cellular functions (cytoskeleton, signal transduction pathway, metabolism, etc.)
Zhao et al. (2007)	Up-regulation of caspase-2, caspase-6 genes occurred in both GSM 1900-MHz "on" and "stand-by" modes in neurons, but only in "on" mode in astrocytes. Additionally, astrocytes showed up-regulation of the Bax gene.
Static/extremely-low frequency EMF	
Agliassa et al. (2018)	Near-null MF condition (i.e., <100 nT) delayed transition to flowering in Arabidopsis thaliana and changes in expression of several genes in leaf and floral meristem.
Ashta et al. (2020)	Temozolomide (TMZ) with static MF or ELF MF (10 Hz) together increased p53 protein expression in the human glioblastoma cell line (A172) and increased cytotoxicity.
Baraúna et al. (2015)	The bacteria Chromobacterium violaceum, exposed to ELF MF, showed differential expression of 5 proteins. Expression of the protein, DNA-biding stress protein, may help to prevent DNA damage.
Bertea et al. (2015)	Exposing *Arabidopsis thaliana* to artificially reversed

	geomagnetic field conditions induced gene expressions.
Chen et al. (2008)	Human breast cancer MCF-7 cells exposed to a 50-Hz MF induced expression of thee responsive genes.
Chen et al. (2020)	Human choriocarcinoma cells exposed to DC electric field showed increased gene expressions of ErbB and HIF-1 signaling pathways
Collard et al. (2013)	Epidermis cultures harvested from human abdominoplasty exposed to ELF electric fields induced expression of various genes. Some genes are involved in cell proliferation or differentiation, mitosis, cell cycle, or in the DNA replication transcription and translation.
Consales et al. (2018)	Exposure to a 50-Hz magnetic field in vitro. We demonstrate that ELF-MFs drive an early reduction of the expression level of miR-34b and miR-34c in SH-SY5Y human neuroblastoma cells, as well as in mouse primary cortical neurons, by affecting the transcription of the common pri-miR-34. Data also indicate epigenetic control of gene expression in vitro and shed light on the possible mechanism(s) producing detrimental effects and predisposing neurons to degeneration.
Cuccurazzu et al. (2010)	Exposure to a 50-Hz MF in vivo induced increases in the transcription of pro-neuronal genes (Mash1, NeuroD2, Hes1) and genes encoding Ca(v)1.2 channel α(1C) subunits in the hippocampus of the mouse. Hippocampal neurogenesis also observed.
Del Re et al. (2006)	ELF-MF influenced the synthesis of heat shock proteins in E. coli in a way that critically depends on the signal characteristics (static or pulsed MF).
Di Campli et al. (2010)	*Helicobacter pylori* biofilm expose to a 50-Hz EMF showed amiA gene expression and decreased cell adhesion. (AmiA protein is responsible for transition of H. pylori from bacillary to coccoid forms. These coccoid forms can escape detection by the immune system and therefore could participate in the persistence of *H. pylori* infection during the lifetime of its human host.)
Dong et al. (2019)	16 T static magnetic field markedly blocked the expression of osteoclast-associated transcription factors and osteoclast marker genes and inhibited iron absorption and iron storage-related protein expression.
Fan et al. (2015)	Rat bone marrow derived-mesenchymal stem cells and mesenchymal stem cells exposed to a 50-Hz EMF induced expressions of various genes. Expressions of hematopoietic growth factors increase proliferation and migration of macrophagocytes.
Fan et al. (2018)	Static magnetic field up-regulated the expression of stress gene (dnaK) and virulence genes (efaA and ace).
Fedrowitz and Loscher	50-Hz MF-exposed F344 rat breast tissue showed alterations in

(2012)	gene expression, which were absent in Lewis rats.
Frisch et al. (2013)	Rat primary fibroblasts exposed to a 10-Hz electric fields induced HSP70 expression.
Heredia-Rojas et al. (2010)	“Electromagnetic field” plasmid transfected into INER-37 and RMA E7 cell lines exposed to a 60-Hz MF. An increased luciferase gene expression was observed in INER-37 cells but had no effect on the RMA E7 cell line.
Jin et al. (2019)	Arabidopsis seedling exposed to static magnetic field showed increased auxin (a plant growth hormone) from expression of PIN3 and AUX1 genes in root tips; cryptochromes (cry1 and cry 2 genes) are also involved.
Ki et al. (2020)	Human hair follicle dermal papilla cells exposed to a 70-Hz EMF enhance cell activation and proliferation via the GSK-3β/ERK/Akt signaling pathway. Various genes were activated.
Kim et al. (2010)	Human normal and cancer cells exposed repeatedly to a 60-Hz MF showed p38 gene expression and induction of checkpoint kinase 2 critical to the DNA damage checkpoint pathway.(P38 mitogen-activated protein kinases are a class of mitogen-activated protein kinases (MAPKs) that are responsive to stress stimuli, and are involved in cell differentiation, apoptosis and autophagy.)
Kimsa-Dudek et al. (2018)	Static magnetic field attenuated expression of antioxidant defense genes (SOD1, PLK3, CLN8, XPA, HAO1) induced by sodium fluoride.
Kimsa-Dudek et al. (2020)	Exposure of human fibroblast cultures that had been co-treated with fluoride ions to a static MF caused specific genes expression that were involved in apoptosis.
Kimura et a. (2008)	Caenorhabditis elegans exposed to high intensity (2, 3, 5 T) static magnetic fields showed induction of genes involved in motor activity, actin binding, cell adhesion, and cuticles; also upregulation of hsp (heat shock protein) 12 and 16 family genes.
Lacy-Hulbert et al. (1995)	No effect on MYC and beta-actin gene expression in human leukemic cells.
Laramee et al. (2014)	Transfected rat primary cells in monolayer were exposed to a static MF caused HSP expression.
Lee et al. (2010)	C. elegans exposed to a 200 mT static magnetic field showed up-regulation of genes involved in development and aging (clk-1,unc-3, age-1,daf-2, lim-7).
Lee et al. (2016)	MCF7 cells showed up-regulation of PMAIP1 gene (gene involved in apoptosis) after 60-Hz magnetic field exposure.
Leone et al. (2014)	ELF-EMF enhanced proliferation and neuronal differentiation of hippocampal neural stem cells by regulation of epigenetic mechanisms leading to pro-neuronal gene expression.
Li et al. (2013)	Male Drosophila melanogaster exposed to ELF-EMF showed changes in gene expression. Differentially expressed genes following short-term exposures were involved in metabolic processes, cytoskeletal organization, mitotic spindle organization,

	cell death, protein modification and proteolysis. Long-term exposure let to changes in expression of genes involved in metabolic processes, response to stress, mitotic spindle organization, aging, cell death, and cellular respiration.
Li et al. (2014)	Zebra fish embryos exposed to a 50-Hz MF showed transcription of apoptosis-related genes (caspase-3, caspase-9) was significantly upregulation.
Li et al. (2015)	Rat oligodendrocyte precursor cells exposed to DC electric field showed upregulated mitogen-activated protein kinase pathway that signals cell migration and downregulation of differentially expressed genes in chemotaxis.
Li et al. (2019)	Pulsed EMF (20 Hz) increased expression of insulin growth factor 2 (IFG-2) in the hippocampus of streptozotocin-induced dementia rats.
Lin et al. (2016)	Budding yeast exposed to a 50-Hz EMF caused upregulation expression of genes involved in glucose transportation and the tricarboxylic acid (TCA) cycle, but not the glycolysis pathway. (A response to environmental stress.)
Lupke et al. (2006)	Human umbilical cord blood-derived monocytes exposed to ELF-MF caused expression of 5 genes.
Ma et al. (2014)	Mouse embryonic neural stem cells exposed to a 50-HZ EMF induced expression of genes regulating neuronal differentiation although cell proliferation and the percentages of neurons and astrocytes differentiated from eNSCs were not affected which might be compensation by post-transcriptional mechanisms to support cellular homeostasis.
Mahaki et al. (2019)	A 50-Hz EMF reduced the expression levels of c-Maf, STAT6, and RORα genes in the spleen of rats.
Mahmoudinasab and Saadat (2016)	Human MCF-7 breast cancer cells exposed to a 50-Hz EMF showed decreased NQO1 and increased NQO2 gene expression. (NQO1 and NQO2 are detoxification enzymes).
Mahmoudinasab and Saadat (2018a)	Patterns of up-regulation of antioxidant genes are different between MCF-7 and SH-SY5Y cells exposed to an intermittent 50-Hz EMF.
Mahmoudinasab and Saadat (2018b)	SH-ST5Y cells exposed to a 50-Hz EMF. NQO1 mRNA level decreased in the "15 min field-on/15 min field-off" condition, the expression level of NQO2 was increased.
Mahmoudinasab et al. (2016)	Human MCF-7 breast cancer cells exposed to a 50-Hz EMF showed up and down regulations of 7 antioxidant genes.
Manzella et al. (2015)	50-Hz magnetic field affected in human dermal fibroblasts expression of clock genes: BMAL1, PER2, PER3, CRY1, and CRY2.
Mastrodonato et al. (2018)	50-HZ EMF exposure increased Wnt3 (neurogenesis gene) mRNA expression in subventricular zone of the lateral ventricle of mice.
Moraveji et al. (2016)	50-Hz EMF activated MAP2 gene in dermal papilla mesenchymal

	cells.
Mouhoub et al. (2017)	Static magnetic field enhanced expression of gene involved in the production of acdiolipin and phosphatidylethanolamine in Salmonella hadar.
Nasrabadi et al. (2018)	In neonatal human retinal pigment epithelial cells exposed to pulsed 50-Hz EMF, gene expressions of NES, RPE65, and PAX6 were decreased. (NES gene encodes nestin involved in radial growth of neurons. The RPE65 gene provides instructions for making a protein that is essential for normal vision**.** PAX6 acts as a "master control" gene for the development of eyes and other sensory organs.)
Nikolova et al. (2005)	Mouse embryonic stem cells exposed to a 50-Hz EMF changed transcript levels of the apoptosis-related bcl-2, bax, and cell cycle regulatory "growth arrest DNA damage inducible" GADD45 genes.
Pesqueira et al. (2017)	Short term exposure (8 h) upregulated the expression of tendon-associated genes SCX, COL1A1, TNC and DCN. Long-term exposure (8 h every 24 h up to 14 days) significantly upregulated COL1A1, COL3A1 and TNC.
Potenza et al. (2004a)	Escherichia coli exposed to static magnetic field showed three cDNAs to be expressed only in the exposed cells, whereas one cDNA was more expressed in the controls.
Reyes-Guerrero et al. (2010)	ELF EMF exerted a biphasic effect on female olfactory bulb estrogen receptor-beta mRNA gene expression, which increased during diestrous and decreased during estrous. No effect on estrogen receptor-alpha gene expression and in male rats.
Sadri et al. (2017)	Static magnetic field decreased expression of Sox-2, Nanong, and Oct-4 genes in human mesenchymal stem cells derived from newborn umbilical cords.
Sanie-Jahromi et al. (2016)	Human MCF-7 breast cancer cells and neuroblastoma SH-SY5Y cells exposed to a 50-Hz EMF had mostly down regulation of 7 DNA repair genes in MCF-7 cells. Co-treatment with cisplatin and EMF can enhance down-regulation of the genes involved in non-homologous end-joining pathway in both cell types.
Sanie-Jahromi et al. (2017)	ELF-EMF enhanced the effects of cisplatin + bleomycin on viability of MCF-7 cells, while SH-SY5Y cells were not affected. MCF-7 and SH-SY5Y cells showed non-random disagreement in DNA repair gene expression in these conditions.
Sanie-Jahromi and Saadat (2018)	MCF-7 and SH-SY5Y cells were treated with morphine and then exposed to a 50-Hz EMF. Non-homologous end joining (NHEJ) related genes were significantly decreased in co-treatment of cisplatin and "morphine + EMF".
Seong et al. (2014)	Human bone marrow-mesenchymal stem cells were exposed to a 50-Hz EMF. Analysis of neurons derived from these cells showed that early growth response protein 1 (Egr1) is one of the key transcription factors in ELF-EMF-induced neuronal

	differentiation.
Shokrollahi et al. (2018)	Soybean plants exposed to static magnetic field had decreased gene expression of Fe transporter at 20 mT. Opposite response observed at 30 mT. The results suggest that SMF triggered a signaling pathway that is mediated by iron.
Wang et al. (2009)	Human embryonic cells exposed to static magnetic field showed a short-term (<24 h) activation of IL-6 involved the coordinate up-regulation of toll-like receptor-4 (TLR4) with complementary changes to NEU3 and ST3GAL5 that reduced ganglioside GM3 and augmented the activation of TLR4 and IL-6. Loss of GM3 also provided a plausible mechanism for the attenuation of cellular responses to SMF that occurred over longer exposure periods.
Wang et al. (2020)	Caenorhabditis elegans exposed to 50-Hz, 3 mT EMF for 15 generations showed enhanced up-regulations of genes encoding ATPase and superoxde dismutase.
Yao et al. (2015)	Rat Schwann cells exposed to DC electric field showed expression of genes participate in multiple cellular signaling pathways involved in the regulation of cell migration, including pathways of regulation of actin cytoskeleton, focal adhesion, and PI3K-Akt.
Zhang H et al. (2016)	Mice exposed to a 50-Hz EMF showed a significant suppression in Bcl-2 expression and increase in Bax, Caspase-3 and Caspase-9 expression in splenic cells. G0/G1 cycle arrest observed.
Zhao et al. (2020)	Escherichia coli exposed to 3.1 THz RFR for 8 h showed increased plasmid copy number and protein expression.
Zheng et al. (2018)	Static magnetic field increased expression of several growth factors, migration genes, and upregulated the two YAP/TAZ-regulated genes in human dental pulp mesenchymal stem cells.

Supplement 4

Genetic effects at low intensity exposure to RFR and static/ELF EMF (literature up to January 2021)

	Power density/SAR (<0.1 W/Kg) or magnetic flux density	**Effects observed**
RFR studies		
Aitken et al. (2005)	Mice to 900-MHz RFR for 7 days at 12 h/day; SAR 0.09 W/kg	Mitochondrial genome damage in epididymal spermatozoa.
Akdag et al. (2016)	Male Wistar-Albino rats to 2400 MHz RFR from a Wi-Fi signal generator for a year; SAR 0.000141 (min)-0.007127 (max) W/kg	DNA damage in testes.
Alkis et al. (2019a)	Rats exposed to 900 MHz (brain SAR 0.0845 W/kg), 1800 MHz (0.04563 W/kg), and 2100 MHz (0.03957 W/kg) RFR 2 h/day for 6 months	Increased DNA strand breaks and oxidative DNA damage in brain.
Alkis et al. (2019b)	Rats exposed to 900 MHz, 1800 MHz, and 2100 MHz RFR 2 h/day for 6 months; maximum SAR over the rat 0.017 W/kg	
Atasoy et al. (2013)	Male Wister rats exposed to 2437 MHz (Wi-Fi) RFR; 24 h/day for 20 weeks; maximum SAR 0.091 W/kg	Oxidative DNA damage in blood and testes.
Beaubois et al. (2007)	Leaves of tomato plant exposed to 900-MHz RFR for 10 min at 0.0066 mW/cm^2	Increased expression of leucine-zipper transcription factor (bZIP) gene.
Belyaev et al. (2005)	Lymphocytes from human subjects exposed to GSM 915 MHz RFR for 2 h ; SAR 0.037 W/kg;	Increased condensation of chromatin.

Belyaev et al. (2009)	Human lymphocytes exposed to UMTS cell phone signal (1947.4 MHz, 5 MHz band width) for 1 h; SAR 0.04 W/kg	Chromatin affected and inhibition of DNA double-strand break.
Bourdineaud et al. (2017)	Eisenia fetida earthworms exposed to 900 MHz for 2 h; SAR 0.00013-0.00933 W/kg	DNA genotoxic effect and HSP70 gene expressions up regulated.
Campisi et al. (2010)	Rat neocortical astroglial to CW 900 MHz RFR for 5, 10, or 20 min; incident power density 0.0265 mW/cm^2	Significant increases in DNA fragmentation.
Chaturvedi et al. (2011)	Male mice exposed to 2450 MHz RFR, 2 h/day for 30 days; SAR 0.03561 W/kg	Increased DNA strand breaks in brain cells.
Deshmukh et al. (2013)	Male Fischer rats exposed to 900 MHz (0.0005953 W/kg), 1800 MHz (0.0005835 W/kg), and 2450 MHz (0.0006672 W/kg) RFR for 2 h/day, 5 days/week for 30 days.	Increased DNA strand breaks in brain tissues.
Deshmukh et al. (2015)	Male Fischer rats exposed to 900 MHz (0.0005953 W/kg), 1800 MHz (0.0005835 W/kg), and 2450 MHz (0.0006672 W/kg) RFR for 2 h/day, 5 days/week for 180 days.	Increased DNA strand breaks in brain tissues.
Deshmukh et al. (2016)	Male Fischer rats exposed to 900 MHz (0.0005953 W/kg), 1800 MHz (0.0005835 W/kg), and 2450 MHz (0.0006672 W/kg) RFR for 2 h/day, 5 days/week for 90 days.	Increased DNA strand breaks in brain tissues.

Eker et al. (2018)	Female Wistar albino rats exposed to 1800-MHz RFR for 2 h/day for 8 weeks; SAR 0.06 W/kg	Caspase-3 and p38MAPK gene expressions increased in eye tissues.
Furtado-Filho et al. (2014)	Rats of different ages (0-30 days) exposed to 950 MHz RFR for 0.5 h/day for 51 days (21 days of gestation and 6-30 days old): SAR pregnant rat 0.01-0.03 W/kg; neonate 0.88 W/kg, 6-day old 0.51 W/kg, 15-day old 0.18 W/kg, 30-day old 0.06 W/kg.	Decreased DNA strand breaks in liver of 15-day old and increased breaks in 30-day old rats.
Gulati et al. (2016)	Blood and buccal cells of people lived close (<400 meters) to a cell tower; 1800 MHz, Maximum power density (at 150 meters) 0.00122 mW/cm^2, some subjects lived in the area for more than 9 yrs	Increased DNA strand breaks in lymphocytes and micronucleus in buccal cells.
Gürler (2014)	Wistar rats exposed to 2450 MHz RFR 1 h/day for 30 consecutive days; power density 0.0036 mW/cm^2	Increased oxidative DNA damage in brain and blood.
Hanci et al. (2013)	Pregnant rats exposed 1 h/day on days 13-21 of pregnancy to 900-MHz RFR at power density 0.0265 mW/cm^2.	Testicular tissue of 21-day old offspring showed increased DNA oxidative damage.
He et al. (2016)	Mouse bone marrow stromal cells exposed to 900 MHz RFR 3 h/day for 5 days; SAR 4.1 x 10^{-4} W/kg (peak), 2.5 x 10^{-4} W/kg (average)	Increased expression of PARP-1 mRNA

Hekmat et al. (2013)	Calf thymus exposed to 940 MHz RFR for 45 min; SAR 0.04 W/kg	Altered DNA structure at 0 and 2 h after exposure.
Kesari and Behari (2009)	Male Wistar rats exposed to 50 GHz RFR for 2 h/day for 45 days; SAR 0.0008 W/kg	Increased in brain tissue DNA strand.
Kumar R. et al. (2021)	Male Wistar rats exposed to 900 MHz, 1800 MHz and 2450 MHz RFR at a specific absorption rate (SAR) of 5.84×10^{-4} W/kg, 5.94×10^{-4} W/kg and 6.4×10^{-4} W/kg, respectively for 2 h per day for 1-month, 3-month and 6-month periods.	Epigenetic modifications in the hippocampus, bigger effects with increasing frequency and duration of exposure.
Kumar S. et al. (2010)	Male Wistar rats exposed to 10-GHz RFR for 2 h a day for 45 days, SAR 0.014 W/kg	Increased micronucleus in blood cells.
Kumar S. et al. (2013)	Male Wistar rats exposed to 10 GHz RFR for 2 h a day for 45 days; SAR 0.014 W/kg	Increased micronucleus in blood cells and DNA strand breaks in spermatozoa.
Marinelli et al. (2004)	Acute T-lymphoblastoid leukemia cells exposed to 900 MHz RFR for 2-48 h, SAR 0.0035 W/kg	Increased DNA damage and activation of genes involved in pro-survival signaling.
Markova et al. (2005)	Human lymphocytes exposed to 905 and 915 MHz GSM signals for 1 h; SAR 0.037 W/kg	Affected chromatin conformation and 53BP1/gamma-H2AX foci
Markova et al. (2010)	Human diploid VH-10 fibroblasts and human adipose-tissue derived mesenchymal stem	Inhibited tumor suppressor TP53 binding protein 1 (53BP1) foci that are typically formed at the sites of DNA double strand break

	cells exposed to GSM (905 MHz or 915 MHz) or UMTS (1947.4 MHz, middle channel) RFR for 1, 2, or 3 hr; SAR 0.037-0.039 W/kg	location.
Megha et al. (2015a)	Fischer rats exposed to 900 and 1800 MHz RFR for 30 days (2 h/day, 5 days/week), SAR 0.00059 and 0.00058 W/kg	Reduced levels of neurotransmitters dopamine, norepinephrine, epinephrine, and serotonin, and downregulation of mRNA of tyrosine hydroxylase and tryptophan hydroxylase (synthesizing enzymes for the transmitters) in the hippocampus.
Megha et al. (2015b)	Fischer rats exposed to 900, 1800, and 2450 MHz RFR for 60 days (2 h/day, 5 days/week); SAR 0.00059, 0.00058, and 0.00066 W/kg	Increased DNA damage in the hippocampus
Nittby et al. (2008)	Fischer 344 rats exposed to 1800 MHz GSM RFR for 6 h; SAR whole body average 0.013 W/kg, head 0.03 W/kg	Expression in cortex and hippocampus of genes connected with membrane functions.
Odaci et al. (2016)	Pregnant Sprague - Dawley rats exposed to 900 MHz RFR 1 h each day during days 13 - 21 of pregnancy; whole body average SAR 0.024 W/kg	Testis and epididymis of offspring showed higher DNA oxidation.
Pandey et al. (2017)	Swiss albino mice exposed to 900-MHz RFR for 4 or 8 h per day for 35 days; SAR 0.0054-0.0516 W/kg	DNA strand breaks in germ cells.
Pesnya and Romanovsky (2013)	Onion (Allium cepa) exposed to GSM 900-MHz RFR from a cell phone for 1 h/day or 9 h/day for 3 days;	Increased the mitotic index, the frequency of mitotic and chromosome abnormalities, and the micronucleus frequency in an exposure-duration manner.

	incident power density 0.0005 mW/cm^2	
Phillips et al. (1998)	Human Molt-4 T-lymphoblastoid cells exposed to pulsed signals at cellular telephone frequencies of 813.5625 MHz (iDEN signal) and 836.55 MHz (TDMA signal) for 2or 21 h. SAR 0.0024 and 0.024 W/Kg for iDEN and 0.0026 and 0.026 W/kg for TDMA)	Changes in DNA strand breaks
Qin et al. (2018)	Male mice exposed to 1800-MHz RFR 2 h/day for 32 days, SAR 0.0553 W/kg	Might be mediated through CaMKI/RORα signaling pathway.
Rammal et al. (2014)	Tomato exposed to a 1250-MHz RFR for 10 days at 0.0095 mW/cm^2	Increased expression of two wound-plant genes.
Roux et al. (2006)	Tomato plants exposed to a 900-MHz RFR for 2-10 min at 0.0066 mW/cm^2	Induction of stress gene expression.
Roux et al. (2008)	Tomato plants exposed to a 900-MHz RFR for 10 min at 0.0066 mW/cm^2	Induction of stress gene expression.
Sarimov et al. (2004)	Human lymphocytes exposed to GSM 895-915 MHz signals for 30 min; SAR 0.0054 W/kg	Condensation of chromatin was observed.
Shahin et al. (2013)	Female mice (Mus musculus) exposed to continuous-wave 2.45 GHz RFR 2 h/day for 45v days; SAR 0.023 W/kg	Increased DNA strand breaks in the brain.
Sokolovic et al. (2015)	Wistar rats exposed to RFR (4 h/day, for 20, 40, and 60 days) from a Nokia 3110 cell	DNA fragmentation and oxidative changes in testicular tissues.

	phone; SAR 0.043-0.135 W/kg.	
Sun Y. et al. (2017)	Human HL-60 cells exposed to 900 Hz RFR 5 h/day for 5 days; peak and average SAR 4.1 x 10^{-4} and 2.5 x 10^{-4} W/kg	Increased oxidative DNA damage and decreased mitochondrial gene expression.
Tkalec et al. (2013)	Earthworm (Eisenia fetida) exposed to continuous-wave and AM-modulated 900-MHz RFR for 2 - 4 h; SAR 0.00013, 0.00035, 0.0011, and 0.00933 W/kg	Increased DNA strand breaks.
Tsybulin et al. (2013)	Japanese Quail embryos exposed in ovo to GSM 900 MHz signal from a cell phone intermittently (48 sec ON/12 sec OFF) during initial 38 h of brooding or for 158 h (120 h before brooding plus initial 38 h of brooding): SAR 0.000003 W/kg	The lower duration of exposure decreased DNA strand breaks, whereas higher duration resulted in a significant increase in DNA damage.
Vian et al. (2006)	Tomato plants exposed to a 900-MHz RFR for 10 min at 0.0066 mW/cm^2	Induction of mRNA encoding the stress-related bZIP transcription factor.
Yakymenko et al. (2018)	Quail embryos exposed to GSM 1800 GHz signal from a smart phone (48 s ON/12 s OFF) for5 days before and 14 days during incubation, power density 0.00032 mW/cm^2	Increased DNA strand breaks and oxidative DNA damage.
Zong et al. (2015)	Mice exposed to 900 MHz RFR 4 h/day for 7 days; SAR 0.05 W/kg	Attenuated bleomycin-induced DNA breaks and repair.

Static and ELF EMF Studies		
Agliassa et al. (2018)	Arabidopsis thaliana (thale cress) exposed to 0.00004 mT static magnetic field for 38 days after sowing	Changes in gene expression in leaf and floral meristem.
Back et al. (2019)	Mouse embryonic stem cells exposed to hypomagnetic field (<0.005 mT) up to 12 days	Induced abnormal DNA methylation.
Bagheri Hosseinabadi et al. (2020)	Blood samples from thermal power plant workers; mean levels of exposure to ELF magnetic and electric fields were 0.0165 mT (±6.46) and 22.5 V/m (±5.38), respectively.	DNA strand breaks .in lymphocytes.
Baraúna et al. (2015)	Chromobacterium violaceum bacteria cultures exposed to ELF-EMF for 7 h at 0.00066 mT	Five differentially expressed proteins detected including the DNA-binding stress protein.
Belyaev et al. (2005)	Human lymphocytes exposed to 50 Hz magnetic field at 0.015 mT (peak) for 2 h (measurements made at 24 and 48 h after exposure).	Induced chromatin conformation changes.
Dominici et al. (2011)	Lymphocytes from welders (average magnetic field exposure from personal dosimeters 0.00781 mT (general environmental level 0.00003 mT)	Higher micronucleus frequency correlated with EMF exposure levels; decreased in sister chromatid exchange frequency.
Heredia-Rojas et al. (2010)	Human non-small cell lung cancer cells (INER-37) and mouse lymphoma cells (RMA E7) (transfected with a	An increased in luciferase gene expression was observed in INER-37 cells.

	plasmid with hsp70 expression when exposed to magnetic field and contains the reporter for the luciferases gene) exposed to a 60-Hz magnetic field at 0.008 and 0.00008 mT for 20 min.	
Sarimov et al. (2011)	Human lymphocytes exposed to 50-Hz magnetic field at 0.005-0.02 mT for 15-180 min	Magnetic field condensed relaxed chromatin and relaxed condensed chromatin.
Villarini et al. (2015)	Blood leukocytes from electric arc welders presumably exposed to 50-Hz EMF (mean 0.0078 mT; range: 0.00003-0.171 mT)	Decreased DNA strand beaks.
Wahab et al. (2007)	Human peripheral blood lymphocytes exposed to 50 Hz sinusoidal (continuous or pulsed) or square (continuous or pulsed) magnetic fields at 0.001 or 1 mT for 72 h.	Increase in the number of sister chromatid exchange/cell
Zendehdel et al. (2019)	Peripheral blood cells of male power line workers in a power plant. The median value of the magnetic field at the working sites was 0.00085 mT.	Increased in DNA strand breaks.

Supplement 5

Effects of EMF wave-form and cell types (*in italic*) studied (Literature up to January 2021)

RFR	
Belyaev et al. (2009)	UMTS different from GSM signal on DNA repair foci in human lymphocytes.
Campisi et al. (2010)	Increased DNA fragmentation in rat neocortical astroglial by 50-Hz modulated 900-MHz RFR, but no effect from continuous wave field.
D'Ambrosia et al. (1995)	Micronucleus frequency in human lymphocytes affected by pulsed but not CW 9 GHz RFR.
D'Ambrosia et al. (2002)	Micronucleus frequency in human lymphocytes affected by pulsed but not CW 1748-MHz RFR.
Del Re et al. (2019)	*Changes in repetitive–DNA in human cell exposed to GSM 900-MHz RFR depended on cell type studied (HeLa, BE(2)C, and SH SY5Y).*
Franzellitti et al. (2008)	HSP70C gene expression enhanced after 24 h exposure to GSM-217Hz signals and reduced after 4 and 16 h exposure to GSM-Talk signals In human trophoblasts.
Franzellitti et al. (2010)	DNA damage in human trophoblasts induced by GSM 1800 MHz RFR, but not by continuous-wave field.
Gapeyev et al. (2014)	Protective effect to x-ray induced DNA strand break in mouse lymphocytes with pulse-modulated and not continuous-wave RFR.
Heredia-Rojas et al. (2010)	*"Electromagnetic field" plasmid transfected into INER-37 and RMA E7 cell lines exposed to a 60-Hz MF. An increased luciferase gene expression was observed in INER-37 cells but had no effect on the RMA E7 cell line.*
Kumar et al. (2020)	1800-MHz more effective than 900-MHz RFR on inducing DNA damage in onion.
Lopaz-Martin et al. (2009)	Unmodulated RFR caused higher neuronal c-fos expression than pulsed modulated 900-MHz GSM field.
Luukkonen et al. (2009)	872-MHz continuous-wave RFR increased DNA strand breaks in SH-SY5Y human neuroblastoma cells, but no effect from GSM –modulated field.
Markova et al. (2005)	GSM-915 MHz RFR induced more consistent

	effect on human lymphocyte chromatin conformation than GSM-905 MHz RFR.
Martin et al. (2020)	*Four different types of human keratinocytes showed different patterns (Up- and down-regulation or no change) of expression of ADAMTS6, IL7R, and NOG genes exposed to a 60-GHZ RFR.*
Ozgur et al. (2014)	1800-MHz RFR more potent than 900-MHz RFR on inducing DNA fragmentation (apoptosis) in hepatocarcinoma cells.
Nylund and Leszczynski (2006)	*Gene and protein expressions in response to GSM 900-MHz RFR depended on the type of human endothelial cell line (EA.hy926 and EA.hy926v1).*
Remondini et al. (2006)	*Gene expressions after exposure to 900 and 1800 –MHz RFR- NB69 neuroblastoma cells, T lymphocytes, and CHME5 microglial cells did not show significant changes, whereas EA.hy926 endothelial cells, U937 lymphoblastoma cells, and HL-60 leukemia cells showed up- or down-regulated genes.*
Romano-Spica et al. (2000)	Oncogene expression only occurred when exposed to 16-Hz modulated 50MHz RFR
Sarimov et al. (2004)	Different potencies between 915 MHz and 905-MHz RFR on chromatin conformation in human lymphocytes.
Schwartz et al. (2008)	*UMTS 1950-MHz RFR increased DNA breaks and micronucleus frequency in human fibroblasts, but not in lymphocytes.*
Semin et al. (1994)	4000-8000 MHz RFR, 1-6 Hz modulated RFR showed narrow "window" peak intensity and modulation frequency effects on DNA secondary structure.
Shckorbatov et al. (2009)	35-GHz RFR caused condensation of chromatin in human buccal epithelium cells-left circularly polarized radiation induced less effect than linearly polarized radiation.
Shckorbatov et al. (2010)	36.65-GHz RFR caused chromosome condensation in human fibroblasts –right-handed elliptically polarized radiation was more biological activity than the left-handed polarized one.
Tkalec et al. (2013)	AM-modulated 900- MHz RFR more potent than continuous-wave field in inducing DNA damage in earthworms coelomocytes.
Valbonesi et al. (2014)	GSM 1800-MHz signal, but not continuous-

	wave field, induced HSP-70 gene expression in rat PC-12 cells.
Vilic et al. (2017)	DNA damage in honey bee larvae- AM-modulated 900-MHz RFR more potent than continuous-wave field.
Xu et al. (2013)	*Gamma-H2AX foci after exposure to GSM 1800-MHz RFR induced in in Chinese hamster lung cells and Human skin fibroblasts (HSFs), but not in rat astrocytes, human amniotic epithelial cells, human lens epithelial cells, and human umbilical vein endothelial cells.*
Zhang et al. (2008)	Intermittent 1800-MHz RFR more potent than continuous exposure on gene expression in rat neurons.
Zhao et al. (2007)	*Capase-2and Capase-6 expressions up-regulated in neuron, but not in astrocytes.*
Static/ELF EMF	
Del Re et al. (2006)	50-Hz sinusoidal MF increased where as pulse square wave decreased heat-shock protein induction in E. coli.
Focke et al (2010)	Increased DNA fragmentation by intermittent 50-Hz MF, but no effect by continuous exposure.
Giorgi et al. (2011)	E. coli gene expression decreased by sinusoidal MF and increased by pulsed square-wave MF- not frequency dependent (25, 50, 75 Hz)
Heredia-Rojas et al. (2010)	*60-Hz MF induced luciferase gene expression in INER-37 cells, but not in RMA E7 cells.*
Ivancsits et al. (2002)	Intermittent more potent than continuous exposure of a 50-Hz MF on DNA damage in human fibroblasts.
Lee et al. (2016)	*60-Hz MF induced delay of cell cycle progression in MCF7 and MCF10A cells, but not in Jurkat and NIH3T3 cells.*
Mahmoudinasab and Saadat (2018a)	*Patterns of up-regulation of antioxidant genes are different between MCF-7 and SH-SY5Y cells exposed to an intermittent 50-Hz EMF.*
Mahmondinasab et al. (2016)	Different schedules of intermittent exposure to a 50-Hz MF had different effect on gene expression in human MCF-7 breast cancer cells
Mercado-Saenz et al. (2019)	Decreased spontaneous mitochondrial mutation in yeast by pulsed MF (25-Hz), no effect by sinusoidal field.

Robison et al. (2002)	*60-Hz MF exposure decreased DNA repair rate in HL-60 and HL-60R cells, but not in Raji cells.*
Sanie-Jahromi and Saadat (2018)	*co-treatment of "cisplatin +morphine + EMF" made bleomycin more cytotoxic in SH-SY5Y cells, but not in MCF-7cells.*
Sanie-Jahromi et al. (2016)	Significant differences in DNA-repair gene expression in MCF-7 cell exposed under 3 different patterns of 50-Hz EMF (5 min field-on/5 min field-off (30 min), 15 min field-on/15 min field-off (30 min), 30 min field-on continuously.)
Sanie-Jahromi et al. (2017)	*50-Hz MF exposure synergistic with cisplatin and bleomycin on DNA-repair gene expression and cell viability in MCF-7 cells, but not in SH-SY5Y cells.*
Udroiu et al. (2015)	*50-Hz MF exposure affected genotoxic effect of x-ray in mouse male germ cells, but not in peripheral blood erythrocytes.*
Wahab et al. (2007)	Sister chromatid exchange in human lymphocytes exposed to a 50-Hz MF (continuous or pulsed sinusoidal or continuous or pulsed square-wave). Square continuous-wave MF was the most potent.

Health Matters

FCC Announces Its Existing RF Exposure Limits Apply to 5G

■ **James C. Lin**

Citing support from the U.S. Food and Drug Administration's Center for Devices and Radiological Health, the U.S. Federal Communications Commission (FCC) announced in December 2019 that it reaffirms the RF radiation exposure limits it first adopted in 1996 [1]. The action was undertaken in the face of appeals from some to tighten, and others to loosen, the existing limits.


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In the process, the FCC also resolved and terminated a 2013 Notice of Inquiry that sought public input on whether it should modify its existing RF exposure rules considering recent scientific opinions and authoritative expert views, among other issues [2]. Apparently, six years since the Notice of Inquiry, the FCC deems it appropriate to maintain the existing RF exposure limits. It is interesting to observe that the FCC declined to make changes that would stiffen the current rules or to make any changes that would effectively relax the current rules.

Note that the FCC's exposure limits are currently specified up to 100 GHz. These limits could, in principle, be applied to the millimeter-wave (mm-wave) bands used for 5G services and to future uses of wireless technologies at even higher frequencies; in fact, the FCC has signified such.

In the recently released Notice of Proposed Rulemaking and Memorandum Opinion and Order [2], the FCC proposes to formalize additional limits on localized RF exposure from devices operating at higher gigahertz frequencies and extend this to terahertz frequencies. It further proposes to extend the same constant exposure limits that presently apply from 6 to 100 GHz up to a maximum frequency of 3,000 GHz (3 THz), which is commonly regarded as the upper bound of the RF bands.

Newer technologies that employ techniques like adaptive array antennas and beamforming create complex electromagnetic fields that present challenges for current RF measurement methods. The FCC's RF exposure rules do not yet specify a metric or spatial maximum power density limit for localized exposure at higher frequencies. As wireless devices and systems are being developed to operate at higher frequencies for future 5G services in the mm-wave bands, the FCC appears ready to propose a general localized power density exposure limit above 6 GHz of 40 W/m^2, averaged over 1 cm^2 and applicable up to the upper frequency boundary of 3 THz, for the general population or in cases of uncontrolled exposure. The FCC is currently inviting comments on this proposal [2].

The RF and microwave exposure rules established by the FCC are based on specific absorption rate (SAR) and maximum permissible exposure (MPE) limits [3], [4]. SAR is the accepted

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metric or quantity corresponding to the relative amount of RF and microwave power deposition/energy absorption in a portion of or in the whole body (i.e., any part of a wireless-device or cell phone-handset user but the entire body when a user is in the radiation domain of a Wi-Fi antenna or base station). The basic restrictions for human exposure are defined by SAR limits. MPE limits are derived from the SAR limits, in terms of free-space field strength and power density.

For exposures from cell-phone-related operations, the FCC specifies a quantity of local tissue SAR of 1.6 W/kg, as determined in any 1 g of body tissue. Also, an average value of 0.08 W/kg in any 1 g of body tissue was set for whole-body exposures.

The FCC rules impose basic restrictions on SAR limits for general public and occupational exposures to avoid whole-body heat stress and excessive localized tissue heating, specifically to prevent biological and health effects in response to an induced body temperature rise of 1 °C or more for an average period of 6 min [3], [4]. This level of temperature increase results from individuals' exposure under moderate environmental conditions to a whole-body SAR of approximately 4 W/kg for about 30 min. A whole-body average SAR of 0.4 W/kg was chosen as the restriction in order to provide protection for occupational exposure. An additional reduction factor of five was introduced for public exposure, giving an average whole-body SAR limit of 0.08 W/kg. This value was purposefully relaxed by a factor of 20 to permit a maximum local tissue SAR of 1.6 W/kg. The power density limits or MPE applicable to general population and occupational exposure for 1.5–100 GHz are 10 W/m^2 and 50 W/m^2, respectively, for whole-body continuous exposure.

According to the FCC, more than 1,000 comments and representations were filed in response during the six years since the 2013 Notice of Inquiry. It is not surprising to learn that some of the filings urged the FCC to tighten RF exposure limits, whereas others asked for less restrictive limits.

Supporters for stricter RF guidelines include the American Academy of Pediatrics, American Academy of Environmental Medicine, California Brain Tumor Association, Center for Family and Community Health at the University of California Berkeley, and International EMF Scientist Appeal, among others. They have called on the FCC to adopt stronger exposure limits on RF radiation exposure. Many also implored the FCC to impose a moratorium on the wireless industry to pause its deployment of 5G services. The stated reason is that more research is needed due to the paucity of scientific knowledge regarding the effects on human health of much higher RF frequencies and the impact of the ubiquitous small-cell base stations dictated by 5G deployment.

Among those advocating for the FCC to adopt weaker regulatory limits on RF radiation are CTIA–The Wireless Association, the Mobile Manufacturers Forum, the Telecommunications Industry Association, and consultants for the wireless industry. Many of these petitions also contended that the scientific evidence to date suggests that, in terms of health effects, 5G is no different from any other cellular mobile technology and systems deployed to date. Arguments were presented for weakening cell-phone RF exposure limits to peak local SARs at 2 W/kg, averaged over 10 g of tissue (the FCC limit is 1.6 W/kg over 1 g). This larger averaging mass would make the limits less stringent by a factor of two or more.

More specifically, some submissions also expressed opposition to the requirement that cell-phone retailers warn customers about the possible radiation dangers of holding phones close to their bodies. In this regard, it is noteworthy that recently [5] the U.S. Supreme Court rejected a challenge filed by CTIA–The Wireless Association against the "cell-phone right to know" law adopted by the City of Berkeley, California, in May 2015 (see http://bit.ly/berkeleymedia).

The city's ordinance took effect in 2016. It requires dealers to notify customers of the FCC's RF radiation standards for cell phones and, specifically, that RF exposure "may exceed the federal guidelines" if users carry a phone in a shirt or pants pocket or tucked into a bra while they're connected to a wireless network. Furthermore, retailers must display the warning on a poster or in a handout flyer, as attributed to the City of Berkeley.

However, the FCC did accede to treat the pinnae (outer ears) like other extremities of the body for purposes of determining compliance with the FCC's RF exposure limits, irrespective of petitions that appealed otherwise. As extremities, the pinnae, along with the hands, wrists, feet, and ankles, are subject to less stringent localized RF exposure limits than the rest of the body. For these parts of the human body, the peak spatial-average SAR limit for general population exposure is set at 4 W/kg, averaged over any 10 g of tissue.

It is significant to note that, in affirming treatment of the pinnae as extremities and through associated comments, the FCC acknowledged that its RF radiation exposure limits are based solely on localized thermal effects. Also, the FCC refused to recognize that, unlike the hands, wrists, feet, and ankles, the pinnae are contiguous to the head: any RF-induced field will impact the head and brain directly.

More importantly, as noted previously, the larger averaging mass renders the exposure limits less stringent by a factor of two or more for local SARs averaged over 10 g of tissue. Thus, the 4-W/kg SAR averaged over 10 g is equivalent to a 1-g SAR of 8–12 W/kg in the pinnae or external ear, causing excessive local tissue temperature elevation that is easily masked by a 10-g SAR. Moreover, the mass of pinnae is about 10 g and is geometrically jagged and uneven, which would further accentuate SAR and temperature disparity in causing localized thermal effects.

Recent scientific results on the correlation of SAR with induced tissue temperature elevation, and the dependence on mass of averaging tissue and exposure duration, show that, in general, SAR provides a better correlation with temperature elevation for exposure durations between 1 and 2 min (short durations) at most frequencies used for current wireless technologies [6], [7]. In this case, a mass of 1 g is optimal, but the correlation coefficient remains above 0.9 at 2 min for a 2-g mass.

For longer exposures, the maximum correlation coefficient is reduced, and the correlation favors a larger averaging mass. At steady state (30 min), the correlation of temperature increase with SAR is maximum for a mass of 5–9 g at frequencies below 6 GHz.

However, for exposures at higher gigahertz frequencies (mm-waves and 5G), RF energy absorption tends to be more superficial and concentrated. Energy deposition could occur quickly in a smaller tissue area or mass, causing intense temperature elevation within a very short exposure time period.

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Electromagnetic fields, 5G and health: what about the precautionary principle?

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ABSTRACT

New fifth generation (5G) telecommunications systems, now being rolled out globally, have become the subject of a fierce controversy. Some health protection agencies and their scientific advisory committees have concluded that there is no conclusive scientific evidence of harm. Several recent reviews by independent scientists, however, suggest that there is significant uncertainty on this question, with rapidly emerging evidence of potentially harmful biological effects from radio frequency electromagnetic field (RF-EMF) exposures, at the levels 5G roll-out will entail. This essay identifies four relevant sources of scientific uncertainty and concern: (1) lack of clarity about precisely what technology is included in 5G; (2) a rapidly accumulating body of laboratory studies documenting disruptive in vitro and in vivo effects of RF-EMFs—but one with many gaps in it; (3) an almost total lack (as yet) of high-quality epidemiological studies of adverse human health effects from 5G EMF exposure specifically, but rapidly emerging epidemiological evidence of such effects from past generations of RF-EMF exposure; (4) persistent allegations that some national telecommunications regulatory authorities do not base their RF-EMF safety policies on the latest science, related to unmanaged conflicts of interest. The author, an experienced epidemiologist, concludes that one cannot dismiss the growing health concerns about RF-EMFs, especially in an era when higher population levels of exposure are occurring widely, due to the spatially dense transmitters which 5G systems require. Based on the precautionary principle, the author echoes the calls of others for a moratorium on the further roll-out of 5G systems globally, pending more conclusive research on their safety.

BACKGROUND

Fifth generation (5G) technology is being widely promoted by politicians, government officials, and private sector interests.[1–3] They contend that its advent will bring clear economic and lifestyle benefits, through massive increases in wireless and mobile connectivity at home, work, school and in the community. Examples of these 5G benefits include driverless vehicles and 'The Internet of Things'—automated and continuous communication between the machines in our daily lives.[4 5] On the other hand, the public health response to this wave of communications innovation has become a sense of deep concern, related to widespread scientific uncertainties, as well as a lack of use of existing evidence, in the current international safety guidelines for 5G and related radio frequency electromagnetic field (RF-EMF) exposures.[5–8] This commentary sets out the reasons for such concern.

WHAT IS 5G AND WHY IS IT DIFFERENT FROM PAST EMF EXPOSURES?

Developed over just the last decade, radio frequency (wireless) transmission systems in the 5G category are being rolled out throughout the world. These systems will massively increase the volume, speed and spatial reach of digital data transfer.[4–6] The four successive previous generations (1G, 2G, 3G and 4G) of wireless transmission systems were deployed initially for wireless and mobile phones (1980s and 1990s), followed by WiFi (2000s), and then smart metres and the Internet of Things (2010s). Each successive generation of transmission systems has used higher frequencies of electromagnetic waves to carry ever-larger volumes of data, faster, in more ubiquitous locations. 5G is widely acknowledged to be a step change in this sequence, since it additionally uses much higher frequency (3 to 300 GHz) radio waves than in the past. 5G will also make use of very new—and thus relatively unevaluated, in terms of safety—supportive technology (including pulsing, beaming, phased arrays and massive input/massive output (MIMO)—see below) to enable this higher data transmission capacity.[4–6]

However—unlike prior generations of wireless transmission systems—5G ultrahigh-frequency waves are easily interrupted by vegetation foliage (and building walls, often requiring additional signal boosting within each building). This inherent fragility of 5G high-frequency waves means that transmission boosting 'cell' antennae are generally required every 100–300 m or less—far more spatially dense than the miles-apart transmission masts required for older 2G, 3G and 4G technology using lower frequency waves.[4–6]

This dense transmission network is also required in order to achieve the 'everywhere/anytime' connectivity promised by 5G developers, and necessitated by new technology such as driverless cars, which must never be out of internet contact, for safety reasons. Critics of 5G agree[6–8]—but its supporters do not[9 10]—that the overall population levels of exposure to RF-EMFs will be greatly increased by the 5G roll-out. One compelling argument for that view is the 'inverse square law' of EMF exposure: intensity varies as the inverse of the square of the distance from the emitting source.[11] With plans afoot internationally to put a 5G booster antenna on 'every second or third lamp-post', it is difficult to believe that overall population exposures will not increase substantially. Existing 4G

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systems can service up to 4000 radio frequency using devices per square kilometre; 5G systems will connect up to one million devices per square kilometre—greatly increasing the speed of data transfer (by a factor of 10) and the volume of data transmitted (by a factor of 1000).[6]

THE CURRENT CONTROVERSY

International health protection agencies and their scientific advisory bodies have published several reviews over the last decade, of varying scientific quality, of the research evidence regarding potential adverse biological and health effects of RF-EMFs.[5 12–15] These reviews—by Health Protection England,[12] the International Agency for Research on Cancer (IARC),[13] an Expert European Union (EU) Committee[14] and the International Commission on Non-Ionising Radiation Protection (ICNIRP)[15]—have, with one exception, not converged around a strong warning about such effects. IARC is the outlier in this respect, having determined in 2011 that EMFs are 'possibly carcinogenic to humans'.[13] Meanwhile, independent radiation and health scientists have published serious concerns about the current roll-out of 5G transmission systems.[6–8 16–18] Their reasoning is twofold: (1) these systems have an unprecedented potential to create human and non-human RF-EMF exposures orders of magnitude more intense (eg, in terms of 'power flux density') than was the case only a few decades ago (16); (2) there is a remarkable dearth of evidence on the safety of 5G-specific EMF emissions, but a growing body of research suggestive of harms from other RF-EMF exposures, which have been studied for much longer.[6–8 17 18]

Moreover, a growing number of engineers, scientists, and doctors internationally have been calling on governments to raise their safety standards for RF-EMFs, commission more and better research, and hold off on further increases in public exposure, pending clearer evidence of safety.[18–21] Some politicians have listened: France, Israel, Cyprus and Russia have banned WiFi in preschool and restricted its use in primary schools. Belgium has banned the sale of mobile phones to children under seven. In response to such concerns, several jurisdictions have recently blocked the installation of 5G antennae systems in their communities: Brussels, Florence, Rome, as well as Glastonbury, Frome and Totnes in the UK; and widespread anti-5G campaigns are now emerging in Australia, North America and elsewhere.[21]

Some countries have lowered allowable RF-EMF exposure levels far below those permitted in the UK and USA. Powerwatch, a non-profit, independent organisation in the UK, has published comparisons of international recommendations on permitted maximum exposure levels to EMFs.[22] Those comparisons show that the highest permitted RF-EMF exposures which are used globally, as the basis for national safety guidelines, are those used in the USA, the UK and most of the EU. These exposure limits are derived from the recommendations to WHO in 1998 (recently updated, but essentially not changed, in March 2020) by the ICNIRP.[15] These international comparisons show that the safety limit for RF-EMF exposure set by ICNIRP is 10-fold higher than that set by the next most liberal guidelines, found in Israel and India, and 100-or-more-fold higher than the limits set by other guidelines, spanning 14 EU jurisdictions as well as China. As discussed in detail below, one reason that ICNIRP's permitted exposures are so high is that they are based solely on the acute thermogenic (heat-producing) effects of RF-EMF in animal tissues; this is unlike more conservative jurisdictions' guidelines, which are based on a wider variety of biological and health effects documented in recent decades, including effects resulting from chronic rather than acute exposures, and effects not mediated by thermogenesis.

KEY CONTENTIOUS ISSUES AND SCIENTIFIC UNCERTAINTIES

Lack of clarity about precisely what sorts of EMFs will result from 5G roll-out

A striking feature of this public controversy is that various commentators—even those with advanced training in telecommunications physics and engineering—inconsistently refer to quite different specific technologies when they discuss the pros and cons of '5G'. American authors tend to state that the 5G system roll outs already underway in that part of the world are using very high-frequency (24–100 GHz)/short-wavelength RF transmission—so-called 'millimetre range' waves.[6] However, some UK/EU industry websites[9] state that 'no new frequencies are required' (at present) beyond those already in use in existing 4G mobile networks, WiFi, smart metres. However, independent authors commenting on current private sector plans in the EU, to extend 5G networks more widely in the future, tell a different story.[23 24] These commentaries imply that the use of millimetre wave frequencies—about which we have very few conclusive studies of human health effects—is already planned and inevitable in the EU, and eventually globally, in order to accommodate anticipated consumer requirements—especially the 'Internet of Things' and driverless vehicles. Tellingly, the Guardian (one of the UK's most respected newspapers) reported last year[25] that UK lamp posts were becoming the subject of expensive legal battles, over 'who can charge what' for mounting 5G booster cell antennae on them. Cash-strapped Local Councils had hoped to profit from such charges to telecom companies. These companies have taken local governments to court to block those charges. The USA provides a cautionary tale in this respect: nearly 25 years ago national legislation there took local authorities completely out of the telecommunications regulatory system, leaving local 5G installation and similar decisions entirely in the hands of central authorities—that is, the Federal Communications Commission.[6]

Equally inconsistently described in writings about 5G is the complex set of special signal modulations, pulses, polarisation, phased arrays and novel equipment designs—for example, 'massive MIMO antennas'—which represent the cutting edge technologies that accompany 5G system installation—many of them proprietary. As some commentators on potential health effects from such exposures have pointed out, it is highly likely that each of these many forms of transmission causes somewhat different biological effects—making sound, comprehensive and up-to-date research on those effects virtually impossible.[5–7 26 27]

In short, '5G systems' is not a consistently defined term. This confusion has not helped clarify the health and safety issues surrounding 5G roll outs internationally.

An emerging preponderance of laboratory studies indicating RF-EMFs' disruptive biological effects: with many knowledge gaps

The lack of a consistent definition of '5G' matters enormously. This is clearly demonstrated in a sophisticated recent review of the laboratory science evidence of RF-EMF effects in diverse biological systems.[26] That review shows that the existing scientific literature on the biological effects of more recently developed technology is quite limited, in that there is hardly any study replication—the hallmark of reliable research. We often have only one extant study of any given biological effect of a specified combination of radio frequencies, modulation and pulse patterns. The literature that does exist identifies remarkably heterogeneous biological effects, across hundreds of such specific RF-EMF exposure patterns. Furthermore, a comprehensive Canadian review of the same evidence states that some of the new RF-EMF technologies—such as innovations in radio frequency 'pulsing,' 'polarisation' and 'modulation'—are so new that biological scientists have not been able to keep up—that is, no studies yet exist of these new technologies' biological effects.[27]

These recent reviews of laboratory (ie, non-epidemiological) studies of the biological effects of RF-EMFs do identify diverse, multibody system effects, operating by a range of physicochemical pathways which are not mediated by thermogenesis.[6 8 26 27] The reviewers document a growing body of evidence that RF-EMF exposures produce effects spanning reproductive/teratogenic, oncological, neuropsychiatric, skin, eye and immunological body systems. In addition, there are many fundamental effects at the subcellular level, in terms of oxidation, DNA alteration, gene expression and bacterial antibiotic resistance. Particularly striking is a 2018 study from Israel documenting the capacity of the sweat ducts in human skin to act as 'helical antennae' receptive to 5G frequencies of RF-EMF. When sweat ducts are exposed to these RF-EMFs, there are remote systemic effects, through the skin's established capacity to secrete and send hormones and other signals to the entire body.[28] This report alters one's sense of the potential risks from such high frequency waves, since they have long been thought to be 'inherently less dangerous', because they are largely absorbed in the top few millimetres of exposed tissue (thus limiting any adverse effects, in theory, to the skin or eye).

Finally, it is instructive to look at the two widely cited NIH toxicological studies of specific EMFs' effects on thousands of rodents,[29 30] conducted by experienced and highly respected laboratory scientists at a world-leading institution. Since their publication in 2018, epidemiologists and other scientists have pointed out several methodological weaknesses in the conduct and analysis of these studies that make their unequivocal interpretation almost impossible, particularly in terms of their relevance to human health: excessive statistical inference testing of multiple (over 1000) hypotheses, without appropriate adjustment of p values considered 'statistically significant'; reporting of results 'often ignoring statistical tests'; failure to explain major internal inconsistencies of findings across EMF doses, tumour types and rodent sexes; use of experimental EMF exposures far in excess of any known human ones; uncontrolled confounding by direct thermogenesis effects—the list goes on.[31 32]

In short, laboratory studies of EMF exposure are fraught with both internal and external validity issues, and cannot replace high-quality human epidemiological studies—though, as we will now discuss, these are also hard to come by.

Lack of conclusive human epidemiological studies of 5G-specific health effects (but increasing epidemiological evidence of serious health effects from previous generations of RF-EMF exposures)

Canada's most senior cancer epidemiologist, Miller *et al* have last year summarised the human epidemiological evidence[33] linking human breast and brain tumours, male reproductive outcomes and child neurodevelopmental conditions to RF-EMF exposures resulting from the use of past generations of transmission systems. Critically, this evidence is not about exposure to the high radio frequency/short wavelength 5G systems. These systems are too newly deployed to have been extensively studied, especially by the highest-quality epidemiological study designs for establishing evidence of causation: prospective cohort studies. Such studies typically require decades of follow-up to detect delayed health effects, such as most cancers.

Miller *et al* find compelling evidence of carcinogenesis, especially in the brain and acoustic nerve, as well as the breast, from strong RF-EMF exposures to previous generations of mobile phone transmissions. Perhaps the most convincing evidence they cite comes from the oldest and most-often-maligned study design—case reports. While admittedly old-fashioned, case reports can, when they involve pathognomonic effects (ie, pathological features absolutely specific to a particular exposure) provide useful evidence of exposure/outcome specificity—a valuable but often unobtainable epidemiological criterion for inferring causation, according to the standard epidemiological criteria first enunciated by Sir Austin Bradford Hill over 50 years ago.[34 35] Strikingly localised breast tumours, of unusual morphology, have been diagnosed in several women with particularly strong exposures to previous generations of mobile phones: they habitually placed their phones in their bras, on the same side of the body where the tumour has developed. Miller *et al* call for an urgent update of the last (2011) review of EMFs and cancer by the International Agency for Research on Cancer.[13] They predict that such an update would now rate RF-EMFs as, at minimum, 'probable' (not merely 'possible' as in 2011) carcinogens, based on current evidence.

Persistent allegations of unscientific bases for existing health protection guidelines on RF-EMFs and unmanaged conflicts of interest on expert advisory panels

A senior epidemiologist from Sweden, Hardell, has repeatedly published in peer-reviewed journals detailed allegations regarding the main WHO scientific advisory body on EMF health effects and safety—the previously mentioned ICNIRP. Hardell contends that ICNIRP's membership includes over-representation of vested interests, especially the giant multinational telecommunications firms who are heavily invested in the roll out of 5G systems internationally.[36 37] ICNIRP has long been influential in EMF regulation: its scientific recommendations to WHO were first issued in 1998, updated in 2009, and revised and updated again in March 2020.[15] Hardell points out that ICNIRP's pro-industry bias may explain its continued reliance only on studies of the thermogenic (heat-producing) effect of RF-EMFs in biological tissues: these studies would be expected to paint an overly benign picture of RF-EMF safety. This narrow ICNIRP focus flies in the face of published reviews by independent scientists (6, 8, 13, 26, 27) citing compelling research evidence, accumulating steadily over the last few decades, of non-thermogenic adverse effects of RF-EMFs, affecting diverse human and animal subcellular function, tissues and organ systems (see above). In detailed, almost lawyer-like publications,[36 37] Hardell fastidiously documents the ICNIRP's 20 years of dogged defiance, in the face of widespread criticism by other scientists, that the scientific base for their recommendations remains dated and narrow, rendering their guidelines on 'safe' RF-EMF exposure unsafe.

The most damning evidence adduced by Hardell is a table of the cross-appointments held by six members of the WHO Monograph Group, across five major international advisory panels on the health effects of non-ionising radiation [36 – page 408]. Hardell also describes these scientists' strong personal links to the telecommunications industry, a situation likely arising from the fact that the ICNIRP itself is a 'private organisation (non-governmental organisation; NGO) based in Germany. New expert members can only be elected by members of ICNIRP.' Hardell contrasts the ICNIRP's reports to the publications of the 'BioInitiative 2012'[38] group, of nearly 30 international experts in this field, whose operations are not only wholly independent of any such 'vested interests,' but also entirely transparent. The current version (March 2020) of the BioInitiative 2012 website[38] provides detailed descriptions of 988 peer-reviewed scientific studies of adverse potential health and biological effects of EMFs arising from RF and similar non-ionising sources. The vast majority (84.6%) of these 988 studies document disruptive biological effects from such EMFs, almost all of them operating via non-thermogenic pathways. (This writer would have preferred to see more 'critical appraisal' of the quality of the studies than the BioInitiative 2012 website provides. However, the major effort entailed in assembling this massive body of scientific evidence, and updating it regularly since 2012, is impressive).

Finally, Carpenter has recently published a well-researched analysis of how source of funding correlates with study findings, across many peer-reviewed publications over the last few decades, of the relationship between various kinds of EMF exposure and several cancers.[39] He shows convincingly that studies funded by private sector entities, with strong vested interests in maintaining their current use of the sources of EMFs under study, tend to find no association—whereas studies funded by public sector or independent sources find the opposite. As Carpenter points out, this suggests that many systematic reviews and meta-analyses in this field, having failed to correct for this 'source of funding bias,' likely underestimated the evidence for causation.

CONCLUSIONS AND RECOMMENDATION

In assessing causal evidence in environmental epidemiology, Bradford Hill himself pointed out that 'the whole picture matters;' he argued against prioritising any subset of his famous nine criteria for causation. One's overall assessment of the likelihood that an exposure causes a health condition should take into account a wide variety of evidence, including 'biological plausibility'.[34 35] After reviewing the evidence cited above, the writer, an experienced physician-epidemiologist, is convinced that RF-EMFs may well have serious human health effects. While there is also increasing scientific evidence for RF-EMF effects of ecological concern in other species,[6–8 16–18 23] both plant and animal, these have not been reviewed here, for reasons of space and the author's disciplinary limitations. In addition, there is convincing evidence, cited above, that several nations' regulatory apparatus, for telecommunications innovations such as the 5G roll-out, is not fit for purpose. Indeed, significant elements in that apparatus appear to have been captured by vested interests. Every society's public health—and especially the health of those most likely to be susceptible to the hazard in question (in the case of EMFs, children and pregnant women)—needs to be protected by evidence-based regulations, free from significant bias.

Finally, this commentary would be remiss if it did not mention a widely circulating conspiracy theory, suggesting that 5G and related EMF exposures somehow contributed to the creation or spread of the current COVID-19 pandemic. There are knowledgeable commentators' reports on the web debunking this theory, and no respectable scientist or publication has backed it.[40 41] Indeed, combatting it is widely viewed by the scientific community as critical to dealing with the pandemic, as conspiracy theorists holding this view have already carried out violent attacks on mobile phone transmission facilities and other symbolic targets, distracting the public and authorities at a time when pandemic control actions are paramount.[42] This writer completely supports that view of the broader scientific community: the theory that 5G and related EMFs have contributed to the pandemic is baseless.

It follows that, for the current 5G roll-out, there is a sound basis for invoking 'the precautionary principle'.[43] This is the environmental and occupation health principle by which significant doubt about the safety of a new and potentially widespread human exposure should be a reason to call a moratorium on that exposure, pending adequate scientific investigation of its suspected adverse health effects. In short, one should 'err on the side of caution'. In the case of 5G transmission systems, there is no compelling public health or safety rationale for their rapid deployment. The main gains being promised are either economic (for some parties only, not necessarily with widely distributed financial benefits across the population) or related to increased consumer convenience. Until we know more about what we are getting into, from a health and ecological point of view, those putative gains need to wait.

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5G Wireless Deployment and Health Risks: Time for a Medical Discussion in Australia and New Zealand

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INTRODUCTION TO THE ISSUE

There is an urgent need for clinicians and medical scientists in the Australia-New Zealand region to engage in an objective discussion around the potential health impacts of the fifth generation (5G) wireless technology currently being deployed. The statements of assurance by the industry and government parties that dominate the media in our region are at odds with the warnings of hundreds of scientists actively engaged in research on biological/health effects of anthropogenic electromagnetic radiation/fields (EMR/EMF).[1] There have been worldwide public protests as well as appeals by professionals and the general public[2] that have compelled many cities in Europe to declare moratoria on 5G deployment and to begin investigations. In contrast, there is no medically-oriented professional discussion on this public health topic in Australia and New Zealand, where 5G deployment is being expedited. 5G is untested for safety on humans and other species and the limited existing evidence raises major concerns that need to be addressed. The vast body of research literature on biological/health effects of 'wireless radiation' (radiofrequency EMR)[3,4] indicates a range of health-related issues associated with different types of wireless technologies (1G-4G, WiFi, Bluetooth, Radar, radio/TV transmission, scanning and surveillance systems). These are used in a wide range of personal devices in common use (mobile/cordless phones, computers, baby monitors, games consoles etc) without users being aware of the health risks. Furthermore, serious safety concerns arise from the extra complexity of 5G as follows:

- 5G carrier waves use a much broader part of the microwave spectrum including waves with wavelengths in the millimetre range (hence called 'millimetre waves') which will be used in the second phase of 5G). Until now, millimetre waves have had limited applications such as radar, point-to-point communications links and non-lethal military weapons.[5]

- Extremely complex modulation patterns involving numerous frequencies form novel exposures.

- Beam formation characteristics can produce hotspots of high unknown intensities.

- A vast number of antenna arrays will add millions of microwave transmitters globally in addition to the existing RF transmitters thereby greatly increasing human exposure. This includes 5G small cell antennas to be erected every 200-250 metres on street fixtures, such as power poles and bus shelters, many of which will be only metres from homes with the homeowners having absolutely no say in where the antennas will be located.

This massive leap in human exposure to RF-EMR from 5G is occurring in a setting where the existing scientific evidence overwhelmingly indicates biological interference,[3,4] therefore suggesting the need to urgently reduce exposure. It is already late to educate the population on the risks of wireless radiation and to take public health measures such as those taken with tobacco to reduce exposure by recommending safer wired communications for regular use while leaving wireless communications for short emergency communications. Some European countries have been taking steps to reduce children's exposure to RF-EMR by limiting or discouraging wireless use e.g. France banning WiFi in small children's facilities and limiting use at schools.

As for the new 5G technology, it is concerning that leading experts in the technical field[6] have reported the possibility of damaging thermal spikes under the current exposure guidelines (from beam forming 5G millimetre waves that transfer data with short bursts of high energy) and some animals and children may be at an increased risk due to smaller body size. Even working within the entirely thermally-based current regulatory process, they pointed out 5G millimetre waves "may lead to permanent tissue damage after even short exposures, highlighting the importance of revisiting existing exposure guidelines".[6] Microwave experts from the US Air Force have reported on 'Brillouin Precursors' created by sharp transients at the leading and trailing edges of pulses of mm waves, when beam forming fast millimetre waves create moving charges in the body which penetrate deeper than explained in the conventional models, and have the potential to cause tissue damage.[7] In fact, concerns about moving charges affecting deep tissue are associated with other forms of pulsed RF radiation currently used for wireless communications. This may be one factor explaining why the pulsed radiation used in wireless communication technologies is more biologically active than continuous RF radiation.[8] Such effects of high energy 5G mm waves could have potentially devastating consequences for species with small body size and also creatures that have innate sensitivity to EMF, which include birds and bees that use nature's EMFs for navigation.[9] Unfortunately, non-thermal effects and chronic exposure effects are not addressed in the current guidelines.[10]

As scientists and medical doctors from Australia and New Zealand who have been conducting independent research on the health-related literature of RF-EMR, we would like to urge the medical community to take an active role to encourage investigation into this important issue. Australia and New Zealand have the world's highest and second highest cancer incidence rates out of 185 countries respectively.[11] Our region also has the highest rates of allergic immune diseases on a global scale.[12] When we examine the biological effects of RF-EMR presented in the scientific literature (the ORSAA database is the largest categorised database of peer-reviewed studies on RF-EMR),[13] applying the Bradford Hill criteria, we find compelling evidence suggesting a causal link with many chronic diseases, including cancer, cardiovascular disease, immune diseases and neurodegenerative diseases.[14-18] Moreover, published research shows that Australia has relatively high RF-EMR exposure levels.[19] Therefore, given the scientific evidence of biological/health effects of RF-EMR[3,4] and given the region's concerning health statistics in chronic diseases, it is concerning that no medical input has been made in the health risks assessment process on the part of government health departments.

Members of ORSAA previously reported on the serious flaws of the health risk assessment conducted by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). An analysis of ARPANSA's 2014 literature review report TRS-164 titled "Review of Radiofrequency Health Effects Research – Scientific Literature 2000 – 2012"[20] revealed that its conclusions were not substantiated by their nominated evidence.[21-23] Moreover, a review of 1955 peer-reviewed studies on the ORSAA database[13] (which contained the studies ARPANSA reviewed) revealed 68% of those publications had reported on significant biological/health effects. This refutes the claim that there is no evidence indicating health risks. However, ARPANSA has merely rejected our reported findings without presenting any evidence to substantiate their position.[24] Furthermore, ARPANSA continues to make assurances of safety about wireless technologies (RF-EMR) in general and also about the new and untested 5G. Such unfounded statements jeopardise the safety of Australians because the Australian healthcare professionals and organisations solely depend on ARPANSA's advice. Remarkably, the ARPANSA health risk assessment was conducted by only four reviewers with reported academic qualifications in physical sciences, psychology and epidemiology. Such a lack of biomedical expertise in a "Health Effects" assessment is an unsatisfactory composition for our government advisory body. Moreover, ARPANSA's disclaimers on their website suggests a lack of accountability: "Nothing contained in this site is intended to be used as medical advice and it is not intended to be used to diagnose, treat, cure or prevent any disease, nor should it be used for therapeutic purposes or as a substitute for your own health professional's advice. ARPANSA does not accept any liability for any injury, loss or damage incurred by use of or reliance on the information." In spite of this disclaimer, but likely due to many misleading statements by ARPANSA, the medical community continues to reject health complaints made by patients relating their symptoms to wireless radiation. The situation in New Zealand is very similar. Claims of safety for RF-EMR, and 5G in particular, by ARPANSA and the respective health departments of Australia and New Zealand have been readily accepted even though they have failed to present the primary scientific studies that can support those claims. To our knowledge, based on the published scientific literature, they do not exist.

CLAIMS OF SAFETY MADE BY ARPANSA WITHOUT MEDICAL EXPERTISE

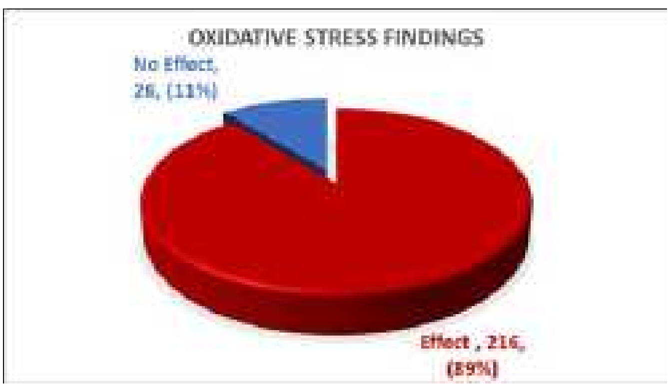
A public information sheet published by ARPANSA in 2019[25] claimed that: "At exposure levels below the limits set within the ARPANSA safety standard, it is the assessment of ARPANSA and international organisations such as the World Health Organization (WHO) and the International Commission on Non-Ionising Radiation Protection (ICNIRP) that there is no established scientific evidence to support any adverse health effects from very low RF EME exposures to populations or individuals." It further stated: "Dr Ken Karipidis, Assistant

Director of ARPANSA's Assessment and Advice Section is an expert on how radiation affects the human body."

The claim of "no established scientific evidence to support any adverse health effects" is refuted by several thousand peer-reviewed scientific studies[3,4] that have demonstrated a wide range of biological or health effects, some of which we highlighted in our previous papers.[21-22] These effects include oxidative stress, DNA damage, mitochondrial/cell membrane damage (including that of RBC), disruption of neurotransmitter levels and ion channels, altered immune/endocrine functions, cancer initiation and promotion.

OXIDATIVE STRESS

Our investigation into the scientific literature has found RF-EMR to be a potent inducer of oxidative stress even at so-called "low-intensity" exposures (which are in fact billions of times higher than in nature[26]) such as those from commonly used wireless devices. An analysis[22] of 242 publications (experimental studies) which had investigated endpoints related to oxidative stress - biomarkers of oxidative damage such as 8-oxo-2'-deoxyguanosine (indicating oxidative DNA damage) and/or altered antioxidant levels - revealed that 216 studies (89%) had reported such findings (Fig. 1). This evidence base on RF-associated oxidative stress from 26 countries (only one study from Australia and none from New Zealand) is relatively new and mostly post 2010, i.e. after the WHO's International Agency for Research on Cancer (IARC) classified RF-EMR as a Group 2B possible carcinogen. Moreover, 180 studies out of the 242 (74.7%) were in vivo studies (including several human studies) which presents strong evidence. It refutes the conclusion in ARPANSA's health risk assessment TRS-164: "the putative link between RF energy and altered ROS production remains tenuous".[20] Only one physical scientist was tasked by ARPANSA to perform this important review assessing the in vivo and in vitro studies and the reviewer was working outside his area of expertise when assessing the oxidative stress literature. In contrast, the medical fraternity has knowledge of the pathophysiological importance of oxidative stress in many diseases, and needs to further investigate RF-induced oxidative stress (as well as other bioeffects) and enact measures to reduce risks associated with current population-wide chronic exposure to RF-EMR. An urgent medical investigation into the safety of existing wireless signals (WiFi, 3G, 4G) and the new 5G is required. Such investigations need to use real-life signals because simulated signals are different from real-life ones in their physical characteristics and have been found to be less bioactive.[8]



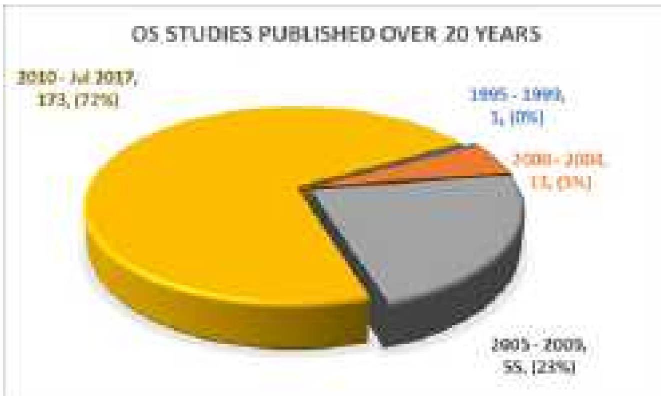


Figure 1. *A. Oxidative stress-related significant findings were reported by 89% of 242 peer-reviewed experimental studies that investigated biomarkers of oxidative damage or altered antioxidant levels. B. Most of the studies on oxidative stress, i.e. 173 (72%) were published after 2010 and therefore comprise the more recent evidence for biological harm from RF-EMR.*

Unfortunately for all Australians, ARPANSA has made their health risks assessment without involving medical expertise. ARPANSA's in-house RF-EMR expert Dr. Karipidis who is described as "an expert on how radiation affects the human body" has reported academic training in physics and epidemiology. Similarly, the International EMF Project (IEMFP) at the WHO that has been entrusted to protect public health from man-made EMR/EMF is headed by an electrical engineer. There is an apparent shortage of biomedical expertise within the IEMFP and also the NGO professional body they depend on for exposure regulation of RF-EMR – International Commission on Non-Ionizing Radiation Protection (ICNIRP).[23] One of ARPANSA's four health effects reviewers, psychology researcher Prof. Rodney Croft is the newly appointed Chairman of the ICNIRP having previously served as the Chair of the ICNIRP's RF Guidelines Project Group, setting international exposure guidelines. Croft also was the lead researcher for RF health research in Australia for many years as the head of the Australian Centre for Electromagnetic Bioeffects Research (ACEBR) (https://www.uow.edu.au/acebr/) and its previous form, the Australian Centre for Radiofrequency Bioeffects Research (ACRBR) that operated from 2004-2011 with direct wireless industry partnership. Croft does not have medical expertise, and it is therefore questionable how he could lead or advise on a true investigation into the biological and health effects of RF-EMR.

The lack of clinicians and biomedical experts within the ARPANSA expert panel for their health risk assessment, along with their seriously questionable conclusions appear to have mislead the Australian medical system. While scientists other than medical scientists are able to read scientific studies and learn that RF-EMR exposure can alter the transcription of certain genes, alter levels of certain neurotransmitters, hormones, enzymes, cytokines, antioxidants etc, how do they interpret the significance of these biological effects in a health context without biomedical training and experience providing an in-depth knowledge of biology: including biochemistry, physiology, and clinical medicine? A health risk assessment of this nature requires input from a large panel of multidisciplinary experts –

predominantly with strong biomedical backgrounds.

Similar to the Australian situation, the health risk evaluation of RF-EMR in New Zealand has been undertaken without medical expertise. A publication that questioned this risky approach by one of the authors (SP) was unilaterally retracted by the journal based on an anonymous complaint despite three thousand downloads in three months.[27] Furthermore, the same author was denied an author response to a rebuttal of a publication in the New Zealand Medical Journal.[28] What is becoming apparent is there is a gagging of those who are trying to refute claims of safety by highlighting poor risk management, conflicts of interest, and inadequate expertise by government scientists.

MISLEADING OF PRIMARY CARE PHYSICIANS BY ARPANSA

Dr. Karipidis was advising Australian clinicians in an article[29] titled "What do GPs need to know about the new 5G network?" ARPANSA has claimed "Dr Ken Karipidis, Assistant Director of the Australian Radiation Protection and Nuclear Safety Agency's (ARPANSA) Assessment and Advice Section, wants GPs and their patients to know there is no evidence to support the concern that 5G technology, which uses radio waves and emits low-level radiofrequency (RF) electromagnetic energy (EME), will cause harms to the public." Dr. Karipidis stated in that report: "There's been a lot of research into whether radio waves cause adverse health effects, and the only established health effects of radio waves are very high power levels, where they raise temperature." This article further claimed: "While the increased presence of 5G base stations is often perceived negatively, Dr Karipidis has found this to be more of a psychological issue than a cause of genuine harm."

While our previous papers[21-23] alone provide ample scientific evidence for low-intensity non-thermal biological effects such as oxidative stress, refuting the obsolete notion that RF EMR causes thermal effects only ("raise temperature"), it is necessary that ARPANSA be asked by the medical community in Australia to provide details of their research that found "a psychological issue than a cause of genuine harm". We understand that extensive research needs to be conducted to rule out biochemical, and physiological causes before suspecting a psychological origin underlying a health complaint. To our understanding, such research has not been done by ARPANSA or any other body in Australia or New Zealand.

In several media reports on Australians complaining of adverse health effects which they attributed to exposure to wireless radiation, Prof. Croft has promoted the nocebo theory discouraging medical investigations into RF-EMR. For instance, a report titled "Woman claims severe health problems are caused by wi-fi but international studies find no link"[30] about a female who had to abandon her home due to debilitating neurological symptoms which she attributed to a new NBN WiFi tower erected near her home, claimed: "Professor Rodney Croft, director of the Australian Centre for Electromagnetic Bioeffects Research, said the symptoms experienced by sufferers of EHS were recognised as genuine, but the cause was something other than exposure to wi-fi."

"He said the symptoms appeared as a result of anticipation by the sufferer that they were going to be affected."

"Professor Croft said there needed to be research into causes other than electromagnetic radiation (EMR)."

The reported position of the patient's GP alerts to the problems faced by clinicians in assessing/managing EMR/EMF-associated health problems: "Ms Southern's local GP, Dr Gudrun Muller Grotjan, said the difficulty for GPs was that there was no evidence of a cause, so there was no clear path to treating the problem.

Dr Muller Grotjan said she was aware that research was finding no link with wi-fi, but accepted Ms Southern's attribution of wi-fi as the cause was credible, so she was keeping an open mind about the possible cause."

A medical discussion in our region will certainly help to close the existing large gap between the research front and clinical medicine in this field. It is unfortunate that the expert findings/recommendations of reputable medical organisations such as the European Academy for Environmental Medicine (EUROPAEM)[31] and its American counterpart AAEM[32] on adverse health effects of anthropogenic EMF/EMR and their management have not reached the medical community in our region.

OCCUPATIONAL EXPOSURES TO MILLIMETRE WAVES

In a separate public information sheet titled "Misinformation about Australia's 5G network" [33] ARPANSA has made several questionable claims regarding safety:

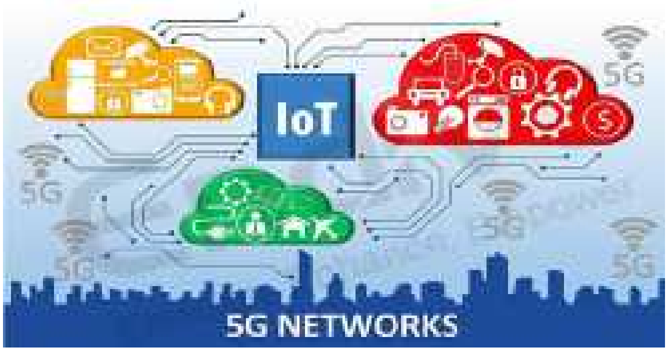
"Higher frequency radio waves are already used in security screening units at airports, police radar guns to check speed, remote sensors and in medicine and these uses have been thoroughly tested and found to have no negative impacts on human health."

"ARPANSA and the World Health Organization (WHO) are not aware of any well-conducted scientific investigations where health symptoms were confirmed as a result of radio wave exposure in the everyday environment."

ARPANSA has not produced any evidence from the scientific literature that supports the above claim – that thorough testing of security screening units at airports, police radar guns, and remote sensors used in medicine has been conducted and found to have no negative impacts on human health. Given the chronic 24/7 exposure scenarios expected with high frequency 5G microwaves for the entire population, unlike acute exposures with security scanners or limited occupational exposures of radar, establishing the evidence of safety is of paramount importance. Australian doctors need to urge ARPANSA to publish a list of these studies confirming safety for evaluation by the medical community.

Contrary to the ARPANSA claims, the limited number of studies that have investigated effects of millimetre waves (carrier waves of 5G in the next phase), have found concerning evidence. A search for airport screening/radar safety studies, did not find a single Australian/New Zealand investigation while studies from elsewhere appear to have mostly found evidence of biological impact. For example, a study by researchers at Shiraz University, Iran[34] published in 2013, but later retracted without an expressed reason, reported a high prevalence of neuro-behavioural problems in the occupationally exposed people significantly associated with their time at work. Their test cohort of airport radar personnel exposed to mm waves (14-18 GHz) revealed neurological, behavioural and cognitive problems despite being young (33 ± 6.8 years). The first author informed us that there was pressure from the government authorities that researchers would face litigation unless they withdrew the publication. Their findings were similar to a number of studies that have found adverse health effects in people exposed to radar.[35-37] Neurological problems (such as migraine, headache and dizziness) were found in exposed residential populations around military radar in a study in Cyprus with a dose response (more severe effects closer to the radar).[35] However, the authors of this military-funded study attempted to attribute their findings to antenna visibility (a nocebo effect) or aircraft noise without evidence to substantiate this claim and also ignoring a large body of evidence demonstrating that RF-EMR exposure can cause neurological symptoms.[4] Moreover, researchers at University of Washington Medical Center had previously reported an increased risk of testicular cancer in personnel exposed to hand-held police radar units.[36]

Researchers at the Institute for Medical Research and Occupational Health of Croatia studied people occupationally exposed to marine radar (including millimetre waves at 9.4 GHz) comparing them to those without such occupational exposure.[37] They found that RF exposure was associated with increased oxidative cell damage including DNA damage and reduced antioxidant defence. They concluded: "Results suggests that pulsed microwaves from working environment can be the cause of genetic and cell alterations and that oxidative stress can be one of the possible mechanisms of DNA and cell damage." This is in agreement with our finding that oxidative stress associated with RF-EMR exposure.[22] On the basis of the evidence of oxidative stress in disease pathology,[38] (and a range of other bioeffects) we have urged Australian authorities to take measures to reduce the exposure of people to all forms of RF-EMR to prevent deleterious effects on health, but our calls have been ignored/dismissed without counterevidence. Therefore, a great risk to the health of the population has been left unattended; undermining the health and wellbeing of the population and the surety of a viable work force of the future.



In a quick investigation of the literature into the effects of millimetre waves (associated with 5G in the next phase), we extracted all the papers from the ORSAA database that mention millimetre waves in the abstract. Table 1 below compares the number of these papers that report significant biological effects for exposures versus those that report no effects versus those that are uncertain. These studies must be further evaluated to assess all effects: thermal and non-thermal.

Study Outcome	Number of publications	Percentage of total
Effect	53	77.9%
No Effect	13	19.1%
Uncertain Effect	2	2.9%
Total	68	100%

Table 1: *Outcomes of publications investigating millimetre waves (RF-EMR similar to carrier waves of second phase 5G) based on the ORSAA database.*

While there are no epidemiological studies on millimetre waves from the Australia-NZ region, we would like to also highlight that the highest RF-EMR exposure source at the ABC's Toowong studios where a breast cancer cluster was identified (site now demolished) was also a millimetre wave source: "The THL RF Hazard control document10 indicates that the most prominent RF source is the 7 meter satellite dish on the TV Building rooftop, operating at 14 Ghz. The three VHF Comms 3-metre antennae have high maximum power and operate between 168 and 172 MHz. Overall the RF sources on site cover a wide range of frequencies and power outputs."[39]

While acknowledging that sufficient data do not exist to draw conclusions, it cannot be ruled out that RF exposure at the Toowong site, including the millimetre wave exposure, contributed to the development of those breast cancers given that there is evidence linking RF-EMR exposure to cancer.[14-15,40] Other disease statistics were not investigated at the Toowong site.

CHIEF MEDICAL OFFICER'S STATEMENT ON 5G

Recently the then Chief Medical Officer of Australia, Prof. Brendan Murphy on behalf of the Australian Government's Department of Health issued a statement[41] on the safety of 5G. In this statement Prof. Murphy declared: "I'd like to reassure the community that 5G technology is safe." While it appears that the CMO (since departed from this role) was operating on the advice of ARPANSA, it warrants that the medical community request the Department of Health provide the list of studies with the scientific evidence for this claim of the safety of 5G. It would be appropriate to publish this evidence on the department's website for evaluation by anyone. Unsubstantiated claims of safety on a public health matter are risky. In this case, it involves population-wide exposure to a novel man-made form of microwave radiation that can put people's health and quality of life at serious risk.

AUSTRALIAN PARLIAMENTARY INQUIRY ON 5G 2019-2020

Unlike the 2001 Australian Senate Inquiry on the health effects of RF-EMR,[42] the recent Australian parliamentary inquiry into 5G did not address the potential health impacts of 5G deployment by calling on independent expert witnesses. Despite the vast majority of the 500+ submissions from the general public expressing concern about the potential adverse health effects, very little hearing time was allocated to investigating those concerns. Out of the total hearing time (1065 minutes), only 6% was allocated for opponents of 5G, while 91% was provided to proponents. Not a single medical expert was called upon as a witness. In an extraordinary move prior to the completion of the inquiry, the government announced that it would allocate $9 million of public funds to educate the public on 5G (and counter so-called "misinformation" warnings of detrimental health effects). Based on the scientific evidence that has been collated and analysed, authors are extremely concerned about the lack of independence and medical expertise in this field of study, and the rush in Australia and New Zealand to deploy 5G without safety testing.

Proponents of 5G often dismiss concerns about health risks claiming that 5G microwaves will minimally penetrate the skin and therefore any effects are limited to minor skin heating (and they acknowledge that there is some uncertainty around heating effects on the eyes). The medical community understands that skin is the largest organ of the human body and a key part of the neuro-immune and neuro-endocrine systems. Natural UVA and UVB (also so-called non-ionizing radiation) that penetrate the skin less than 5G millimetre waves have profound effects on health and wellbeing of humans. Therefore, artificial 5G waves must be subjected to rigorous safety testing.

Unfortunately, the questionable conduct of regulatory agencies such as ARPANSA and WHO's international EMF Project[43] with conflicts of interest due to funding links to the wireless industry[44] remains to be investigated. More open questioning and protests are appearing in Europe and North America where there is some level of engagement on the part of government bodies in response to warnings of adverse health effects of anthropogenic EMF/EMR by expert medical bodies such as EUROPAEM and AAEM[31,32] (despite industry opposition). In contrast, there is a strong media censorship on the 5G safety issue in Australia and New Zealand. This gagged situation is a major blow to the evidence-based approach to health management, and to science in general. As informed scientists and clinicians, authors urge an open and constructive discussion on the safety of 5G in order to protect public health. Planetary electromagnetic pollution[26] is already excessive and it is impacting the health and wellbeing of life on Earth. The plan to deploy 30,000 satellites in space and millions of 5G transmitters on Earth without any formal health or environmental assessments is both reckless and negligent. We appeal to the medical community in Australia-New Zealand to actively engage with this important topic in order to protect public health.

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Human Electromagnetic Field Exposure in 5G at 28 GHz

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***Abstract*—The fifth-generation wireless (5G) has already started showing its capability to achieve extremely fast data transfer, which makes itself considered to be a promising mobile technology. However, concerns have been raised on adverse health impacts that human users can experience in a 5G system by being exposed to electromagnetic fields (EMFs). This article investigates the human EMF exposure in a 5G system and compares them with those measured in the previous-generation cellular systems. It suggests a minimum separation distance between a transmitter and a human user for keeping the EMF exposure below the safety regulation level, which provides consumers with a general understanding on the safe use of 5G communications.**

CONCERN ON HUMAN EMF EXPOSURE IN 5G

As a means to fulfill the latest skyrocketing bandwidth demand, the fifth-generation wireless (5G) is expected to achieve far higher data rates compared to the previous-generation wireless systems. However, the 5G's requirement of a very high data rate entails an increase in signal power received at a user's end, which in turn results in an increase in the amount of electromagnetic energy imposed on the user.[1–3] Not only that, this article identifies three technical features adopted in 5G, which can increase the human electromagnetic field (EMF) exposure "further."

First, the 5G targets to operate at *higher frequencies* (e.g., 28, 60, and 70 GHz[4]) in addition to the existing lower frequency bands for cellular communications. The advantages are 1) the availability of wide bandwidths and 2) the possibility of integrating a larger number of antennas in small dimensions.[4] At a higher frequency, however, the EMF "absorption" rate into human skin also rises.

Second, *larger numbers of transmitters* will operate. In 5G, more base stations (BSs) will be

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deployed due to employment of small cells. As a direct consequence, BSs serve smaller geographic areas and thus are located closer to human users, which again results in a higher chance of a human user being exposed to EMF.

Third, *directional beams* will be employed in 5G as a solution for faster attenuation of a signal power due to operation in high-frequency bands.[4] Notice that the main purpose of using such a multiple-antenna system is to increase the antenna gain. This higher concentration of electromagnetic energy results in a greater potential for an EMF to penetrate further into a human body.

CURRENT UNDERSTANDING AND EFFORT

While substantial attention has been paid to technical advancements that the 5G will introduce, the potential impacts that the technology may pose on human health have not been discussed as closely and thoroughly.

Health Effect

"Heating" of skin is one representative impact on a human body caused by EMF exposure. The temperature for a skin outer surface normally ranges from 30 to 35°C. The pain-detection threshold temperature for human skin is approximately 43 °C[14] and any temperature exceeding it can cause a long-term injury. Heating is considered as a significant impact since it can cause subsequent effects such as cell damage and protein induction.[5] It is also known that high-frequency EMF affects the sweat glands (which may serve as helical antennas), peripheral nerves, the eyes, and the testes, and may have indirect effects on many organs in the body.[6]

Recent studies showed health impacts of EMF in frequencies above 6 GHz. In a latest study,[7] EMF power transmitted to the body was analyzed as a function of angle of incidence and polarization, and its relevance to the current guidelines was discussed. Another study[8] determined a maximum averaging area for power density (PD) that limits the maximum temperature increase to a given threshold. Also, considering "bursty" traffic patterns in modern wireless data communications, an analytical approach to "pulsed" heating was developed and applied to assess the peak-to-average temperature ratio as a function of the pulse fraction.[9]

Acknowledgement by Organizations

The United States (U.S.) Federal Communications Commission (FCC)[10] and the International Commission on Non-Ionizing Radiation Protection (ICNIRP)[11] set guidelines on the maximum amount of EMF energy allowed on a human body. It is noteworthy that the FCC's guideline on specific absorption rate (SAR) is averaged over 1 gram (g) of tissue while that set by the ICNIRP is averaged over 10 g. It implies that the FCC's guideline is more conservative, while the ICNIRP allows for two to three times as much energy absorption.

Also, the U.S. Food and Drug Administration (FDA) states that the current understanding on adverse impacts of EMF emissions on human health is insufficient to conclude whether exposure to the emissions is safe or not, and thus, additional research is needed to address the current gaps in the literature on human health safety in use of wireless systems.[12]

Meanwhile, the World Health Organization (WHO)'s International Agency for Research on Cancer (IARC) classifies EMF exposure as possibly carcinogenic.[13]

Measurements

PD and SAR are the two most widely accepted metrics to measure the intensity and effects of EMF exposure.[15] However, selection of an appropriate metric evaluating the EMF exposure still remains controversial. The FCC suggests PD as a metric measuring the human exposure to EMF generated by devices operating at frequencies higher than 6 GHz,[10] whereas a recent study suggested that a guideline defined in PD is not efficient to determine the impacts on health issues especially when devices are operating in a very close proximity to the human body such as in an uplink.[14]

However, PD cannot evaluate the effect of certain transmission characteristics (e.g., reflection) adequately. Thus, temperature elevation and SAR at a direct contact area are proposed as the appropriate metric for EMF exposure above 6 GHz.[16] This article chooses SAR as a more adequate metric than the skin temperature, which is subject to be dispersed during propagation and affected by the external atmosphere (i.e., air temperature).

Every wireless device should pass compliance tests before going to the market. An international standard entitled IEC62232[17] has been acting as a key reference in compliance tests for BSs and user equipment (UE). It focuses on change of characteristics in radio frequency (RF) field with distance from an RF source. Relevant studies are also found. Exposure to RF EMF from a UE[18] and that from a BS[19] are studied.

Reduction of Human EMF Exposure

Albeit not many, schemes for EMF emission reduction in a wireless system have been studied.[20,21] Note that the human exposure can be reduced if a BS adopts a power control or adaptive beamforming technique.[22] Also, the exposure level can be reduced when multiple spectrum bands are combined for coordinated use. The reason is that with a higher carrier frequency, a wireless system should reduce the cell size, which leads to more severe threats to human health.

Focus of This Article

Four points on which this article puts particular focus are highlighted as follows.

First, we discuss the human EMF exposure in the *downlink* as well as the uplink. Most of the prior work studies the uplink only, while hardly paying attention to EMF emissions generated by BSs in a 5G network. Recall the aforementioned changes that the 5G adopts: 1) operation at higher carrier frequencies; 2) reduction of cell size (which leads to increase in number of BSs); and 3) concentration of higher EMF energy into an antenna beam. They all imply that in 5G, unlike the previous-generation wireless systems, the downlink can also be a threat to human health as well as the uplink.

Second, we suggest that *both SAR and PD* should be used to display human EMF exposure for a wireless system. The reason is that SAR captures an amount of EMF energy that is actually "absorbed" into human tissues, whereas PD is an efficient metric only to present the EMF energy being introduced to a human user.

Third, we present an *explicit comparison* of human EMF exposure in 5G to those in the currently deployed wireless standards. For 5G, we adopt the system model defined in the Third-Generation Partnership Project (3GPP) 5G New Radio (NR).[23] Meanwhile, currently operating technologies are represented by 4G[24] and 3.9G.[25] Notice that 4G represents the 3GPP's Long Term Evolution (LTE)-Advanced, and 3.9G is the last release by the 3GPP before 4G was deployed (from which the name "3.9G" originated).

Fourth, we consider the maximum possible exposure that a human user can experience. In other words, no technique for mitigation of received power is considered in this article's system model. It is for advising the consumers with most conservative perspectives in using 5G wireless.

CASE STUDY MODELS

In order to understand how much EMF energy is imposed on a human user in a 5G wireless system, this article suggests two "comparative" case study models: 1) among different wireless systems—i.e., 5G, 4G, and 3.9G, and 2) between downlink and uplink.

5G versus 4G versus 3.9G

Commonly, for all of the three systems, we assume a fully loaded network in order to understand the "worst case" of EMF exposure. As mentioned earlier, none of the three systems is supposed to adopt any "adaptive" techniques—namely, power control and adaptive beamforming. That is, there is no particular method applied to reduce the amount of EMF energy being imposed on a user at a certain time instant. The rationale is to provide the "most conservative" suggestion on consumer safety, leaving room for a safety margin.[18]

Figure 1 depicts the difference in the cell size among the three wireless standards. As mentioned in the "Concern on Human EMF Exposure in 5G" section, a 5G system adopts the smallest cell diameter (i.e., 200 m) among the three systems, pursuing to form a small-cell network. This difference in cell size is a significant factor differentiating the level of human EMF exposure

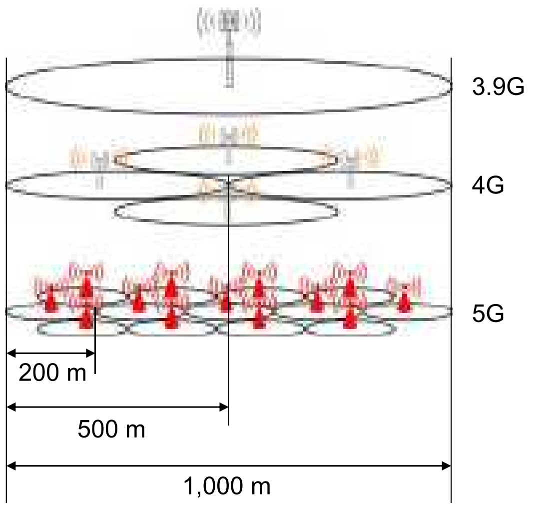

Figure 1. Comparison of cell size.

among 5G, 4G, and 3.9G, as discussed in the "Numerical Results and Discussions" section.

Downlink versus Uplink

Another case study is defined as a comparison between uplink and downlink in a 5G system. Figure 2 illustrates the geometric difference between the two directions of communication. In this case study, the user's head is placed between the BS and the handheld device, which represents a case where the impact of human EMF exposure is highlighted.

There is a key similarity between the downlink and the uplink: both adopt beamforming.[23] Accordingly, they both adopt directional antennas, which results in concentration of electromagnetic energy higher than 0 dB in an antenna beam.

The differences between downlink and uplink are as follows. First, in uplink, the equivalent isotropically radiated power (EIRP) that a transmitter generates is lower than that in a downlink. The reason is twofold: 1) an uplink requires a lower data rate than a downlink; and 2) a UE, as a transmitter, is less capable of accommodating as many antennas as a BS can. Second, a signal propagates shorter in an uplink than in a downlink. The inter-site distance (ISD) for a 5G cell is 200 m, as indicated in Table 1, which yields a cell radius to be 100 m. As a consequence, in downlink, the maximum distance that a user can be separated from a BS is 100 m. In contrast, in an uplink scenario, the maximum separation

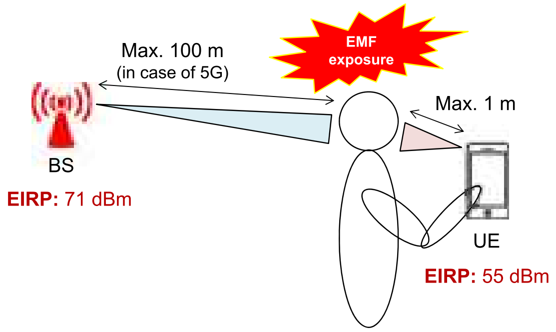

Figure 2. Comparison of uplink and downlink in 5G.

distance from the human user and the transmitter (a handheld device as being in an uplink) is supposed to be 1 m. When a handheld device is held in a user's hands, one can consider a number of representative scenarios such as directly contacting at an ear, moderate separation for texting or web surfing, and further separation with the use of an ear bud. The "maximum 1 m" in Figure 2 came from assumption of the last scenario that yields the maximum distance between the handheld device and the user's head. Third, an antenna beam in an uplink is less strong and sharp than that in a downlink. This is associated with the aforementioned geometric difference: a downlink beam is designed stronger and sharper for overcoming larger attenuation through a longer propagation.

NUMERICAL RESULTS AND DISCUSSIONS

Now, we evaluate human EMF exposure for the three wireless systems (i.e., 5G, 4G, and 3.9G) via Monte Carlo simulations in the case studies defined in the "Case Study Models" section. Specifically, to consider the variation of a mobile user's relative location in a cell, both PD and SAR are "averaged" in 10 000 experiments, each of which generates 10 UE per sector. Also, a cell is assumed fully loaded; the calculation considers a time length that is enough for all the 10 UE that are served based on TDD.

5G versus 4G versus 3.9G

In the simulation of the first case study, the Urban Macro (UMa) system layout is assumed, which is commonly defined in all of the three wireless standards that this article refers to, as already

Table 1. Parameters for case study in 5G, 4G, and 3.9G.

Parameter	Value		
	5G[23]	4G[24]	3.9G[25]
Carrier frequency	28GHz	2 GHz	1.9 GHz
System layout	Urban Macro (UMa)	Urban Macro (UMa)	Urban Macro (UMa)
Inter-site distance (ISD)	200 m	500 m	1 Km
Bandwidth	850 MHz	20 MHz	20 MHz
BS max antenna gain	8 dBi per element	8 dBi per element	17 dBi
BS transmit power	18 dBm per element	44 dBm	43 dBm
BS number of antennas (w/ separation of $\lambda/2$)	256 and 64	4	4
BS antenna height	25 m	35 m	32 m
BS noise figure	5 dB	5 dB	5 dB
UE max antenna gain	20 dBi	1 dBi	1 dBi
UE transmit power	35 dBm	23 dBm	33 dBm
UE number of antennas (w/ separation of $\lambda/2$)	16	4	1 (omnidirectional)
UE antenna height	1.5 m	1.5 m	1.5 m
UE noise figure	9 dB	9 dB	9 dB
Cell sectorization	3 sectors/site		
Deployment	Outdoor 100%		
Duplexing	Time-division duplexing (TDD)		
Transmission scheme	Single-user (SU)-MIMO		

shown in Table 1. See the following specifications for technical details: 5G,[23] 4G,[24] and 3.9G.[25]

In Figure 3(a) and (b), there is a BS located at "0 m" mark for all 5G, 4G, and 3.9G systems. Now, a mobile user is moved from the 0 m mark to the 1000 m mark. Since each of 5G, 4G, and 3.9G systems adopts a different cell radius (also known as ISD), the downlink signal that the UE receives gets bounced up as it passes another BS standing at different distance marks. This experiment setting is to highlight the impact of adopting smaller cells in 5G. Comparing 5G to 4G in both Figure 3(a) and (b), despite faster attenuation than 4G due to operation at a higher frequency, PD and SAR in 5G are kept elevated more frequently, as the UE meets the next BS in a shorter distance. That is, in a 5G network, a consumer is likely to be exposed to high EMF energy more consistently. Nevertheless, it is easier to apply a "compliance distance"[17] in a downlink than in an uplink. Thus, this article suggests 1) an overhaul of the compliance distances defined in different standards and 2) the consumers' discretion on being close to a BS.

Compare black and blue curves in Figure 3(a) and (b). It is evident that the difference between 5G (with 256 antennas) and 4G is larger in SAR than that in PD. This is explained by the formal expression of $\mathrm{SAR}(d,\phi) = 2\mathrm{PD}\,(d,\phi)\,(1-\mathcal{R}^2)/(\delta\rho)$, where $\mathcal{R}$ is the reflection coefficient,[14] ρ is the tissue mass density (1 $\mathrm{g/cm^3}$ is used), and δ is the skin penetration depth (10^{-3} m is used).[14] Recall that 5G and 4G operate at 28 GHz and 2 GHz, respectively. The SAR is inversely proportional to the penetration depth, and hence, a shallower penetration occurring in 5G yields a higher absorption.

Figure 4 compares the depth that an EMF penetrates into human skin among the three wireless systems of 5G, 4G, and 3.9G. Note that the level of SAR varies according to a number of disparate

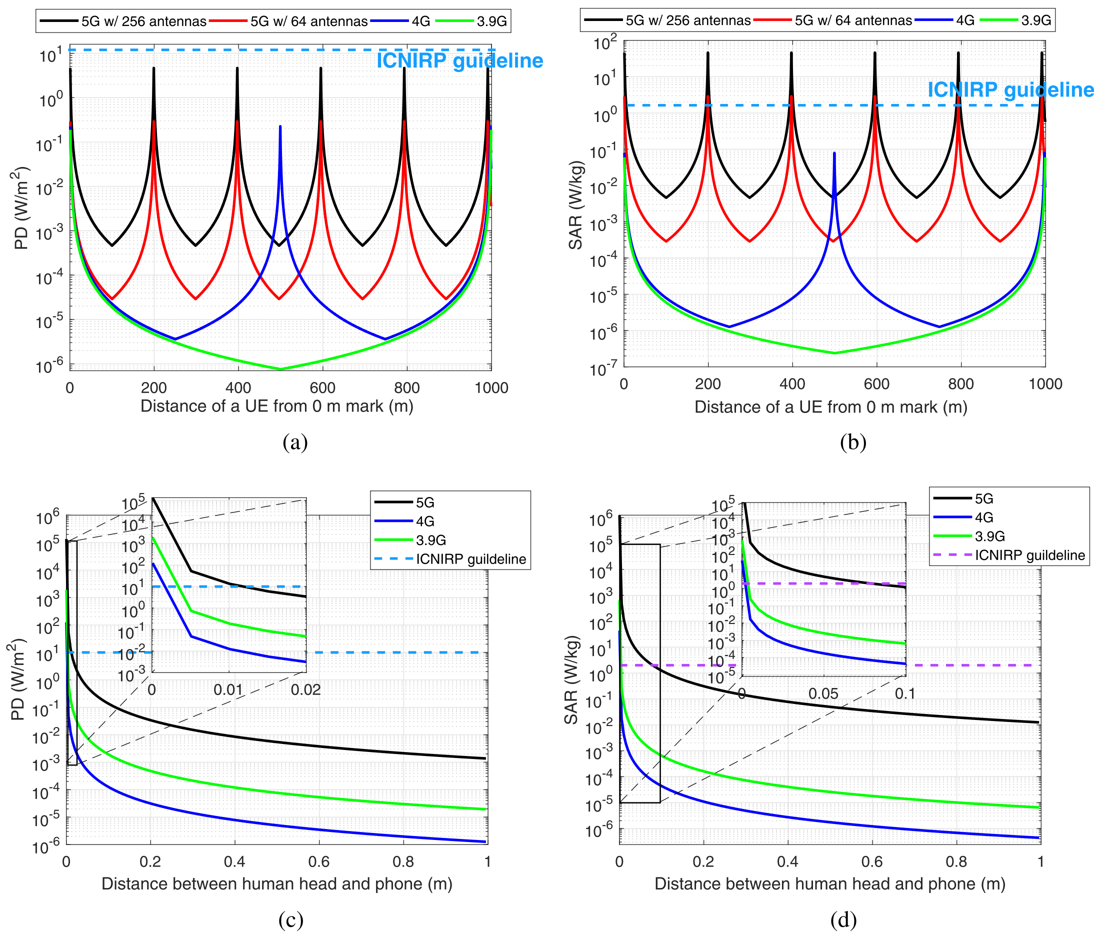

Figure 3. Comparison of human exposure levels. (a) Comparison of time-averaged PD in downlink. (b) Comparison of time-averaged SAR in downlink. (c) Comparison of time-averaged PD in uplink. (d) Comparison of time-averaged SAR in uplink.

variables–i.e., type of material, frequency, etc. The example shown in Figure 4 presents a measurement of SAR being introduced on human skin at the distance of 10 cm from a transmitter in an uplink. It clearly shows a scenario where the current belief is not valid; the fact that a high-frequency EMF cannot penetrate deep into human skin does not mean that it is not dangerous. Specifically, although the penetration is limited only at the skin surface, the SAR (illustrated as a heat map in Figure 4) can be higher within the concentrated area, which can cause subsequent health problems such as skin heating.

Downlink versus Uplink

Figure 3(c) and (d) compare PD and SAR in uplink to the ICNIRP guidelines set at 10 W/m^2 and 2W/kg, respectively. PD and SAR are remarkably higher in uplink than those in downlink, shown via a comparison of the results for uplink to those for downlink shown in Figure 3(a) and (b). It is attributed to smaller separation distance between a transmitter and a human body. Imagine one talking on a voice call; it is a "direct" physical contact of the phone and the head!

Also, it is significant to notice that no regulation exists at 28 GHz where this article investigates for 5G. As such, we refer to the ICNIRP's guideline that is set to be 2 W/kg by ICNIRP[11] at a frequency "below 10 GHz." In Figure 3(d), it provides a ""inferred" understanding on SAR in an uplink. The zoom-in look shown in Figure 3(d) suggests that in 5G, use of a handheld device within the distance of 8 cm causes an EMF absorption exceeding 2 W/kg, which would have

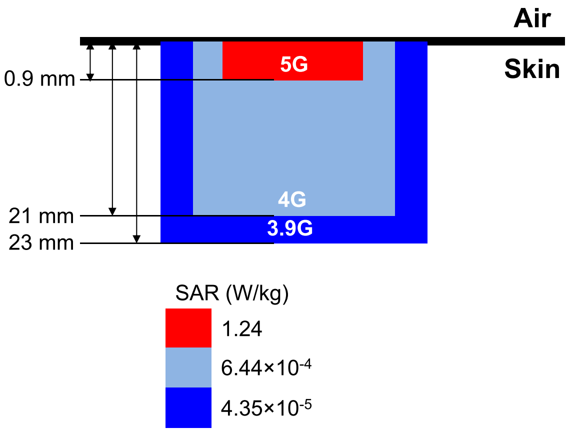

Figure 4. Comparison of EMF penetration depth into human skin and SAR.

been prohibited if the carrier frequency was lower than 10 GHz. This implies the gravity of human EMF exposure in an uplink of 5G.

CONCLUSION

This article has discussed human EMF exposure in 5G operating at 28 GHz, while most of the prior work focuses only on the technological benefits that the technology brings. Considering the significance of wireless technologies in our daily life, the potential danger of using them should also be emphasized for sustainable advancement of the technologies. In this article, the first case study has demonstrated how much EMF exposure is caused in a 5G system compared to 4G and 3.9G. Then, the latter case study has suggested an adequate separation distance from a transmitter, in order to keep a human user from being exposed to EMF below a regulatory guideline. This article is expected to ignite continued interest in overarching research on the design of future wireless systems that achieve high performance while keeping consumer safety guaranteed.

However, considering the gravity of this issue, we suggest several directions to be achieved in our future research.

- *Human EMF exposure mitigation strategy:* We are particularly interested in exploiting the technical features in future wireless systems—i.e., a larger number of BSs within a unit area. Such a paradigm change will enable a holistic, network-based approach to mitigate the EMF exposure as an optimization problem with a set of constraints representing the PD, SAR, and skin-temperature elevation.
- *Further studies regarding exact human health impacts caused by EMF exposure:* The particular focus will be put on 1) skin dielectric effect with respect to frequency and 2) the effect of radiation when the body is covered with clothing or garment materials.

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State of New Hampshire

GENERAL COURT

CONCORD

MEMORANDUM

DATE:	**November 1, 2020**
TO:	**Honorable Christopher T. Sununu, Governor** **Honorable Stephen J. Shurtleff, Speaker of the House** **Honorable Donna Soucy, President of the Senate** **Honorable Paul C. Smith, House Clerk** **Honorable Tammy L. Wright, Senate Clerk** **Michael York, State Librarian**
FROM:	**Representative Patrick Abrami, Chair**
SUBJECT:	**Final Report on Commission to Study the Environmental and Health Effects of Evolving 5G Technology (RSA 12-K:12-14, HB 522, Ch. 260, Laws of 2019)**

Pursuant to RSA 12-K:14, III, enclosed please find the Final Report of the Commission to Study the Environmental and Health Effects of Evolving 5G Technology.

If you have any questions or comments regarding this report, please do not hesitate to contact me.

I would like to thank those members of the commission who were instrumental in this study. I would also like to acknowledge all those who testified before the commission and assisted the commission in our study.

Enclosures

cc: Members of the Commission

Final Report of the

Commission to Study
The Environmental and Health Effects of
Evolving 5G Technology

(HB 522, Chapter 260, Laws of 2019, RSA 12-K:12–14)

Membership

Name	Organization/Representing
Rep. Patrick Abrami (Chair)	NH House of Representatives
Rep. Kenneth Wells	NH House of Representatives
Rep. Gary Woods	NH House of Representatives
Sen. James Gray	NH Senate
Sen. Tom Sherman	NH Senate
Denise Ricciardi	Public
Brandon Garod, Esq.	Attorney General's Office
Carol Miller	Department of Business and Economic Affairs
David Juvet	Business and Industry Association
Kent Chamberlin, PhD	University of New Hampshire
Bethanne Cooley	CTIA – wireless communications industry
Michele Roberge	Department of Health and Human Services
Paul Héroux, PhD	McGill University Medicine

November 1, 2020

Members of the Commission to Study the Environmental and Health Effects of Evolving 5G technology agree to the filing of this final report by the Chairman. This action should not be construed in any way as an adoption of any position by any Commission member or state agency or organization they represent on the underlying issue of the deployment of 5G technology.

Table of Contents

INTRODUCTION

Commission Responsibilities and Evolving Role

The Commission to Study the Environmental and Health Effects of Evolving 5G Technology came about from the passage and signing into law of HB 522. The Legislature, after hearing testimony of potential health risks and the political ramifications of small cell antennae being deployed on the public rights-of-way throughout New Hampshire, agreed that a Commission be formed to take a deeper look at this evolving technology. For the record, 5G stands for the 5th Generation of wireless communication. This technology utilizes frequencies in the millimeter wave range of the electromagnetic spectrum. See Appendix A for a chart showing this spectrum.

What the Commission learned early on in its work is that you cannot talk about 5G without talking about the earlier generations 3G and 4G. Then the Commission embraced the concept of the Internet of Things (IoT) which is a world in which all electronic devices communicate via electromagnetic waves. This led to discussion of routers and other internal technologies. The devices receiving and sending signals via electromagnetic waves also became part of the discussion. So as the presentations and discussions went on, the Commission concluded that all things emitting radio frequency (RF) radiation needed to be considered together because of the interaction of all these waves. We also discovered early on that 5G means something different to each of the major cellular companies ranging from how 5G antennae interact with other generation antennae to whether small cell towers in the public right-of-way will be needed. The conclusion by many experts is that 5G is a marketing concept centered around speed of data transmission using many different engineering strategies.

At the heart of the discussion was the research as to whether non-ionizing radiation causes biological effects on humans as well as other living organisms, either animal or plant. No one argues that ionizing radiation from the high energy and frequency ultraviolet, x-ray, and gamma ray end of the electromagnetic spectrum are a danger to all living things. Of concern to the Commission, and internationally, are the electromagnetic waves in the microwave range of energy and frequency. There is mounting evidence that DNA damage can occur from radiation outside of the ionizing part of the spectrum.[1, 2, 3, 4] The Commission heard arguments on both sides of this issue with many now saying there are findings showing biological effects in this range. This argument gets amplified as millimeter waves within the microwave range are beginning to be utilized.

Then the Commission was presented with varying facts about the Federal Communication Commission (FCC) having total say over this issue as granted to it by Congress in the Telecommunication Act of 1996. In brief, this Act says, among many other things, that the siting of any antennae cannot be denied due to health concerns. Many on the Commission are concerned that this Act did not contemplate small cell towers being located on the public rights-of-way in front of people's homes. In addition, the FCC, using the science that they receive from other agencies and scientific/engineering associations, has set the allowable power intensity that can be emitted from these antennae. Testimony shows these limits are set well above many other industrialized nations. There are concerns by many Washington, DC watchers that the FCC is a captive agency whose Commission members come from the industry they are overseeing. These are the realities that can only be altered by Congressional action. As a New Hampshire Commission, as we moved through the Commission process, many of the members concluded we could first encourage our federal delegation to enact changes and second, assuming the federal realities cannot be changed, recommend protective measures that will stay within the current federal framework.

As far as the FCC and federal agencies, we made several attempts to have them testify before the Commission. The Commission was disappointed that they did not reply to these requests, because we thought it important for completeness of our work to hear from these agencies. When the agencies did not reply, we asked several agencies to answer very specific written questions. Instead of answering

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our specific questions, the responses directed Commission members to certain locations on websites for what turned out to be more general information on topics of public interest. The communications with these agencies are contained in Appendix B.

Summary of Commission Meetings

The Commission met a total of 13 times over a period from September 2019 to October 2020. Unfortunately, due to the Covid-19 pandemic, all activity at the NH State House came to a halt from mid-March to mid-June this year. This meant that the Commission missed four meetings and thus heard from fewer experts on this topic than planned. It is important to stress that the Chair was planning to call additional witnesses from the scientific community as well as the telecommunication industry. When we resumed meeting, starting with one on July 1, all remaining meetings were conducted via Zoom. After our July 24th meeting, a work group consisting of seven members was formed to start formulating recommendations for the full Commission to consider. This work group met approximately every other week through the finalization of this report at the end of October. The table below summarizes the full Commission meeting dates and who the main speakers were.

#	Date	Major Topics and/or Guest Speakers
1	9/16/19	Organizational meeting
2	10/10/19	Electromagnetic Spectrum Physics Presentation Dr. Kent Chamberlin, Chair of UNH Electrical and Computer Engineering Department Presentation on Biological Effects of RF radiation Dr. Paul Heroux, Professor of Toxicology, McGill University
3	10/31/19	National Toxicology Program Study on RF-Radiation Michael Wyde, PhD Framing the Issue Video Frank Clegg, Former Microsoft Canada President
4	11/21/19	Non-Existence of RF-Radiation Biological Effects Argument Eric Swanson, PhD, University of Pittsburgh.
5	12/13/19	Reinventing Wires and 5G in Colorado Tim Schoechle, PhD, Colorado State University

6	1/10/20	Studies Showing RF-Radiation Biological Effects Devra Davis, PhD, MPH, Founder/President Environmental Health Trust (EHT) The Landscape Nationally and Internationally Surrounding RF-Radiation, Theodora Scarato, Executive Director EHT
7	2/14/20	What is 5G and What Do We Know About the Health Effects of 5G David Carpenter, MD, Director, Institute for Health and the Environment, University of Albany
COVID-19 NH STATE HOUSE CLOSURE		
8	7/1/20	13 Objections To 5G/4G Herman Kelting, PhD, Retired Las Vegas, NV
9	7/24/20	Around the table discussion of where we are and next steps. Established a work group to formulate recommendations.
10	8/31/20	Presentation of work group recommendations and discussion. Discussed that a minority report would be required.
11	9/22/20	Discussion and voting on first half of recommendations
12	10/8/20	Discussion and voting on second half of recommendations
13	10/27/20	Review and vote on final report.

There are extensive minutes of all of these meetings that are included at the end of this report in Appendix O. In addition, the Commission has maintained a webpage on which is posted the various documents and links to information that it has collected during the course of its study, including many of the presentations provided during the meetings.

Questions Posed in HB 522

There were eight questions asked in the legislation creating the Commission. Research by the Commission has resulted in lengthy answers with supporting credits. With that we are showing the questions asked in the body of this report only, with the answer to each question shown in Appendix C. The questions are as follows:

1. Why does the insurance industry recognize wireless radiation as a leading risk and has placed exclusions in their policies not covering damages by the pathological properties of electromagnetic radiation?
2. Why do cell phone manufacturers have in the legal section within the device saying keep the phone at least 5mm from the body?
3. Why have 1,000s of peer-reviewed studies, including the recently published U.S Toxicology Program 16-year $30 million study, that are showing a wide

range of statistically significant DNA damage, brain and heart tumors, infertility, and so many other ailments, been ignored by the Federal Communication Commission (FCC)?

4. Why are the FCC-sanctioned guidelines for public exposure to wireless radiation based only on the thermal effect on the temperature of the skin and do not account for the non-thermal, non-ionizing, biological effects of wireless radiation?

5. Why are the FCC radiofrequency exposure limits set for the United States 100 times higher than countries like Russia, China, Italy, Switzerland, and most of Eastern Europe?

6. Why did the World Health Organization (WHO) signify that wireless radiation is a Group B Possibly Carcinogenic to Humans category, a group that includes lead, thalidomide, and others, and why are some experts who sat on the Who committee in 2011 now calling for it to be placed in the Group 1, which are known carcinogens, and why is such information being ignored by the FCC?

7. Why have more than 220 of the world's leading scientists signed an appeal to the WHO and the United Nations to protect public health from wireless radiation and nothing has been done?

8. Why have the cumulative biological damaging effects of ever-growing numbers of pulse signals riding on the electromagnetic sine waves not been explored, especially as the world embraces the Internet of Things, meaning all devices being connected by electromagnetic waves, and the exploration of the number of such pulse signals that will be created by implementation of 5G technology?

The answers to these questions have been embraced by the majority of the members of the Commission.

SUMMARY AND OBSERVATIONS

House Bill 522 established "a Commission to study the environmental and health effects of evolving 5G technology." The Commission that was convened as a result of this legislation is comprised of thirteen members with backgrounds that include physics, engineering electromagnetics, epidemiology, biostatistics, occupational health, toxicology, medicine, public health policy, business, and law. The Commission also has representation from the telecommunications industry. The Commission began its work on September 16, 2019 and submitted this report on November 1, 2020.

The Commission recognizes that cellular and wireless communications is very important to the citizens of New Hampshire. The rollout of wireless services and new products in the industry can be key to enhancing public safety, economic opportunity, and healthcare. Regardless of the evidence presented and the risks associated with RF electromagnetic field effects, business and residents alike want 100% coverage and seamless connectivity. The majority of the Commission believes that some balance can be struck to achieve the benefits of technology without jeopardizing the health of our citizens.

To become acquainted with the issues relevant to 5G radiation exposure and health, the Commission heard from ten recognized experts in the fields of physics, epidemiology, toxicology, and public policy. All but the presenter representing the Telecommunications Industry (the transcript of that presentation can be found in the Commission's minutes of Nov 21st) acknowledged the large body of peer-reviewed research that shows that the type of RF-radiation generated by wireless devices can have a deleterious effect on humans, especially children, as well as animals, insects, and vegetation (see Appendix D).

The Commission was unable to meet for four months due to the shutdown of the NH State House caused by COVID-19. While this loss of time did limit the number of presenters that could be accommodated, the majority of the Commission did not believe that additional presenters were necessary because the information provided by the ten experts was deemed sufficient.

5G is moving forward because of its potential benefits and because of assurances by federal regulatory agencies that 5G technology is not harmful. However, those assurances have themselves come into question because of the thousands of peer-reviewed studies documenting deleterious health effects associated with cellphone radiation exposure. Most of the federal regulatory agencies' radiation exposure limits were established in the mid-1990s before the studies were carried out, so they did not take those studies into account when setting exposure limits. In addition, the initial exposure limits were developed at a time before wireless devices, and the radiation associated with them, became ubiquitous. Not only are wireless devices far more prevalent than in the past, but these radiating devices are typically carried in direct, or near direct, contact with peoples' bodies. Further, the total radiation exposure for individuals is compounded by the radiation from nearby sources, including others' devices, cell towers, wireless routers, Bluetooth devices, etc. Because of the large number of radiating devices in today's environments, exposure for people is many times greater than when radiation thresholds were established, and the nature of today's radiation (high-data-rate signals) has been shown to be more harmful than the lower-data-rate signals that were prevalent before.

The significant disconnect between the regulatory agencies' pronouncements that cellphone radiation is safe and the findings of thousands of scientific studies was one of the major issues that the Commission sought to address. The Commission is not alone in wrestling with this issue as many others (see Appendix E) have challenged the radiation thresholds specified. It is to be noted that the only country with higher radiation thresholds than the U.S. is Japan (see Appendix F), and a large number of independent scientists have concluded that the thresholds for Japan and the U.S. are unsafe.

A likely explanation as to why regulatory agencies have opted to ignore the body of scientific evidence demonstrating the negative impact of cellphone radiation is that those agencies are "captured" (see Harvard University publication entitled, "Captured Agency: How the Federal Communications Commission Is Dominated by the Industries It Presumably Regulates" linked in Appendix G). This report documents how the leadership roles in some agencies (the FCC in particular) are filled by individuals with strong industry ties and hence are more focused on industry interests than the health of citizens. As is shown in other sections of this report, federal legislation uses policy set by the regulatory agencies to wrest control of wireless facility placement from individuals, cities, and states. Consequently, some of the Commission's recommendations call for a reassessment of the makeup and policies of federal regulatory agencies. Current policies in place by federal regulatory agencies (such as section 704 of the Telecommunications Act of 1996) are tailored to prevent local objections to cell tower siting that are based upon health or environmental concerns, and this leaves citizens with little legal recourse regarding equipment placement.

Industry projects that over 800,000 small cell towers[5] will be necessary to implement 5G. Many are being erected in the public rights-of-way in New Hampshire neighborhoods and mounted on new poles, streetlights, and utility poles directly in front of homes. However, because of the rules currently in place, individuals and municipalities cannot use health or environmental concerns as a reason to object.

The majority of the Commission has endorsed the 15 recommendations presented in this report. These recommendations are not in prioritized order, and each should be given equal consideration. The objective of those recommendations is to bring about greater awareness of cell phone, wireless and 5G radiation health effects and to provide guidance to officials on steps and policies that can reduce public exposure. We also recommend partnering with our federal delegation to facilitate the reevaluation of radiation exposure guidelines and policies by federal agencies (i.e., the FCC, FDA, NASA, NOAA, FAA, EPA, etc.) to protect people, wildlife, and the environment from harmful levels of radiation.

Since the Commission could not reach full agreement on all that is contained in this report, the minority of the Commission has been given the opportunity to express its opinion as provided in the Minority Report.

[5] The number of projected cell towers for 5G was taken from the CTIA website: "There are 154,000 cell towers today. To meet growing mobile data demands and win the Race to 5G Accenture projects we will need to install hundreds of thousands of small cells in the next few years. S&P Global Market Intelligence projects more than 800,000 small cells deployed by 2026."

RECOMMENDATIONS

The Commission has heard from many experts on both sides of the argument concerning the health and environmental effects of 5G and RF-radiation in general; reviewed countless study reports; attempted to get direct answers to our specific questions from the FCC and other federal agencies to no avail; has become aware of a number of lawsuits against the FCC for not accounting for biological effects in the setting of their standards; is still not certain why the standards for acceptable RF-radiation are set so much higher in the United States than other industrialized nations; is concerned that the modulation of frequencies and the combined effect of "the soup" of RF-waves surrounding us today, which will likely increase with time; is aware that there is much research showing potential health risks and understands that much more research is required; is cognizant that our country historically has been beset by examples of products being declared safe only later to be proven unsafe; and is very aware that the World Health Organization and the whole insurance industry are hedging their bets against RF-radiation because of potential harm. Given these considerations, the majority of the Commission yields to the precautionary principle in formulating many of these recommendations. These recommendations cover a broad range of topics. One topic given much consideration had to do with liability from potential harm caused by small cell antennae placed on the public rights-of-way. A majority of the Commission could not agree upon a recommendation surrounding this topic.

RECOMMENDATION 1- Propose a resolution of the House to the US Congress and Executive Branch to require the Federal Communication Commission (FCC) to commission an independent review of the current radiofrequency (RF) standards of the electromagnetic radiation in the 300MHz to 300GHz microwave spectrum as well as a health study to assess and recommend mitigation for the health risks associated with the use of cellular communications and data transmittal. The Telecommunications Act of 1996 was adopted before the health risks and biological effects of RF-radiation to the human body were fully known to the scientific community as well as the public. The majority of the Commission believes that the FCC has not exercised due diligence in its mission to manage the electromagnetic environment by not setting exposure limits that protect against health effects. They have failed to support technical means and investigations aimed at reducing human exposures to electromagnetic radiation (EMR) in telecommunications systems and optimize wireless modulations to reduce biological and health impacts. Commissioned research should study the health effects and should be conducted by an independent research organization with standards which have been mutually agreed to by all the stakeholders. The FCC shall then ensure that the findings and recommendations are adequately disseminated to the public.

RECOMMENDATION 2- Require that the most appropriate agency (agencies) of the State of New Hampshire include links on its (their) website(s) that contain information and warnings about RF-radiation from all sources, but specifically from 5G small cells deployed on public rights-of-way as well as showing the proper use of cell phones to minimize exposure to RF-radiation, with adequate funding granted by the Legislature. In addition, public service announcements on radio, television, print media, and internet should periodically appear, warning of the health risks associated with radiation exposure. Of significant importance are warnings concerning the newborn and young as well as pregnant women. Even without further study, there is evidence that the public should be warned of the potential dangers of RF-radiation and be told simple steps to lessen the risks of unnecessary exposure. Appendix H shows an example of a simple RF-radiation warning.

The website must provide an option for visitors to register their opinions about current FCC exposure guidelines. In particular, this registry should provide a convenient and formal mechanism for New Hampshire municipalities and residents to weigh in concerning the 1996 Telecommunications Act Section 704 that disallows using radiation-related health concerns as a reason to challenge cell phone tower siting. The primary use for the data collected on this registry will be to gauge the level of interest about RF-radiation exposure on the part of New Hampshire citizens.

RECOMMENDATION 3- Require every pole or other structure in the public rights-of-way that holds a 5G antenna be labeled indicating RF-radiation being emitted above. This label should be at eye level and legible from nine feet away. In the view of the Commission, the State of New Hampshire has the right to warn the public of potential harm of 5G antennae deployed in the public rights-of-way. Large cell towers all currently have fencing around them at their base to protect the public. This will not be the case with small cell towers or any pole with an antenna on top in the public right-of-way. These public rights-of-way are the jurisdiction of our municipalities and not of the Federal Government. The Telecommunication Act of 1996 did not contemplate antennae being placed on the public rights-of way of municipalities. Thus, the State of New Hampshire has the right to warn the public by requiring the owners of these antennae to inform the public of potential harm from RF-radiation. See Appendix I for an example symbol.

RECOMMENDATION 4- Schools and public libraries should migrate from RF wireless connections for computers, laptops, pads, and other devices, to hard-wired or optical connections within a five-year period starting when funding becomes available. There is strong evidence that the younger the child the more susceptible they are to the negative impacts of RF-radiation. Hard-wired connections or optical wireless do not subject children to RF-radiation. The Commission is aware that school districts and public libraries have invested much in wireless infrastructure and that a movement to radiation-less connections would require additional investment of resources.

New optical networking solutions for the classroom and office spaces (such as LiFi) offer faster, healthier, and more secure connections than RF-based WiFi. This technology utilizes visible light, which organisms can withstand without any harm at far higher intensity levels (such as direct sunlight) than is required for data transmission. Such optical data transmission using visible light offers gigabit speed, as well as plug-and-play replacement of current RF WiFi routers. The optical wireless system can be incorporated in an upgrade to cost-efficient LED room lighting which can save schools and public libraries significant energy dollars.

The hard-wiring and/or optical projects should be completed within five years from when the federal funding (e.g., through the FCC's E-Rate program for telecommunications and IT in schools and public libraries) is procured.

RECOMMENDATION 5- Signal strength measurements must be collected at all wireless facilities as part of the commissioning process and as mandated by state or municipal ordinances. Measurements are also to be collected when changes are made to the system that might affect its radiation, such as changes in the software controlling it. Signal strength is to be assessed under worst-case

conditions in regions surrounding the tower that either are occupied or are accessible to the public, and the results of the data collection effort is to be made available to the public via a website. In the event that the measured power for a wireless facility exceeds radiation thresholds, the municipality is empowered to immediately have the facility taken offline. The measurements are to be carried out by an independent contractor and the cost of the measurements will be borne by the site installer. It is recognized that theoretical calculations show that existing FCC guidelines will be met by standard cell tower configurations. However, there are cases where the radiation from towers can be focused by buildings, terrain, and beamforming antennas, causing signal levels to be considerably higher than would be expected in theoretical calculations unless those effects are taken into account. Collecting field measurements provide the only valid approach for determining whether exposure guidelines have been met. It is to be noted that some municipalities (e.g., the town of Burlington, MA [1]) have ordinances requiring measurements at cell towers.

Federal law and NH law grant to municipalities the power to enact zoning rules regulating the placement of personal wireless service facilities within the geographic boundaries of the municipalities. Municipalities should be proactive in this area and, through the exercise of zoning power, establish where, how, and a process for compliance with existing FCC guidelines for signal strength in the surrounding coverage area. Municipalities should establish a hierarchy of siting values and compliance acknowledgements so that the siting most favored by the municipality is the easiest siting for the wireless applicant to obtain and, conversely, the siting which is least desirable should be the most difficult siting for the applicant to obtain. The zoning ordinance should lay out the compliance requirement as part of the zoning approval.

[1] Burlington, MA zoning Bylaw Wireless Facilities section 8.4.6.2 - “Annual RF emissions monitoring is required for all sites by an independent RF engineer to be hired with Planning Board approval and at the applicant’s expense. Test results will be submitted to the Town as soon as available, and not later than the close of the calendar year. Annual testing of electromagnetic emission shall be required to ensure continual compliance with the FCC regulations.”

Recommendation 6- Establish new protocols for performing signal strength measurements in areas around wireless facilities to better evaluate signal characteristics known to be deleterious to human health as has been documented through peer-reviewed research efforts. Those new protocols are to take into account the impulsive nature of high-data-rate radiation that a growing body of evidence shows as having a significantly greater negative impact on human health than does continuous radiation. The protocols will also enable the summative effects of multiple radiation sources to be measured. Contemporary approaches to performing signal level measurements do not provide a means to evaluate signal impulsiveness or the contribution of multiple radiation sources because of equipment limitations. The measurement protocols proposed will employ wideband equipment that is currently available but is not typically used to measure compliance with radiation safety limits. References that address the deleterious effects of impulsive radiation on organisms are given in Appendix J. The development of the proposed protocols should be funded by the appropriate federal agency (e.g., NSF, NIH, FCC, etc.) and should be facilitated by New Hampshire's federal delegation.

RECOMMENDATION 7- Require that any new wireless antennae located on a state or municipal right-of-way or on private property be set back from residences, businesses, and schools. This should be enforceable by the municipality during the permitting process unless the owners of residences, businesses, or school districts waive this restriction. Local public rights-of-way are under the jurisdiction of municipalities, and the Commission feels that municipalities should uphold the rights of individuals impacted by antennae. The Commission also supports the right of property owners to manage decisions on non-essential devices being placed in front of their property.

The Commission believes that it is important to prioritize citizen safety, particularly as 5G is an upgrade, rather than the provision of wireless service to unserved areas. Additional rationale for this recommendation is shown in Appendix K.

RECOMMENDATION 8- Upgrade the educational offerings by the NH Office of Professional Licensure and Certification (OPLC) for home inspectors to include RF intensity measurements. Home inspectors currently operate as private contractors who may be hired by citizens or enterprises to measure such things as radon, to collect water quality samples, or search for mold or insect damage. Home inspectors routinely supply test results to both their clients and government entities.

The majority of the Commission believes the public has the right to discover, on a voluntary basis, the RF power intensity related to radio frequencies at a property which they will be purchasing or renting before the transaction is closed. Also, the proprietors of publicly accessible venues may wish to reassure the public about the RF power intensity within their establishments, by posting the data collected by a state-approved inspector. In addition, such testing should be paid for by the party requesting it and the testing itself should be performed by a professional who owns or rents the test equipment and has met the state requirements for training of home inspectors regarding RF measurements.

The majority of the Commission proposes that home inspectors be offered training by NH OPLC on how to measure on-site peak and 24-hour average RF intensities. Measurements of frequencies and intensities will be performed using low-cost equipment (such as GQ-390 meters). [Description of existing home inspector training offered for radon, mold, etc. may be seen at https://oplc.nh.gov/home-inspectors/index.htm]

RECOMMENDATION 9- The State of New Hampshire should begin an effort to measure RF intensities within frequency ranges throughout the state, with the aim of developing and refining a continually updated map of RF exposure levels across the state using data submitted by state-trained home inspectors. The data should be collected in such a way as to identify geographic areas of notably high RF exposure, places where RF signal for wireless communication is inadequate (dead spots), and places where RF is unusually low (white spots) sought by people who wish to minimize their RF exposure. One possible use of this data will be buyers/renters of property or the public, in general, using benchmark values to make comparisons and make their own decisions based on their comfort level with RF exposure. After a while, an extensive New Hampshire RF database will exist to provide useful maps and data for future public health investigations. Appendix L outlines in more detail the technical aspects of this recommendation.

RECOMMENDATION 10- Strongly recommend all new cell phones and all other wireless devices sold come equipped with updated software that can stop the phone from radiating when positioned against the body. The Commission has been made aware that cell phones contain proximity sensors that will allow a cell phone to only radiate signals when a certain distance from the body, for example, held in the fingers or placed on a table. This does not change the functionality of the device, only the way it is used, specifically not held against the head or body. Implementation is a software update in the cell phone, as these phones already have a proximity detector to turn off the screen and soft keys when an obstacle is present. With this change, the screen and the RF circuit are automatically turned off. This removes the problems of brain cancers (glioblastomas and acoustic neuromas) and the issue of SAR limits for the industry. See Appendix M for more detailed references to the science behind this recommendation. Cell phones should come set with this inhibition, with instructions in the manual on how to disable it. There should be a soft button on the unit to easily re-enable the radiation inhibition, for example if the unit is handed to a child. In all cases, it should be easier to enable the restriction than to disable it. Cellular phones marketed specifically for children should stop radiating when positioned against the body under all circumstances. The installation of such proximity sensors is also encouraged in laptops and tablets.

RECOMMENDATION 11- Promote and adopt a statewide position that would strongly encourage moving forward with the deployment of fiber optic cable connectivity, internal wired connections, and optical wireless to serve all commercial and public properties statewide. The majority of the Commission believes that fiber optic transmission is the infrastructure of the future. When compared, RF wireless transmission lacks fiber optic characteristics: speed, security, and signal reliability while avoiding biological effects on humans and the environment.

The State should encourage partnerships between towns to make this happen and encourage our federal delegation to support grant money to assist with such deployments when it comes to funding fiber optic cable deployment, especially in rural locations.

RECOMMENDATION 12- Further basic science studies are needed in conjunction with the medical community outlining the characteristics of expressed clinical symptoms related to radio frequency radiation exposure. Further studies are just beginning to explore the quantum mechanical mechanisms which are the fundamental basis for understanding the biological changes occurring during the interaction of radio frequency radiation and molecules. These mechanisms can affect cells, tissues, and whole organs, as well as accumulate over time.

The majority of the Commission feels the medical community is in the ideal position to clarify the clinical presentation of symptoms precipitated by the exposure to radio frequency radiation consistent with the Americans with Disabilities Act (ADA) which identifies such a disability. The medical community can also help delineate appropriate protections and protocols for affected individuals.

All of these endeavors (basic science, clinical assessment, epidemiological studies) must be completely independent and outside of commercial influence.

RECOMMENDATION 13- Recommend the use of exposure warning signs to be posted in commercial and public buildings. In addition, encourage commercial and public buildings, especially healthcare facilities, to establish RF-radiation free zones where employees and visitors can seek refuge from the effects of wireless RF emissions. Many NH citizens report sensitivity to electromagnetic radiation emitted from devices used in the delivery of in-building cellular and fixed wireless services. A majority of the Commission suggests that owners of commercial and public buildings, especially healthcare facilities, voluntarily place signage at entrances concerning RF-levels and RF-free zones within these structures so those entering the building are aware.

RECOMMENDATION 14- The State of New Hampshire should engage agencies with appropriate scientific expertise, including ecological knowledge, to develop RF-radiation safety limits that will protect the trees, plants, birds, insects, and pollinators. The majority of the Commission understands that current federal safety limits were made with the intention of only protecting humans from short term effects, but not protecting flora or fauna from harm. The State of New Hampshire needs to ensure our natural environment and wildlife are protected by effective safety standards. Tree limbs, birds, and pollinators will be closer than humans to 5G cell antennae and associated 4G densified infrastructure. In fact, the wireless radiation from cell antennae is very high in a plume surrounding the antennae. It could exceed FCC limits for several feet in this area, yet this is the exact area where leaves of trees, birds, and pollinators live. Thus, they may have higher exposures being in direct line of sight of wireless RF beams. When pollinators are impacted so are all forms of vegetation that depend on them for reproduction. Research on this issue is shown in Appendix N.

RECOMMENDATION 15- The State of New Hampshire should engage our Federal Delegation to legislate that under the National Environmental Policy Act (NEPA) the FCC do an environmental impact statement as to the effect on New Hampshire and the country as a whole from the expansion of RF wireless technologies. Concern comes from the FCC projection that there will be numerous low orbit satellites and 5G small cell antennae, plus many additional macro towers required for these networks to function. The majority of the Commission is concerned that any new large-scale project that will densify antennae networks to this extent truly requires an environmental impact study. The NEPA statute requires that the agency consider environmental concerns in its decision-making process. NH should be provided documentation of such considerations. Until there is Federal action, NH should take the initiative to protect its environment.

MINORITY REPORT

The following members, being unable to agree with the majority of the Commission, endorse this Minority Report:

Senator James Gray, David Juvet, and Bethanne Cooley

Contrary to the position taken in the Recommendations section, the science related to radiofrequencies, wireless devices, and health is well studied and well known: The consensus of the U.S. and international scientific community is that there are no known adverse health risks from the levels of RF energy emitted at the frequencies used by wireless devices (including cellphones) and facilities (including small cells). Some of those who presented to the NH 5G Commission have sought to sow confusion, but the facts demonstrate otherwise.[6] *First*, when setting limits for the RF emissions of wireless devices, the Federal Communications Commission ("FCC") intentionally provided a significant safety margin—50 times below the threshold at which adverse effects have been observed in laboratory animals.[7] And in its 2019 order, the FCC assessed the available science, including studies related to the safety of 5G networks, and based on the relevant scientific research, concluded that wireless devices and small cells are safe when they adhere to the FCC's current RF exposure limits, as required by law. *Second*, numerous, independent analyses of peer-reviewed studies conducted over several decades by national and international organizations conclude that there are no known health risks to humans from RF

[6] Commission discussions indicated that the Commission was comprised of many individuals who had preconceived opinions about the safety of RF devices and wireless technology in general. Due to many factors, experts in favor of wireless technology were cut short in participating. For example, an additional expert in favor of wireless technology was offered as a speaker during the summer and the Commission indicated no additional experts would be permitted. However, after that request was denied, an "expert" opposed to RF devices and wireless technology spoke at a subcommittee meeting of the majority. In addition, the Commission heard only a portion of expert Eric Swanson's testimony and failed to consider in a balanced fashion the well-developed reviews of the science from the U.S. and international health and safety organizations. Thus, in this report we have cited those authorities even though the Commission did not include them as part of the formal record.

[7] The threshold for adverse effects was set at the level at which heating caused a "disruption of observable behavior" in animals. *See Proposed Changes in the Commission's Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields*, First Report and Order, Further Notice of Proposed Rulemaking, and Notice of Inquiry, 28 FCC Rcd. 3498, 3582 ¶ 236 (2013) ("FCC NOI") ("exposure limits are set at a level on the order of 50 times below the level at which adverse biological effects have been observed in laboratory animals as a result of tissue heating resulting from RF exposure"); IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz, IEEE Std C95.1-2019, Annex B Sec. B.5.3.3 and Annex C Sec. C.2.1 (2019) ("Typically, the effect observed has been a decreased rate of responding or decreased reaction time.").

energy emitted by wireless devices and infrastructure. Thus, the scientific consensus as evaluated by experts, international standard-setting bodies, and federal health and safety agencies is that wireless devices and base stations at the FCC's RF exposure levels is safe.

Given the scientific consensus, it is our opinion that the Recommendations exceed what a reasonable response should be to the evidence on this issue. This Minority Report purposely chose not to highlight each recommendation but instead highlights findings from federal agencies, including the FCC and the Food and Drug Administration (FDA), studies conducted by leading international and national health organizations, the IEEE and the scientific community at-large. It will also note the federal preemption issues associated with the Recommendations. Given the scientific consensus, it is our opinion that the Recommendations have no basis in scientific fact, are irresponsible, and will subject the state and any localities implementing these Recommendations to needless and expensive challenges that will drain time and resources from more important and credible priorities.

THE FCC SAFETY REGULATIONS

FCC limits govern RF energy from antennas used in all wireless devices including cellular transmissions from cellphones, cell towers, and 5G small cells. The FCC based these limits on recommendations from the scientific community and expert non-government organizations; the FCC limits currently cover frequencies from 100 kHz to 100 GHz, including the "millimeter wave" or "mmW" frequencies.[8] These guidelines—based on internationally-recognized scientific organizations—set limits for the maximum amount of RF exposure from wireless devices and include a significant margin of safety.[9] Specifically, the FCC has set its limit for a consumer device's Specific Absorption Rate—the measurement for RF emissions for consumer devices such as cellphones—"at a level on the order of *50 times below* the level at which adverse biological effects have been observed in laboratory animals."[10] The agency explained that this 50-fold factor can well

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[8] NPRM, 34 FCC Rcd at 11742 ¶ 120.

[9] Testimony of Christopher C. Davis, Professor of Electrical and Computer Engineering, University of Maryland, *Hearing on S.B. 637 and S.B. 894 Before the Mich. H. Comm. on Energy Policy*, 2018 Leg., 99th Sess., at 4:17 (May 29, 2018) ("Professor Davis Testimony"), http://www.house.mi.gov/SharedVideo/PlayVideoArchive.html?video=ENER-052918-2.mp4.

[10] FCC NOI at ¶236 (emphasis added).

accommodate a variety of variables such as different physical characteristics and individual sensitivities—and even the potential for exposures to occur in excess of [FCC] limits without posing a health hazard to humans."[11] In reality, wireless devices and antennas typically operate well under FCC thresholds.[12]

Further, all wireless devices sold in the U.S. must go through a rigorous approval process to ensure they meet the science-based guidelines set by the FCC.[13] The FCC's testing regime requires cellphones to be tested under "the *most severe, worst-case (and highest power) operating conditions for all the frequency bands* used in the USA for that cell phone" to ensure that they meet the limits under everyday (non-worst-case) conditions.[14] The FDA stands in full support of the adequacy of the FCC's standards. The Director of the FDA's Center for Devices and Radiological Health wrote in 2018: "[B]ased on our ongoing evaluation of this issue and taking into account all available scientific evidence we have received, ***we have not found sufficient evidence that there are adverse health effects in humans caused by exposures at or under the current radiofrequency energy exposure limits.***"[15]

HEALTH ORGANIZATIONS AND FDA STUDIES

International health organizations have also studied the effects of RF exposure and determined that there is no risk from RF emissions from modern wireless device usage. The World Health Organization ("WHO") concludes "[c]onsidering the very low exposure levels and research results collected to date, there is no

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[11] *Id.*; *see also Targeted Changes to the Commission's Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields*, Resolution of Notice of Inquiry, Second Report and Order, Notice of Proposed Rulemaking, and Memorandum Opinion and Order, 34 FCC Rcd 11687, 11696 ¶14 (2019) ("Order") ("[O]ur existing exposure limits are set with a large safety margin, well below the threshold for unacceptable rises in human tissue temperature.").

[12] *See* Professor Davis Testimony (6:00-7:45) (discussing the 50-fold safety factor and typical emissions from small cells); Christopher C. Davis, Professor of Electrical and Computer Engineering, University of Maryland, *Hearing on S.B. 637 and S.B. 894 Before the Mich. H. Comm. on Energy Policy*, 2018 Leg., 99th Sess., Written Testimony at 2 (May 29, 2018), http://www.wirelesshealthfacts.com/wp-content/uploads/2019/06/Davis-Testimony.pdf (observing that "RF exposure levels from wireless base stations are invariably far below the FCC limits").

[13] *See generally* 47 C.F.R. § 1.1307; *id*. part 2 Subpart J; Order, 34 FCC Rcd at 11697-742 ¶¶ 17-118.

[14] FCC, Consumer Guides, Health, Safety and Emergencies, *Specific Absorption Rate (SAR) for Cell Phones: What It Means for You* (emphasis in original), https://www.fcc.gov/consumers/guides/specific-absorption-rate-sar-cell-phones-what-it-means-you (last updated Oct. 15, 2019).

[15] News Release, FDA, *Statement from Jeffrey Shuren, M.D., J.D., director of the FDA's Center for Devices and Radiological Health on the recent National Toxicology Program draft report on radiofrequency energy exposure* (Feb. 2, 2018) ("Shuren Statement"), https://www.fda.gov/news-events/press-announcements/statement-jeffrey-shuren-md-jd-director-fdas-center-devices-and-radiological-health-recent-national.

convincing scientific evidence that the weak RF signals from base stations and wireless networks cause adverse health effects."[16] The WHO has also concluded that "research has not been able to provide support for a causal relationship between exposure to electromagnetic fields and self-reported symptoms, or 'electromagnetic hypersensitivity'".[17] Likewise, both the United Kingdom Health Protection Agency Independent Advisory Group on Non-Ionizing Radiation and Swedish Council for Working Life and Social Research agree that RF exposure below guideline levels consistent with FCC limits do not cause health effects.[18]

The majority also justifies its recommendations by referencing "the problems of brain cancers (glioblastomas and acoustic neuromas) and the issue of specific absorption rate (SAR) limits for the industry." Some have raised questions with respect to cancer and tumors, but experts in cancer have repeatedly found no link between mobile devices and cancer. For example, the National Cancer Institute reported that: "although many studies have examined the potential health effects of non-ionizing radiation from radar, microwave ovens, cell phones, and other sources, there is currently no consistent evidence that non-ionizing radiation increases cancer risk in humans."[19] Likewise, the American Cancer Society explained that the "RF waves given off by cell phone towers don't have enough energy to damage DNA directly or to heat body tissues. Because of this, it's not clear how cell phone towers might be able to cause cancer."[20]

Earlier this year, the FDA released a large-scale review of published literature to

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[16] WHO, *Electromagnetic fields and public health: Base stations and wireless technologies*, Backgrounder (May 2006), https://www.who.int/peh-emf/publications/facts/fs304/en/.

[17] WHO, *Electromagnetic fields and public health: mobile phones*, Backgrounder (Oct. 8, 2014) ("*WHO Mobile Phones Fact Sheet*"), https://www.who.int/news-room/fact-sheets/detail/electromagnetic-fields-and-public-health-mobile-phones.

[18] *See* Health Protection Agency Independent Advisory Group on Non-Ionizing Radiation, *Health Effects from Radiofrequency Electromagnetic Fields* (RCE-20), at 3 (Apr. 2012), https://webarchive.nationalarchives.gov.uk/20140722075005/http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1317133827077 ("The evidence suggests that RF field exposure below guideline levels does not cause acute symptoms in humans, and that people, including those who report being sensitive to RF fields, cannot detect the presence of RF fields."); Anders Ahlbom, et al., Radiofrequency Electromagnetic Fields and Risk of Disease and Ill Health: Research during the last ten years, Swedish Council for Working Life and Social Research, at 6 (2012), https://forte.se/app/uploads/sites/2/2015/11/10-y-rf-report.pdf ("Extensive research for more than a decade … has found no evidence for health risks below current exposure guidelines.").

[19] National Cancer Institute, *Cell Phones and Cancer Risk*, (Jan. 9, 2019) https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/cell-phones-fact-sheet.

[20] American Cancer Society, Cell Phone Towers (emphasis omitted) ("*ACS Cell Phone Towers*"), https://www.cancer.org/cancer/cancer-causes/radiation-exposure/cellular-phone-towers.html (last visited October 7, 2020).

"assess any possible causal relationship between [RF energy] exposure and the formation of tumors."[21] After examining approximately 125 animal studies and 70 epidemiological studies, the FDA stated that "there are no quantifiable adverse health effects in humans caused by exposures at or under the current cell phone exposure limits."[22] As Dr. Jeffrey Shuren, Director of the FDA's Center for Devices and Radiological Health, observed in 2018: "Even with frequent daily use by the vast majority of adults, we have not seen an increase in events like brain tumors."[23] Courts too, after hearing extensive testimony, have determined that there is "no sufficiently reliable and relevant scientific evidence in support of either general or specific causation" that cellphone use caused the plaintiff's brain cancer.[24] Dr. Otis Brawley, chief medical officer of the American Cancer Society, explained that "[t]he incidence of brain tumors in human beings has been flat for the last 40 years. … That is the absolute most important scientific fact."[25]

THE SCIENCE AROUND EXPOSURES FROM 5G TECHNOLOGY

The majority has expressed concern with exposures from 5G technology using millimeter wave ("mmW") bands and on the proliferation of small cell network architecture, and whether there are studies demonstrating that 5G does not create risks to human health.

Although 5G represents a new frontier for wireless communications, mmW frequencies do not. mmW frequencies are well understood by the international scientific community. The Institute of Electrical and Electronics Engineers ("IEEE") has assembled a list of dozens and dozens of studies on mmW frequencies. The IEEE's RF exposure standards over the last thirty years have cited 85 different mmW studies, the earliest was published in 1976 and the most recent in 2018.[26]

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[21] FDA, *Review of Published Literature between 2008 and 2018 of Relevance to Radiofrequency Radiation and Cancer*, at 4 (Feb. 2020), https://www.fda.gov/media/135043/download.
[22] *Id.* at 5.
[23] Shuren Statement.
[24] *Newman v. Motorola, Inc.*, 218 F. Supp. 2d 769 (D. MD 2002), *aff'd per curiam Newman v. Motorola, Inc.*, 78 Fed.Appx. 292 (4th Cir. 2003); *see also Murray v. Motorola, Inc.*, Memorandum Opinion and Order on Expert Witness Admissibility, Case No. 2002 CA 001371 A (Aug. 8, 2014).
[25] Lauran Neergaard & Seth Borenstein, *Cross talk: Federal agencies clash on cellphone cancer risk*, Associated Press (Nov. 1, 2018), https://apnews.com/4da5f1cdfd774af29143ff3f5ccffa0b; *see also* IEEE Std C95.1-2019 at 16 n.8 ("The preponderance of epidemiologic evidence does not provide a sufficient basis for concluding that adult brain cancer is positively associated with mobile telephone use and, by implication, with RF exposures.").
[26] CTIA, Resources, *Millimeter Wave Studies Cited by IEEE*, http://www.wirelesshealthfacts.com/wp-content/uploads/2020/01/Millimeter-Wave-Studies.pdf (last visited October 7, 2020).

Common equipment such as "airport scanners, automotive collision avoidance systems and perimeter surveillance radar security systems" all use mmW technology.[27]

Acting responsibly, scientists and engineers continue to research RF exposure, including RF exposure with 5G technology. IEEE's Committee on Man and Radiation just completed a comprehensive review of 5G systems concluding that, based on the evidence to date, "the likelihood of yet unknown health hazards at exposure levels within current limits to be very low, if they exist at all."[28] The authors explained that "one can expect that exposures from 5G networks will not differ greatly from those associated with present generation networks" because, like "previous generations of cellular systems: [5G must] provide a signal that is strong enough to be useful within a given cell but not so strong as to cause interference to users in nearby cells."[29] In other words, 5G base stations are limited in their power because of the potential for those emissions to cause interference with other base stations.

The American Cancer Society explained that "[w]hile [5G] RF waves are higher frequency (higher energy) than those used by older generations, they are still forms of non-ionizing radiation, so they still lack the ability to directly damage DNA."[30] Further, "these higher frequency RF waves are less able to penetrate the body than lower frequency waves, so in theory they might be less likely to have any potential health effects."[31]

5G will also take advantage of small cell network architecture, which results in more base stations operating at *lower* power levels. A recent overview of exposure from small cells determined that such "[f]ixed small cell wireless communication installations … that operate in compliance with the regulations of the FCC will produce RF exposures well within the recommended exposure limits of the FCC, ICNIRP [International Commission on Non-Ionizing Radiation Protection], and IEEE."[32] Further, "[r]esearch to date does not provide a reliable

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[27] Joan Conrow, *Three reasons why 5G is unlikely to cause harm*, Cornell Alliance for Science, (June 26, 2020), https://allianceforscience.cornell.edu/blog/2020/06/three-reasons-why-5g-is-unlikely-to-cause-harm/.
[28] *Id*.
[29] *Id.*
[30] *ACS Cell Phone Towers*
[31] *Id.*
[32] William H. Bailey, *Wireless 5G Radiofrequency Technology: An Overview of Small Cell Exposures, Standards and*

scientific basis to conclude that the operation of these facilities will cause or contribute to adverse health effects in the population."[33]

In March 2020, ICNIRP released updated, modernized guidelines that expressly cover the new frequencies that 5G will use. Announcing their release, ICNIRP Chairman, Dr. Eric van Rongen, advised that "[t]he most important thing for people to remember is that 5G technologies will not be able to cause harm when these new guidelines are adhered to."[34] The FCC's rules are also designed to protect health and safety, and prevent harm. Indeed, the FCC notes that "the possibility that a member of the general public could be exposed to RF levels in excess of the FCC guidelines is extremely remote."[35]

FEDERAL PREEMPTION

The majority makes several recommendations related to mandated warnings, labeling, compliance regulations, and zoning requirements based on health and safety concerns. These recommendations are not warranted based on the science discussed above, but are also not viable because federal law preempts state and local action that conflicts with the FCC's determination that compliant devices and equipment are safe. Congress determined that the FCC should be the "central[] authority" for regulating communications in the U.S.[36] This charge includes the regulation of "the kind of apparatus to be used" for wireless radio communications and "the emissions" that such equipment may produce.[37] The FCC promulgated its RF exposure rules to ensure that they protect human health nationwide as technology evolves, relying on sound scientific research of government and other expert organizations.

The FCC acted in its role as, in the words of the Supreme Court, the "exclusive"

Science, at 7, Exponent (Apr. 2020), http://www.wirelesshealthfacts.com/wp-content/uploads/2020/04/Bailey-5G-Whitepaper-4-15-20.pdf.

[33] *Id.*

[34] Media Release, International Commission on Non-Ionizing Radiation Protection, *New Guidelines Released by the International Commission on Non-Ionizing Radiation Protection (ICNIRP)*, at 2 (Mar. 11, 2020), https://www.icnirp.org/cms/upload/presentations/ICNIRP_Media_Release_110320.pdf.

[35] FCC Consumer Guide, *Human Exposure to Radio Frequency Fields: Guidelines for Cellular Antenna Sites*, at 2 (Oct. 15, 2019), https://www.fcc.gov/sites/default/files/human_exposure_to_radio_frequency_fields_-_guidelines_for_cellular_antenna_sites.pdf.

[36] 47 U.S.C. § 151.

[37] *Id*. § 303(e).

arbiter in the "technical matters" of radio,[38] which includes control for any environmental effects, including, among other things, RF emissions.[39] For example, the FCC recognized that "very high levels of RF radiation can be harmful due to the ability of RF energy to heat biological tissue rapidly."[40] Accordingly, the FCC's rules *limit* RF exposure to humans "from *all* transmitting facilities, operations, and devices it regulates."[41]

By way of background, the FCC first adopted RF exposure rules in the 1980s and has updated its rules in response to new scientific evidence.[42] In 1996, Congress reaffirmed the FCC's authority to set standards on RF emissions to provide "adequate safeguards of the public health."[43] The FCC updated its RF exposure rules and relied on sound scientific research of government and other expert organizations. In particular, the FCC synthesized "submissions from the Environmental Protection Agency ("EPA"), the Food and Drug Administration ("FDA"), the Occupational Safety and Health Administration ("OSHA"), and the National Institute for Occupational Safety and Health ("NIOSH")."[44] Several courts have examined and affirmed the FCC's process to develop its RF exposure limits.[45] The Third Circuit observed that "the FCC is well positioned to solicit expert opinions and marshal the scientific data to ensure its standards both protect the public and provide for an efficient wireless network."[46] And courts have confirmed that the agency has done so. For example, the D.C. Circuit upheld the

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[38] *Head v. New Mexico Bd. of Exam'rs in Optometry*, 374 U.S. 424, 430 n.6 (1963) (observing that the "Commission's jurisdiction over technical matters … is clearly exclusive").

[39] *Robbins v. New Cingular Wireless LLC*, 854 F.3d 315, 319-20 (6th Cir. 2017) (noting that Congress "delegate[ed] the task of setting RF emission levels to the FCC"). Of course, government entities can and have participated in the notice-and-comment aspect of the FCC's rulemaking. *See, e.g.*, City of Boston, Massachusetts, ET Docket No. 19-226 (filed June 17, 2020).

[40] FCC, RF Safety FAQ, *What Biological Effects Can Be Caused By RF Energy*?, https://www.fcc.gov/engineering-technology/electromagnetic-compatibility-division/radio-frequency-safety/faq/rf-safety#Q5 (last visited October 7, 2020).

[41] Letter from Thomas M. Johnson, Jr., General Counsel, FCC, to Joseph H. Hunt, Assistant Attorney General, DOJ, N.D. Cal. No. C 19-05322 WHA, at 3 (Apr. 13, 2020) (citing 47 C.F.R. §§ 1.1307, 1.1310, 2.1091, 2.1093) (emphasis added), https://docs.fcc.gov/public/attachments/DOC-363717A1.pdf.

[42] Letter from Thomas M. Johnson, Jr. General Counsel, FCC, to Joseph H. Hunt, Assistant Attorney General, DOJ, N.D. Cal. No. 3:15-cv-02529 EMC, at 3-5 (June 22, 2020) (examining the adoption and evolution of the Commission's RF exposure rules).

[43] *Id.* at 4-5 (quoting H.R. Rep. No. 204, 104th Cong., 1st Sess. Pt. 1, at 94 (1995)).

[44] *Cellular Phone Taskforce v. FCC*, 205 F.3d 82, 88 (2d Cir. 2000).

[45] *See, e.g.*, *id*. at 89 (rejecting an APA challenge to the FCC's RF emissions decisions in the 1996 and 1997 proceedings).

[46] *Farina v. Nokia Inc.*, 625 F.3d 97, 126 (3d Cir. 2010); *see also id.* at 129 (confirming the Commission's expertise to select an appropriate standard for RF limits).

agency's reliance on the views of expert agencies.[47]

Every court since 2005 that has addressed this issue has held that federal law preempts state action that challenges the safety of wireless devices including zoning decisions based on safety concerns. The Telecommunications Act itself has an express preemption provision that prohibits state or local regulation of cellular equipment based on alleged health effects.[48] Courts have also struck down state law regulation of RF emissions from cell phones based on alleged health effects as impliedly preempted by the FCC's regulation.[49] And most recently, a United States District Court in the Ninth Circuit held that federal law preempts the City of Berkeley's Ordinance requiring warnings at the point of sale.[50] Preemption, therefore, would invalidate many of the Recommendations, which if adopted, would subject the state and localities to expensive challenges and litigation, and almost certain defeat.

The minority does not oppose individuals or communities who want to convert to technology that better suits their needs, so long as those decisions do not conflict with the FCC's goal of the rapid deployment of wireless technology. We also do not oppose communities providing individuals with information about how to reduce their exposure to RF emissions, consistent with what the FCC already does. While individuals should have access to equipment to measure the levels in apartments they are contemplating renting or homes they want to purchase, testing should not be mandated. Access to the testing or the equipment to conduct the test could be provided by various groups such as home inspectors, real estate agents and the county cooperative extension. Similarly, we do not agree to establishing a State funded oversight group or state funding of the measurement equipment. Nor do we believe, as a practical matter, that any of

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[47] *EMR Network v. FCC*, 391 F.3d 269, 272-73 (D.C. Cir. 2004).

[48] 47 U.S.C. § 332(c)(7)(b)(iv); *See, e.g.*, *Cellular Phone Taskforce*, 205 F.3d at 96 (interpreting the TCA to preempt a state and local government's power to regulate the placement, construction and modification of personal wireless services facilities on the basis of health effects of RF emissions); *Santa Fe Alliance for Public Health and Safety v. City of Santa Fe, N.M.*, 2020 WL 2198120, at *7 (D.N.M. May 6, 2020) (noting the TCA explicitly preempts states and local governments from considering environmental effects of RF emissions in siting decisions).

[49] *Farina*, 625 F. 3d at 129 ("there is no indication . . . that either Congress or the FCC traditionally viewed state regulation of RF emissions as a necessary complement to federal regulation"); *Murray v. Motorola, Inc.*, 982 A.2d 764, 777–778 (D.C. 2009) ("insofar as Plaintiffs' claims rest on allegations about the inadequacy of the FCC's RF radiation standard or about the safety of their FCC-certified cell phones, the claims are preempted under the doctrine of conflict preemption.").

[50] *CTIA – The Wireless Association v. City of Berkeley*, No. 15-cv-02529-EMC, 2020 WL 5576135 (N.D. Cal. Sept. 17, 2020) (holding the Berkeley Ordinance "overwarns and stands as an obstacle to the accomplishment of balancing federal objectives by the FCC.").

the Recommendations have any chance of receiving funding.

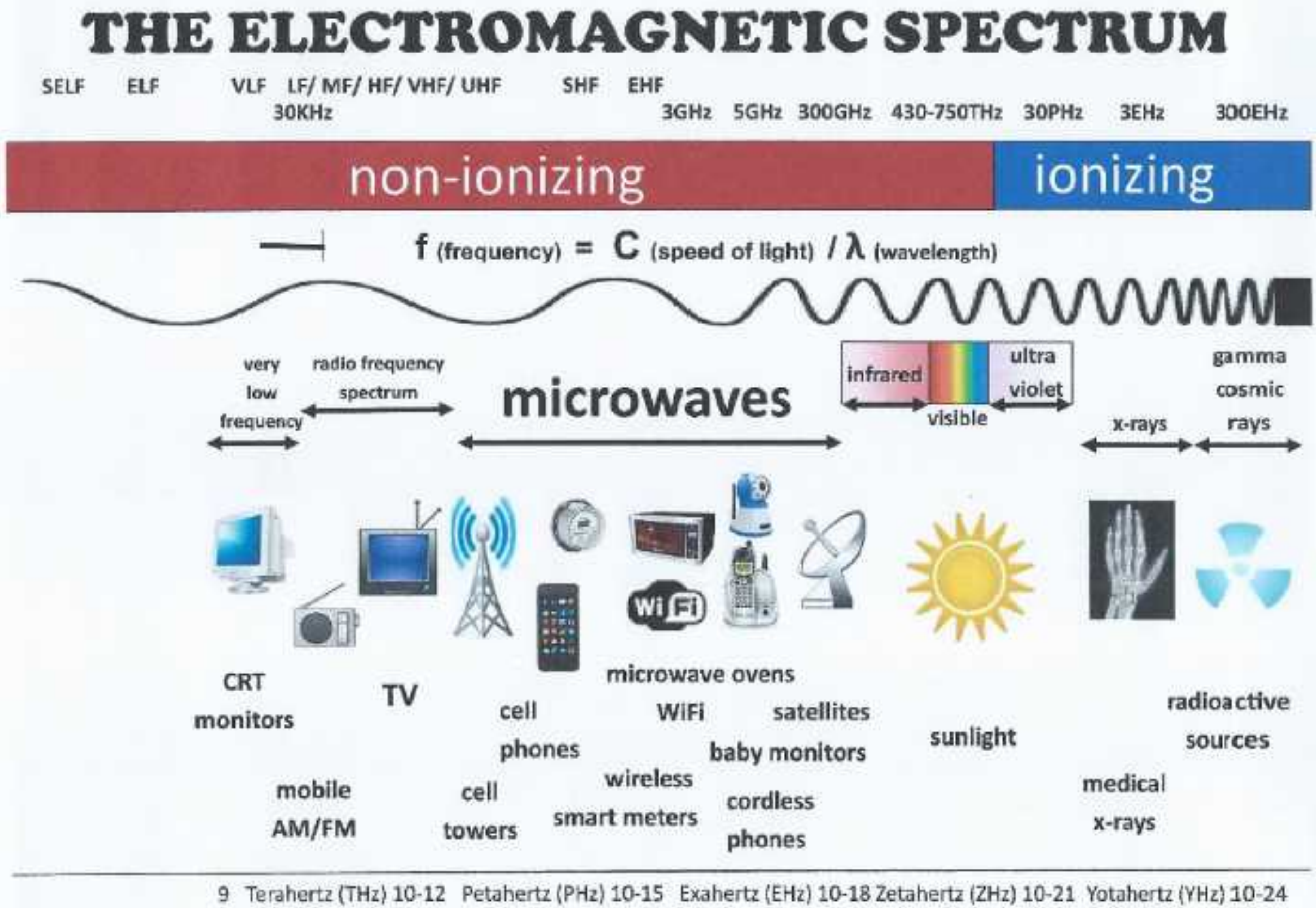
The minority feels strongly that the full body of literature of the science on wireless technology was ignored. Furthermore, the Commission neglected to carry out its mandate to study "…the advantages and risks associated with 5G technology."[51] Had this been done, the Commission would have been made aware of the significant economic and societal benefits that 5G is predicted to provide.[52] The minority has strong concerns that should the majority's conclusions regarding 5G safety – despite their complete odds with the overwhelmingly majority of verified scientific evidence – lead to the enactment of any of the majority's recommendations, the citizens of New Hampshire would be deprived of the enormous benefits of wireless innovation in a time when wireless connectivity could not be more important.

[51] See HB 522: http://gencourt.state.nh.us/bill_Status/billText.aspx?sy=2019&id=267&txtFormat=pdf&v=current (last visited October 14, 2020).

[52] Accenture predicts deploying the next generation of high-speed 5G wireless networks could create up to three million jobs and add approximately $500 billion to U.S. GDP through direct and indirect potential benefits, https://newsroom.accenture.com/content/1101/files/Accenture_5G-Municipalities-Become-Smart-Cities.pdf (last visited October 14, 2020).

APPENDICES

Appendix A *Electromagnetic Spectrum*



Appendix B

Correspondence with federal agencies

Correspondence between Councilwoman Denise Ricciardi, a member of the New Hampshire Commission on 5G, and Dr. Barrington and Dr. Hoover of the National Cancer Institute

Begin forwarded message:

From: NCI Information < nciinfo@nih.gov >
Date: July 30, 2020 at 2:51:16 PM EDT
To: New Bedford Councilmember Denise Ricciardi of the New Hampshire 5G Commission
Subject: Important questions that need to be answered.
Reply-To: "NCI Information" < nciinfo@nih.gov >
Subject: Important questions that need to be answered.

Response By Email (NCI Agent) (07/30/2020 11:51 AM)

Dear Ms. Ricciardi:

I received your follow-up inquiry requesting an answer to each question listed in your email. Please see below:

Councilmember Denise Ricciardi - Question 1. What is the National Cancer Institute opinion on the safety of 5G, 4G and cell towers? If you have one, please share your scientific documentation.

Response from the National Cancer Institute:

> As a Federal research agency, the NCI is not involved in the regulation of radiofrequency telecommunications infrastructure and devices, nor do we make recommendations for policies related to this technology. The Food and Drug Administration (FDA) and the Federal Communications Commission (FCC) are the responsible federal agencies with authority to issue opinions on the safety of these exposures. Rather, NCI gathers and reviews published findings of well-conducted studies with a focus on cancer in humans in the medical literature and makes summaries available on its website and fact sheets.
>
> According to the FCC certain agencies in the Federal Government have been involved in monitoring, researching or regulating issues related to human exposure to radiofrequency radiation. These agencies include the FDA, the Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA), the National Institute for Occupational Safe and Health (NIOSH), the National Telecommunications and Information Administration (NTIA) and the Department of Defense (DOD).

Councilmember Denise Ricciardi - Question 2. Has NCI staff done a systematic research review of the research on wireless radiation?

Response from the National Cancer Institute:

> Experts at the NCI review the research on radiofrequency radiation and other types of non-ionizing radiation electromagnetic fields (EMFs) in order to maintain our fact sheets on these topics. Other federal agencies have the responsibility to formally review the research on these exposures, specifically the FDA and FCC.

Councilmember Denise Ricciardi - Question 3. What is the NCI opinion on the safety of cell phones? If you have one, please share your scientific documentation.

Response from the National Cancer Institute:

> The FDA and FCC are the responsible federal agencies with authority to issue opinions on the safety of these exposures. As a Federal research agency, the NCI is not involved in the regulation of radiofrequency telecommunications infrastructure and devices, nor do we make recommendations for policies related to this technology.
>
> The NCI gathers and reviews published findings of well-conducted studies in the medical literature on cell phones and cancer risk. The NCI fact sheet "Cell Phones and Cancer Risk" outlines the available evidence from human and animal studies regarding cancer risk and cell/mobile telephones. It includes references and the citations are at the bottom of the document.

Councilmember Denise Ricciardi - Question 4. Does the NCI recommend that parents teach their children to reduce exposure to cell phone radiation? Does the NCI think it is not necessary to take precautions and that information on reducing exposure is only for "concerned" people? Or does the NCI recommend all parents educate their children to reduce exposure and that they themselves reduce exposure to their children?

Response from the National Cancer Institute:

> As noted above, the NCI does not make recommendations or issue guidelines. The fact sheet "Cell Phones and Cancer Risk" does include information from the FDA about ways cell phone users—children, teenagers or adults—can reduce their exposure to radiofrequency radiation. The FDA suggests that cell phone users reserve the use of cell phones for shorter conversations or for times when a landline phone is not available; and use a device with hands-free technology, such as wired headsets, which place more distance between the phone and the head of the user.

Councilmember Denise Ricciardi - Question 5. Did the NCI review in a systematic way the research on impacts of wireless and cell towers to trees and plants? If not, what agency is responsible for ensuring wireless signals are safe for trees and plants?

Response from the National Cancer Institute:

> The NCI is not charged with researching the impact of wireless technology and cell towers on trees and plants. NCI is not aware of any Federal agency mandated to

ensure wireless signals are safe for trees and plants.

Councilmember Denise Ricciardi - Question 6. Did the NCI review in a systematic way the research on cell towers and how wireless antennas impact birds. If not, what agency is responsible for ensuring wireless signals are safe for birds?

Response from the National Cancer Institute:

> The NCI is not charged with researching the impact of wireless technology and cell towers on birds. The NCI is not aware of any Federal agency mandated to ensure wireless signals are safe birds.

Councilmember Denise Ricciardi - Question 7. Did the NCI review in a systematic way the research on impact to bees and insects. If not, what agency is responsible for ensuring wireless signals are safe for insects and bees?

Response from the National Cancer Institute:

> The NCI is not charged with researching the impact of wireless technology on bees and other insects. The NCI is not aware of any Federal agency mandated to ensure wireless signals are safe for bees and other insects.

Councilmember Denise Ricciardi - Question 8. Does the NCI only focus on cancer as a health effect?

Response from the National Cancer Institute:

> Yes. In addition, by law, U.S. population-based cancer registries must collect information on benign brain tumors and the NCI fact sheet “Cell Phones and Cancer Risks” describes findings for meningioma, acoustic neuroma and other benign brain and central nervous system tumors.

Councilmember Denise Ricciardi - Question 9. The NCI does not present the findings of the NTP as “clear evidence of cancer” but simply states of the findings that “The primary outcomes observed were a small number of cancers of Schwann cells in the heart and non-cancerous changes (hyperplasia>) in the same tissues for male rats, but not female rats, nor in mice overall.” Why doesn’t the NCI present the findings of DNA damage on their webpage as it is published and was found in rats and mice. In addition cardiomyopathy was found. Why isn’t this presented on the NCI webpage?

Response from the National Cancer Institute:

> The focus of the fact sheet “Cell Phones and Cancer Risk” is limited to cancer risk. As you noted, the fact sheet provided an overview of the primary outcomes found in the National Toxicology Program (NTP) study. These findings are reported on the NTP website A link to this information was included in the fact sheet for those who wish to know more about the NTP study.

Councilmember Denise Ricciardi - Question 10. The FDA disagrees with the National Toxicology Program findings of clear evidence of cancer. What is the NCI position on the determination of “clear evidence”?

Response from the National Cancer Institute:

> The NCI does not comment on the cancer evaluation criteria of other organizations or how researchers use these definitions in their analysis. You may find useful a critical evaluation of the NTP study that was conducted by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

Councilmember Denise Ricciardi - Question 11. Is there evidence that heating can cause cancer? That elevated temperatures can induce cancer?

Response from the National Cancer Institute:

> There is no current evidence that elevated temperatures or heating is a risk factor for cancer.

Councilmember Denise Ricciardi - Question 12. Has the NCI reviewed in a systematic way the research on impacts to the nervous system?

Response from the National Cancer Institute:

> The NCI fact sheet on "Cell Phones and Cancer Risk" provides a summary review of most epidemiologic studies of cell phone use and brain and other central nervous system tumors. Most of the studies are case-control studies. Details are provided on the three most impactful studies, including the 13-country, case-control Interphone study, the large national Danish cohort study, and the Million Women United Kingdom cohort study.

Councilmember Denise Ricciardi - Question 13. Does the NCI believe the current limits protect the public, children, pregnant women and medically vulnerable from health effects after long term exposure. Please provide documentation for each group, children, pregnant women and medically vulnerable that shows research ensuring safety.

Response from the National Cancer Institute:

> The NCI does not regulate issues related to human exposure to radiofrequency radiation.

Councilmember Denise Ricciardi - Question 14. We know that the NCI is aware that cell phones can violate FCC SAR limits at body contact on high power. The FDA has written that because there is a safety factor. What is the safety factor for the SAR the FDA relies on? Do you know?

Response from the National Cancer Institute:

> The FDA shares regulatory responsibilities for cell phones with the FCC. The FCC certifies wireless devices, and all phones that are sold in the United States must comply with FCC guidelines on radiofrequency exposure. The FDA also has the authority to take action if cell phones are shown to emit radiofrequency energy at a level that is hazardous to the user.
>
> In addition, the FDA is responsible for protecting the public from harmful radiation

emissions from consumer products such as microwave ovens, televisions, and computer monitors. You may wish to contact the FDA's Center for Devices and Radiological Health’s Office of Compliance at 301–594–4654, for information about SAR guidelines used in cell phones.

Councilmember Denise Ricciardi - Question 15. Will the NCI be taking action to inform the public about this? If not, please explain why not.

Response from the National Cancer Institute:

NCI staff are committed to regularly reviewing the published findings of well-conducted studies on cancer and making them available on a timely basis to the public through our online fact sheets. As noted above, the NCI continues to make this information available on its website Cancer.gov , the Institute’s primary resource in informing the public about cancer research. The NCI gathers and reviews published findings of well-conducted studies in the medical literature on cell phones and cancer risk. The NCI fact sheet “Cell Phones and Cancer Risk” outlines the available evidence from human and animal studies regarding cancer risk and cell/mobile telephones. As also noted above, the NCI has conducted a review of the research on radiofrequency radiation

and other types of non-ionizing radiation electromagnetic fields (EMFs), available in the fact sheet

“Electromagnetic Fields and Cancer.” NCI will continue to update these factsheets as new relevant studies are published in the peer-reviewed literature.

Our sister agencies, the FDA as well as the FCC, retain responsibility for reviewing guidance on safety concerns and informing the public if those circumstances change.

Councilmember Denise Ricciardi - Question 16. What actions specifically is the NCI doing now in regards to 5G and cell phone radiation in terms of research review?

Response from the National Cancer Institute:

As noted above, the NCI regularly reviews the published findings of studies on cancer and makes them available to the public.

Additionally, given the multi-year latency of brain tumors and most other solid tumors and the need to carefully consider the optimal study design, it would be premature to begin development of a protocol for studying the relation between 5G exposures and cancer risk before 5G systems are implemented. We are in close communication with other epidemiologists and dosimetrists working on radiofrequency exposures and cancer risks. We continue to carefully monitor research in this area.

Councilmember Denise Ricciardi - Question 17. Does the NCI evaluate the safety of 5G cell antennas? If so how? If not, what health agency is ensuring that 5G cell antennas are safe for people, wildlife and trees.

Response from the National Cancer Institute:

The FCC is responsible for developing guidelines for human exposure to radiofrequency electromagnetic fields, which includes antennas.

Councilmember Denise Ricciardi - Question 18. Cell phones and wireless devices emit several types of nonionizing radiation in addition to radiofrequency radiation. For example the devices emit magnetic fields and when a pregnant woman holds a laptop on her lap the measured fields can be high even into the baby. What agency ensures safety related to extremely low frequency (ELF-EMF) electromagnetic fields- also nonionizing? Currently we have no federal limit, no federal guidelines and confirmed associations with cancer and many other health effects. Kaiser Permanente researchers have published several studies linking pregnant women's exposure to magnetic field electromagnetic fields to not only increased miscarriage and but also increased ADHD , obesity and asthma in the woman's prenatally exposed children. A recent large-scale stud y again found associations with cancer. Where is the NCI presentation of this research for the public?

Response from the National Cancer Institute:

As noted above, the FDA is responsible for protecting the public from radiation emissions from consumer products such as microwave ovens, televisions, and computer monitors. You may wish to contact the FDA's Center for Devices and Radiological Health's Office of Compliance at 301–594–4654, for information about research on this topic.

Our sister institute, National Institute of Child Health and Human Development (NICHD) another part of the NIH, investigates human development throughout the entire life process, with a focus on understanding disabilities and important events that occur during pregnancy. You may wish contact to the NICHD for information about radiofrequency radiation exposure and human development. NICHD can be contacted by email at NICHDInformationResourceCenter@mail.nih.gov <mailto: NICHDInformationResourceCenter@ma il.nih.gov >.

NCI staff are committed to regularly reviewing the published findings of well-conducted studies on cancer and making them available on a timely basis to the public through our online fact sheets.

Councilmember Denise Ricciardi - Question 19. Will the NCI be sharing and recommending how to reduce ELF- EMF Exposure? Please clarify which US agency has jurisdiction over ELF-EMF exposures? Please clarify which US agency has authority to set limits for ELF-EMF exposures? As far as we know there is no limit in the USA for this type of exposure.

Response from the National Cancer Institute:

According to the fact sheet "Electromagnetic Fields and Cancer" sources of ELF-EMFs include power lines, electrical wiring, and electrical appliances such as shavers, hair dryers, and electric blankets.

As noted above, the NCI is not responsible for setting limits for ELF-EMF or any other exposure. Manufacturers of electronic radiation emitting products sold in the United States are responsible for compliance with the Federal Food, Drug and Cosmetic Act (FD&C Act), Chapter V

Subchapter C - Electronic Product Radiation Control.

The U.S. Congress created the National Institute of Environmental Health Sciences' (NIEHS) EMF Research and Public Information Dissemination (RAPID) Program in 1992 to study whether exposure to EMFs produced by the generation, transmission, or use of electric power posed a risk to human health. Although this program has ended, the NIEHS continues to study EMFs. For more information, please see the NIEHS website.

Councilmember Denise Ricciardi - Question 20. Who are the NCI staff who have expertise on this issue at the NCI? What NCI staff is in the Interagency workgroup and where can we access the minutes and work of this group?

Response from the National Cancer Institute:

The content on the NCI's website Cancer.gov related to this topic is authored and maintained by NCI staff. The information on this site is science-based, authoritative, and up to date. Medical experts, cancer researchers, and editors review the content before it is published to the website.

Within the NCI, several research divisions conduct or fund extramural research to discover the genetic and environmental determinants of cancer and new approaches to cancer prevention, including the impacts of ionizing and nonionizing radiation. Epidemiologists also monitor cancer incidence trends for potentially relevant malignancies using U.S.-based cancer registries such as the North American Association of Central Cancer Registries and the Surveillance, Epidemiology, and End Results Program, and periodically review the scientific peer-reviewed literature in this area.

If you are compiling a list of EMF experts to contact, it is important to note that NCI scientists receive many requests for interviews or for advice with projects. All such inquiries should be directed to the NCI Office of Communications and Public Liaison through the NCI contact page< mailto:https//www.cancer.gov/contact> ; found on Cancer.gov.

Councilmember Denise Ricciardi - Question 21. The FCC decided not to update their limits on wireless but the NCI did not submit an opinion to the FCC. Why not?

Response from the National Cancer Institute:

As noted above, the NCI does not make recommendations for policies on wireless technology.

Councilmember Denise Ricciardi - Question 22. Will the NCI be submitting an opinion to the FCC about the higher frequencies to be used in 5G?

Response from the National Cancer Institute:

As noted above, the NCI does not make recommendations for policies on wireless technology.

Councilmember Denise Ricciardi - Question 23. The American Cancer Society funded research by Yale that found cancer after cell phone radiation exposure. See it here Thyroid Cancer, Genetic Variations, and Cell Phones Linked in New Yale School of Public Health Study What is the NCI opinion?

Response from the National Cancer Institute:

> NCI staff are committed to regularly reviewing the published findings of well-conducted studies on cancer and making them available on a timely basis to the public through our online fact sheets.

Councilmember Denise Ricciardi Question 24. Will you be updating your webpage with information on thyroid cancer and on genetic susceptibility as found by the Yale study?

Response from the National Cancer Institute:

> Response from the National Cancer Institute: NCI staff are committed to regularly reviewing the published findings of well-conducted studies on cancer and making them available on a timely basis to the public through our online fact sheets.
>
> Sincerely yours,
> Bill Robinson
> Office of Communications and Public Liaison National Cancer Institute

Customer By CSS Email (Denise Ricciardi) (07/19/2020 06:55 AM)

Hello,

You did not satisfy the commission. We requested you answer each question point by point. Not a paragraph that does NOT properly answer the questions.

Please go back and answer the questions number one provide the answer number two provide the answer and so on. Please expedite this request, it is urgent for commission.

Thank you,

Denise Ricciardi

Subject: Important questions that need to be answered.

Response By Email (NCI Agent) (07/16/2020 11:39 AM)

Dear Ms. Ricciardi:

Your email to Dr. Amy Berrington and Dr. Robert Hoover of the National Cancer Institute (NCI) regarding 5G has been forwarded to this office for reply. In your email, you asked questions about the status of research of the health and environmental effects of 5G (fifth-generation) wireless network technology on people and the natural world and which Federal agencies regulate this technology. We can offer information that you may find useful.

The NCI, part of the National Institutes of Health, is the Federal government's principal agency for cancer research and training. Part of the NCI's mission includes gathering and disseminating information about cancer, including risk factors, to the public and medical community through its website, fact sheets, and the NCI's Cancer Information Service (CIS). The fact sheets "Cell Phones and Cancer Risk" and "Electromagnetic Fields and Cancer" outline the available evidence from human and animal studies regarding cancer risk and cellular/mobile telephones and low- to medium-frequency electromagnetic fields.

The National Toxicology Program (NTP) investigated the health effects in animals exposed to radiofrequency (RF) radiation modulations used in 2G and 3G cell phones. According to the lead toxicologist of the studies, Michael Wyde, Ph.D., "5G is an emerging technology that hasn't really been defined yet. From what we currently understand, it likely differs dramatically from what we studied." This comment can be found in the NIH news release about the NTP final reports.

The NCI is committed to reviewing published findings of well-conducted studies in the medical literature and making them available to the public. Sometimes the results of a research study can yield inconsistent and even unanticipated results. Nonetheless, in this way, hypotheses are thoroughly evaluated.

As a Federal research agency, the NCI does not regulate RF electromagnetic field (EMF) exposure or establish guidelines. Within the Federal government, the U.S. Federal Communications Commission (FCC) authorizes or licenses most RF telecommunications services, facilities, and devices used by the public, industry and state and local governmental organizations. The FCC is required by the National Environmental Policy Act of 1969, among other things, to evaluate the effect of EMF emissions from FCC-regulated transmitters on the quality of the human environment. This includes cell phones and towers. The FCC Policy on Human Exposure web page includes links to several organizations that have recommendations for human exposure to EMF.

In addition, the U.S. Food and Drug Administration (FDA) shares regulatory responsibilities for cell phones with the FCC. Although cell phones can be sold without FDA clearance or approval, the agency monitors the effects the phones have on health. The FDA has the authority to take action if cell phones are shown to emit RF energy at a level that is hazardous to the user. The FDA recently provided an updated assessment of the current limits of RF energy based on the currently available scientific evidence (see Letter from the FDA to the FCC on Radiofrequency Exposure).

Sincerely yours,

Bill Robinson

Office of Communications and Public
Liaison National Cancer Institute

Customer By CSS Email (Denise Ricciardi) (07/10/2020 07:25 AM)

Hello,

I serve in New Hampshire on a health study commission. We need these questions answered each one, one by one.

Questions to Dr. Barrington and Dr. Hoover of the National Cancer Institute

1. What is the National Cancer Institute opinion on the safety of 5G, 4G and cell towers? If you have one please share your scientific documentation.

2. Has NCI staff done a systematic research review of the research on wireless radiation?

3. What is the NCI opinion on the safety of cell phones? If you have one please share your scientific documentation.

4. Does the NCI recommend that parents teach their children to reduce exposure to cell phone radiation? Does the NCI think it is not necessary to take precautions and that information on reducing exposure is only for "concerned" people? Or does the NCI recommend all parents educate their children to reduce exposure and that they themselves reduce exposure to their children?

5. Did the NCI review in a systematic way the research on impacts of wireless and cell towers to trees and plants? If not what agency is responsible for ensuring wireless signals are safe for trees and plants? 6.Did the NCI review in a systematic way the research on cell towers and how wireless antennas impact birds. If not, what agency is responsible for ensuring wireless signals are safe for birds?

7. Did the NCI review in a systematic way the research on impact to bees and insects. If not, what agency is responsible for ensuring wireless signals are safe for insects and bees?

8. Does the NCI only focus on cancer as a health effect?

9. The NCI does not present the findings of the NTP as “clear evidence of cancer” but simply states of the findings that” The primary outcomes observed were a small number of cancers of Schwann cells in the heart and non-cancerous changes (hyperplasia>) in the same tissues for male rats, but not female rats, nor in mice overall.” Why doesn’t the NCI present the findings of DNA damage on their webpage as it is published and was found in rats and mice. In addition cardiomyopathy was found. Why isn’t this presented on the NCI webpage?

10. The FDA disagrees with the National Toxicology Program findings of clear evidence of cancer. What is the NCI position on the determination of “clear evidence”?

11. Is there evidence that heating can cause cancer? That elevated temperatures can induce cancer?

12. Has the NCI reviewed in a systematic way the research on impacts to the nervous system?

13. Does the NCI believe the current limits protect the public, children, pregnant women and

medically vulnerable from health effects after long term exposure. Please provide documentation for each group, children, pregnant women and medically vulnerable that shows research ensuring safety.

14. We know that the NCI is aware that cell phones can violate FCC SAR limits at body contact on high power. The FDA has written that because there is a safety factor. What is the safety factor for the SAR the FDA relies on? Do you know?

15. Will the NCI be taking action to inform the public about this? If not, please explain why not.

16. What actions specifically is the NCI doing now in regards to 5G and cell phone radiation in terms of research review?

17. Does the NCI evaluate the safety of 5G cell antennas? If so how? If not, what health agency is ensuring that 5G cell antennas are safe for people, wildlife and trees.

18. Cell phones and wireless devices emit several types of non ionizing radiation in addition to radiofrequency radiation. For example the devices emit magnetic fields and when a pregnant woman holds a laptop on her lap the measured fields can be high even into the baby. What agency ensures safety related to extremely low frequency (ELF-EMF) electromagnetic fields- also non ionizing? Currently we have no federal limit, no federal guidelines and confirmed associations with cancer and many other health effects. Kaiser Permanente researchers have published several studies linking pregnant women's exposure to magnetic field electromagnetic fields to not only increased miscarriage and but also increased ADHD, obesity and asthma in the woman's prenatally exposed children. A recent large scale study again found associations with cancer. Where is the NCI presentation of this research for the public?

19. Will the NCI be sharing and recommending how to reduce ELF- EMF Exposure? Please clarify which US agency has jurisdiction over ELF-EMF exposures? Please clarify which US agency has authority to set limits for ELF-EMF exposures? As far as we know there is no limit in the USA for this type of exposure.

20. Who are the NCI staff who have expertise on this issue at the NCI? What NCI staff is in the Interagency workgroup and where can we access the minutes and work of this group?

21. The FCC decided not to update their limits on wireless but the NCI did not submit an opinion to the FCC. Why not?

22. Will the NCI be submitting an opinion to the FCC about the higher frequencies to be used in 5G.

23. The American Cancer Society funded research by Yale that found thyroid cancer after cell phone radiation exposure. See it here: https://medicine.yale.edu/news-article/22332/ https://protect-us.mimecast.com/s/K3TvCmZnOMf1oANt4 What is the NCI opinion?

24. Will you be updating your webpage with information on thyroid cancer and on genetic susceptibility as found by the Yale study?

Thank you for your cooperation.
Denise Riccciardi

Letters between Councilwoman Denise Ricciardi, a member of the New Hampshire Commission on 5G, and Dr. Shuren of the FDA

Note: The FDA did not answer the questions as asked and did not respond to the request to testify to the Commission

- June 23, 2020 Denise Ricciardi writes the FDA a detailed list of questions regarding their statements about cell phone radiation.
- Jul 15, 2020 FDA writes Denise Ricciardi a short two paragraphs that does not answer the questions.
- July 15, 2020 Denise Ricciardi writes back to the FDA stating that her questions are not answered.
- No additional answers have been provided by the FDA.
- March 2, 2020: The FDA also did not respond to the March 2020 request to testify to the 5G Commission.

July 15, 2020 Denise Ricciardi to the FDA

Hello,

This does not answer our specific numbered questions. Please go back and revisit the questions as requested.

Thank you,

Denise Ricciardi

On Jul 15, 2020, at 5:31 PM, Meister, Karen G < Karen.Meister@fda.hhs.gov > wrote:

July 15, 2020 Letter from FDA to Councilwoman Denise Ricciardi of the New Hampshire Commission on 5G

On Jul 15, 2020, at 5:31 PM, Meister, Karen G

Karen.Meister@fda.hhs.gov > wrote:

Dear Ms. Ricciardi,

Thank you for contacting the Food & Drug Administration (FDA) with your concerns regarding exposure to non-ionizing electromagnetic energy. Your inquiry was forwarded to the Intergovernmental Affairs (IGA) team in the Office of the Commissioner. We understand that you are a member of New Hampshire's "Commission to Study the Environmental and Health Effects of Evolving 5G Technology," and that you are gathering information.

As you may know, FDA shares regulatory responsibilities for cell phones with the Federal

Communications Commission (FCC). Under the law, FDA is responsible for, among other things: consulting with other federal agencies on techniques and programs for testing and evaluating electronic product radiation and collecting, analyzing, and making available scientific information on the nature and extent of the hazards and control of electronic product radiation. FDA's website provides information about cell phones, including the Agency's current assessment on the safety of exposure to non-ionizing electromagnetic fields. See https://www.fda.gov/radiation-emitting-products/home-business-and-entertainment-products/cell-phones The website includes an update to the scientific evidence evaluated by FDA (see https:// www.fda.gov/radiation-emitting-products/cell-phones/scientific-evidence-cell-phone-safety, as well as suggestions for those that may still be concerned about non-ionizing energy exposure (see https://www.fda.gov/radiation-emitting-products/cell-phones/reducing-radio-frequency-exposure-cell-phones).

FDA's doctors, scientists and engineers continually monitor the scientific studies and public health data for evidence that radio frequency energy from cell phones could cause adverse health effects. FDA also works with national and international health agencies to ensure the weight of scientific evidence is appropriately evaluated.

We hope this information is helpful to answer your questions. Best regards.

Karen Meister, J.D.
Acting Director, Intergovernmental Affairs
Senior Advisor, Office of Legislation
Office of the Commissioner/OPPLIA
U.S. Food and Drug Administration
(301) 796-8916 office
(240) 494-6228 (work cell)

From: "Shuren, Jeff" < Jeff.Shuren@fda.hhs.gov >
Date: June 24, 2020 at 4:28:49 PM EDT
To: Denise Ricciardi
Cc: OC Ombudsman < Ombuds@OC.FDA.GOV >, Patrick Abrami < abrami.nhrep@gmail.com >
Subject: RE: Important questions NEED to be answered for N.H. 5G health task commission

Thank you for reaching out to me. I have forwarded your questions to the FDA's Intergovernmental Affairs Staff who handles inquiries from State and local governments. I have included Karen Meister, their Acting Director, on this email, as well.

Best regards, Jeff

----Original Message
From: Denise Ricciardi
Sent: Tuesday, June 23, 2020 10:38 PM
To: Shuren, Jeff < Jeff.Shuren@fda.hhs.gov <mailto: Jeff.Shuren@fda.hhs.gov >>
Cc: OC Ombudsman < Ombuds@OC.FDA.GOV <mailto: Ombuds@OC.FDA.GOV >>;
Patrick Abrami < abrami.nhrep@gmail.com <mailto: abrami.nhrep@gmail.com >>

Subject: Important questions NEED to be answered for N.H. 5G health task commission

Dear Dr. Shuren,

We would appreciate an answer to these questions regarding cell phone radiation. If you could number them one by one it would help with clarity of your response.

Regarding the FDAs report "Review of Published Literature between 2008 and 2018 of Relevance to Radiofrequency Radiation and Cancer"

1. Why did the FDA only focus on cancer as a health effect?

2. The FDA said of the National Toxicology Program findings that the FDA was unsure if the tumors were a causal effect or if these results were "due to weakening of the immune response due to animal stress from cyclic heating and thermoregulation." Does the FDA think that cancer could be an effect of whole body heating, that cancer is a thermally induced effect? If so, what other studies show that heating causes cancer?

3. Did the FDA review in a systematic way the research on impacts to the nervous system?

4. At the Commission, a study on how millimeter waves interact with insects was discussed. Did the FDA review in a systematic way the research on impact to bees, insects and pollinators?

5. Did the FDA review in a systematic way the research on impact to trees and plants?

6. Did the FDA review in a systematic way the research on impact to birds.

7. If the FDA did not investigate impacts to insects or trees, what US agencies have done so?

8. The FDA website page Scientific Evidence for Cell Phone Safety has a section entitled "No New implications for 5G". Does the FDA believe that 5g is safe or that 5G has the same health issues as 3 and 4G? What is the FDA opinion on the safety of wireless?

9. What is the FDA opinion on FCC limits in terms of long term health effects. Does the FDA believe the current limits protect the public, children, pregnant women and medically vulnerable from health effects after long term exposure.

10. The FDA is aware that cell phone can violate FCC SAR limits at body contact on high power. The FDA has written that because there is a safety factor. What is the safety factor for the SAR the FDA relies on. At what SAR level above FCC limits will the FDA intervene?

11. What actions specifically is the FDA doing now in regards to 5G and cell phone radiation in terms of research review? How often will the FDA be releasing reports?

12. Will the FDA be evaluating the safety of 5G cell antennas? If so how? If not, what health agency is ensuring that 5G cell antennas are safe for people, wildlife and trees.

13. Cell phones and wireless devices emit several types of non ionizing radiation in addition to radiofrequency radiation. For example the devices emit magnetic fields and when a pregnant woman holds a laptop on her lap the measured fields can be high even into the baby. What agency ensures safety related to extremely low frequency (ELF-EMF)

electromagnetic fields- also non ionizing? Currently we have no federal limit, no federal guidelines and confirmed associations with cancer and many other health effects. Kaiser Permanente researchers have published several studies linking pregnant women's exposure to magnetic field electromagnetic fields to not only increased miscarriage and but also increased ADHD , obesity and asthma in the woman's prenatally exposed children. A recent large-scale study again found associations with cancer. Please clarify which US agency has jurisdiction over ELF-EMF exposures?

14. Will the FDA be initiating any research studies on 5G and health effects?

We as a health study commission on 5G take these duties very seriously. We are unbiased and we are seeking all answers and facts. We are requiring your answers to the above questions.

Thank you,
Denise Ricciardi
Committee Member appointed by Governor Sununu.

Additional Emails related to the questions:
From: "Meister, Karen G" < Karen.Meister@fda.hhs.gov >

Date: July 14, 2020 at 2:12:10 PM EDT To: Denise Ricciardi

Subject: FW: Important [External]

Hi Ms. Ricciardi-

We apologize for not responding sooner. Dr. Shuren forwarded your inquiry to our office because the Intergovernmental Affairs staff in the Office of the Commissioner handles inquiries from state and local governments like yours. We hope to get you a response very shortly. Thank you for your patience.

Karen
Karen Meister, J.D.
Acting Director, Intergovernmental Affairs
Senior Advisor, Office of Legislation
Office of the Commissioner/OPPLIA
U.S. Food and Drug Administration
(301) 796-8916 office
(240) 494-6228 (work cell)
(703) 201-6952 (personal cell- I will call you back on work phone)

Original Message
From: Denise Ricciardi
Sent: Tuesday, July 14, 2020 9:08 AM
To: Shuren, Jeff < Jeff.Shuren@fda.hhs.gov >
Cc: Patrick Abrami
Subject: Important

We have received no answers for our questions for the 5G health study commission in New Hampshire. Please advise!

Original Message
From: Denise Ricciardi
To: CDRHSpeakerLiaison@fda.hhs.gov < CDRHSpeakerLiaison@fda.hhs.gov >;
jeff.shurren@fda.hhs.govlyndsay.lloud.hhs.gov
<jeff.shurren@fda.hhs.govlyndsay.lloud.hhs.gov >
Cc: Patrick.Abrami@
Subject: Study commission HB522 New Hampshire
Sent: Wed, Mar 4, 2020 2:43 pm

Good afternoon,

Governor Sununu in the State of New Hampshire has tasked a group of us to study the health effects of the 5G rollout.

We are composed of a wide variety of talents. Including Physicians, toxicologists, scientists, epidemiologists, physicists, engineers, the telecom industry and more.

We have been meeting since last October and have had many experts provide testimony.

To complete our findings in an unbiased fashion. It is essential to have a qualified member of the FDA and the FCC present to our commission.

We are making history in New Hampshire. Many other States are watching. Our results will have a profound effect.

When can we count on your participation on such an important issue.

Thank you,
Denise Ricciardi

Appendix C

Answers to the specific questions
posed by HB 522

1. Why does the insurance industry recognize wireless radiation as a leading risk and has placed exclusions in their policies not covering damages caused by the pathological properties of electromagnetic radiation?

As shared with the Commission, insurers rank 5G, wireless, and electromagnetic radiation as high risk based on their white papers which compare the risk to asbestos where it may take decades to know the full extent of health impacts.

Scarato shared a 2019 report by Swiss Re Institute[53] which classifies 5G mobile networks as an "off-the-leash" "HIGH" risk, meaning a high-impact emerging risk that will affect property and casualty claims in more than three years' time. The Swiss Re report states on page 29:

> To allow for a functional network coverage and increased capacity overall, more antennas will be needed, including acceptance of higher levels of electromagnetic radiation. In some jurisdictions, the rise of threshold values will require legal adaptation. Existing concerns regarding potential negative health effects from electromagnetic fields (EMF) are only likely to increase. An uptick in liability claims could be a potential long-term consequence.
>
> Potential impacts:
>
> - Cyber exposures are significantly increased with 5G, as attacks become faster and higher in volume. This increases the challenge of defense.
> - Growing concerns of the health implications of 5G may lead to political friction and delay of implementation, and to liability claims. The introductions of 3G and 4G faced similar challenges.

[53] Swiss Re Institute, New Emerging Risk Insights, 2019

- Information security and national sovereignty concerns might delay implementation of 5G further, increasing uncertainty for planning authorities, investors, tech companies and insurers.
- Heated international dispute over 5G contractors and potential for espionage or sabotage could affect international cooperation, and impact financial markets negatively.
- As the biological effects of EMF in general and 5G in particular are still being debated, potential claims for health impairments may come with a long latency.

A Business Insurance analysis[54] also examined mass tort exposures that may have the potential to cause major difficulties for commercial policyholders and their insurers. It includes workers' overexposure to radio frequency waves from rooftop wireless transmitters as a potential future claim and states that research "has shown biological effects from lower-level 'nonthermal' exposure, and people exposed at lower levels have reported headache, dizziness, nausea, mood disorders, mental slowing, and memory loss." Most insurance plans do not cover electromagnetic fields (EMF) and they have "electromagnetic field exclusions."

For example the California State University Risk Management Authority (CSURMA) Self Insured Program states:

> We will not pay for loss or damage caused by or resulting from any of the following:
> …
> Artificially generated electrical, magnetic or electromagnetic energy that damages, disturbs, disrupts or otherwise interferes with any: (1) Electrical or electronic wire, device, appliance, system or network; or (2) Device, appliance, system or network utilizing cellular or satellite technology. But if fire results, we will pay for the loss or damage caused by that fire if the fire would be covered under this coverage form. For the purpose of this exclusion, electrical, magnetic or electromagnetic energy includes but is not limited to: (1) Electrical current, including arcing; (2) Electrical charge produced or conducted

[54] BusinessInsurance.com, "The Next Asbestos: Five emerging risks that could shift the liability landscape," May 13, 2011.

> by a magnetic or electromagnetic field; (3) Pulse of electromagnetic energy; or (4) Electromagnetic waves or microwaves.

Even AT&T Mobile Insurance[55] excludes loss from pollutants. Their policy states, "Pollutants" means: Any solid, liquid, gaseous, or thermal irritant or contaminant including smoke, vapor, soot, fumes, acid, alkalis, chemicals, artificially produced electric fields, magnetic field, electromagnetic field, sound waves, microwaves, and all artificially produced ionizing or non- ionizing radiation and waste."

Crown Castle states in their 2020 Annual Report:

> If radio frequency emissions from wireless handsets or equipment on our communications infrastructure are demonstrated to cause negative health effects, potential future claims could adversely affect our operations, costs or revenues.
>
> The potential connection between radio frequency emissions and certain negative health effects, including some forms of cancer, has been the subject of substantial study by the scientific community in recent years. We cannot guarantee that claims relating to radio frequency emissions will not arise in the future or that the results of such studies will not be adverse to us.
>
> Public perception of possible health risks associated with cellular or other wireless connectivity services may slow or diminish the growth of wireless companies, which may in turn slow or diminish our growth. In particular, negative public perception of, and regulations regarding, these perceived health risks may slow or diminish the market acceptance of wireless services. If a connection between radio frequency emissions and possible negative health effects were established, our operations, costs, or revenues may be materially and adversely affected. We currently do not maintain any significant insurance with respect to these matters.

[55] AT&T Mobile Insurance Policy, 2014, p. 4

Wireless companies from AT&T[56] to Nokia to T-Mobile to Verizon Wireless have issued similar warnings[57] to their own shareholders.

Contained in Vodafone's 2018 Annual Report are the following statements: "What is the risk? Electro-magnetic signals emitted by mobile devices and base stations may be found to pose health risks, with potential impacts including: changes to national legislation, a reduction in mobile phone usage or litigation" and "EMF health related risks - EMF found to pose health risks causing reduction in mobile usage or litigation." The report also included EMF is a "Principal Risk" rated as high in the graphic on pages 38 – 39.

Additional Insurance Reports that Rank Wireless and Electromagnetic Fields as "High Risk"

- 2016 Austrian Accident Insurance Institute (AUVA) ATHEM Report 2 "Investigation of athermal effects of electromagnetic fields in mobile communications."
- 2014 Swiss Re SONAR Report: New emerging risk insights.
- 2013 AM Best Briefing, Emerging Technologies Pose Significant Risks with Possible Long-Tail Losses.
- 2011 Business Insurance White Paper, "The Next Asbestos: Five emerging risks that could shift the liability landscape."
- 2011 Austrian Accident Insurance Institute (AUVA) ATHEM Report 1, Investigation of athermal effects of electromagnetic fields in mobile radio areas in German
- 2010 Lloyd's of London Report on Electromagnetic Fields
- 2009 Austrian Accident Insurance Institute Report on Health Risks from Cell Phone Radiation "Nonthermal Effects of Electromagnetic Radiation in the Cell Phone Frequency Range."
- 2011 Business Insurance Article "Geisel, Roseanne White. "Insurers exclude risks associated with electromagnetic radiation."

[56] AT&T 2016 Annual Report
[57] EHTrust.org, "Corporate Company Investor Warnings In Annual Reports 10k Filings Cell Phone Radiation Risks."

2. Why do cell phone manufacturers have in the legal section within the device saying keep the phone at least 5mm from the body?

5G will have multiple antennas for 5G as well as 4G, Wi-Fi, Bluetooth, and other technology. All of these antennas emit wireless radiation. Even if you are not on the phone, it has continuous emissions.

Phones are premarket tested for cell phone radiation exposures with a separation distance from the phone and the body phantom. This legal section states the exact separation distance the manufacturers used when testing the phone for compliance. As the 2012 GAO Report "Exposure and Testing Requirements for Mobile Phones Should Be Reassessed" states, "The specific minimum separation distance from the body is determined by the manufacturer. In addition, the U.S. government does not perform independent cell phone compliance testing, allowing each manufacturer to submit their own SAR testing results to the FCC."

If phones are used in positions closer than this manufacturer's stated distance, the cell phone user could potentially receive excessive cell phone radiation SAR levels which violate the FCC regulatory limits. Several reports in the US and internationally have confirmed that when phones are tested at body contact, the measured SAR will exceed FCC limits.[58, 59, 60, 61] Theodora Scarato presented this information to the Commission including an analysis by Professor Om Gandhi which examined data from 450 cell phone models from the French government agency, ANFR, the national radiation assessment bureau, indicating that phones can emit 11 times over the US FCC limit and 3 times over European/ICNIRP limits.

FCC Does Not Require Body Contact Tests for Cell Phone Radiation
As stated in the 2012 GAO report, "Some consumers may use mobile phones against the body, which FCC does not currently test, and could result in RF energy exposure higher than the FCC limit." The GAO report also directed the FCC to review their cell phone testing protocol because they found these protocols could

[58] Gandhi, O. P. (2019). "Microwave Emissions From Cell Phones Exceed Safety Limits in Europe and the US When Touching the Body." *IEEE Access*, 7, 47050-47052. doi:10.1109/access.2019.2906017
[59] Gandhi, Om P., and Gang Kang. "Inaccuracies of a plastic" pinna" SAM for SAR testing of cellular telephones against IEEE and ICNIRP safety guidelines." *IEEE Transactions on Microwave Theory and Techniques* 52.8 (2004).
[60] Gandhi, Om P. "Yes the children are more exposed to radiofrequency energy from mobile telephones than adults." *IEEE Access* 3 (2015): 985-988.
[61] Kang, Gang, and Om P. Gandhi. "SARs for pocket-mounted mobile telephones at 835 and 1900 MHz." *Physics in Medicine and Biology* 47.23 (2002): 4301.

allow for consumers to receive SAR levels that possibly exceed the "on the body" exposure guidelines.

Cell phone manufacturers are not required by the FCC to test cell phones for cell phone radiation compliance in positions which mimic direct contact between the phone and the body. In the USA, manufacturers can set distances of up to 25 mm when they perform SAR radiation testing for their phones and they are still within the law.

In contrast, in Europe the law has changed to ensure phones are tested at least at 5 mm and no more. This happened after France ANFR released radiation measurements for hundreds of cell phones tested independently by the government of France. The ANFR found the radiation levels were so high that most tested phones exceeded European cell phone radiation limits, showing radiation levels up to three times higher than the limits! ANFR has posted the information on their website.

Several phone models have been taken off the European market or software updated to reduce the radiofrequency radiation. The first withdrawal of cell phones from the market due to cell phone radiation levels dates back to April 2018, with the 100,000 Hapi 30 phones marketed by Orange, followed by the Neffos X1 TP902 (May 2018), the Echo Horizon Lite (Oct 2019), and the announcement on May 20 of the withdrawal of the Razer Phone 2 devices.

After the release of the ANFR tests that found phones violated limits in body contact positions, a new European Directive 2014/35/UE called RED, applicable from June 2016, changed the regulations so that now all phones in the European Union are SAR tested at a distance no greater than 5 mm.

Furthermore, the French ministries of Health, Ecology and Economy issued a joint press release on October 25, 2019[62] announcing France will ask the European Commission to further strengthen the SAR tests requirements to be carried out in a body contact position of 0mm from the body phantom. This would ensure that tests mimic the way people use cell phones today, touching the body.

[62] Buzyn A. "The Government is taking action to limit exposure to the emissions of certain mobile phones and to better inform the public." *Ministère Des Solidarités Et De La Santé*. Published 2019. Accessed July 8, 2020.

FCC SAR Limits

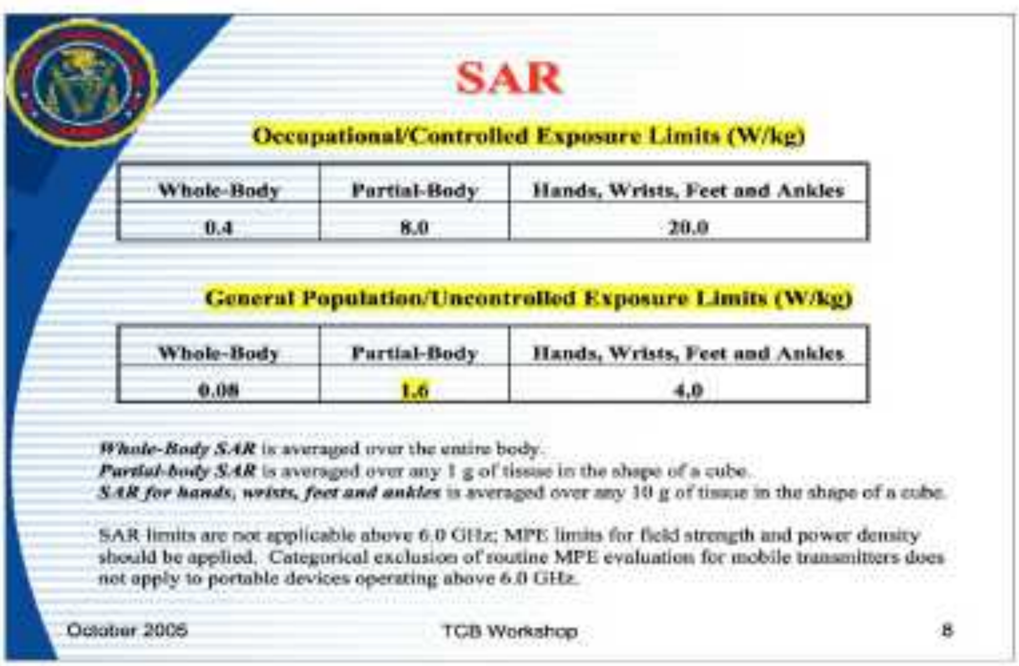
The FCC regulates RF energy emitted from FCC-regulated transmitters and has implemented a certification program to ensure that all mobile phones and wireless devices sold in the United States comply with the agency's limit on RF radiation exposure.

Before a cell phone model is permitted to go on the market for sale, its manufacturer performs Specific Absorption Rate (SAR) tests to evaluate the radiation levels. SAR values are expressed in terms of watts per kilogram (W/kg) and are intended to measure the amount of cell phone radiofrequency radiation absorbed by the body when using a wireless device.

Cell Phone Radiation SAR Limits in the USA

The FCC and Health Canada limit for cell phone radiation exposure to the public from cellular telephones is a SAR level of 1.6 watts per kilogram averaged over 1 gram of tissue. For extremities such as the wrists, ankles, hands, ears, and feet, the allowable SAR limit is much higher and is 4.0 W/kg averaged over 10 grams of tissue.[63]

Image from FCC Presentation[64]



[63] Radio Frequency Safety | Federal Communications Commission. Accessed July 8, 2020.
[64] https://transition.fcc.gov/oet/ea/presentations/files/oct05/RF_Exposure_Concepts_Support_KC.pdf

There also is an occupational SAR limit for cell phones, allowing much higher exposures. The US FCC occupational limit is a SAR level of 8 watts per kilogram averaged over 1 gram of tissue. For extremities such as the wrists, ankles, hands, ears, and feet, the allowable SAR limit is much higher and is 10.0 W/kg averaged over 10 grams of tissue.

According to the FCC[65] the "occupational/controlled exposure limits are applicable to situations in which persons are exposed as a consequence of their employment, who have been made fully aware of the potential for exposure and can exercise control over their exposure."

Thus, the manufacturer's recommended distance for cell phones is a defined number of millimeters. The specific distances for each phone varies and can be found in the cell phone's instruction/user manual. Furthermore, the recommended distance for wireless laptops, Wi-Fi routers, smart security systems, smart speakers and printers is generally 20 centimeters (approximately 8 inches) as stated in the user manual. The FCC states that "mobile devices are transmitters designed to be used in such a way that a separation distance of at least 20 centimeters is normally maintained between the transmitter's radiating structure(s) and the body of the user or nearby persons."

The CTIA has argued that "there is no reliable evidence proving that current testing protocols fail to ensure compliance with RF standards." This is stated in the CTIA submission to the US Federal Communications Commission regarding the FCC Proceeding on Human Exposures to Radiofrequency Radiation. CTIA also stated, "a zero-measuring requirement would not accurately mimic real usage or increase safety."

The French data release refutes these CTIA and FCC statements because they found SAR levels were in violation of limits when phones were tested in body contact positions at highest power levels.

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[65] Chan K. *Overview of RF Exposure Overview of RF Exposure Concepts and Requirements Concepts and Requirements*. http://grouper.ieee.org/groups/scc34/sc2/wg1/appr_memo.html. Accessed July 8, 2020.

Examples of the Manufacturer's Instructions

Here are some examples of the radiofrequency statement for phones as well as other wireless devices people use every day.

Samsung Health and Safety Information	"Body-worn operations are restricted to belt-clips, holsters or similar accessories that have no metallic component in the assembly and must provide at least 1.5cm separation between the device and the user's body."
iPhone 11 Pro Max	"During testing, iPhone radios are set to their highest transmission levels and placed in positions that simulate uses against the head, with no separation, and when worn or carried against the torso of the body, with 5mm separation."
Nokia 8110 4G Phone (2019 Manual)	"This device meets RF exposure guidelines when used against the head or when positioned at least 5/8 inch (1.5 centimetres) away from the body. When a carry case, belt clip or other form of device holder is used for body-worn operation, it should not contain metal and should provide at least the above stated separation distance from the body."
Safety & regulatory information (Pixel & Pixel XL 2016)	"Body worn operation: Pixel complies with radio frequency specifications when used near your ear or at a distance of 0.4 in (1.0 cm) from your body. Pixel XL complies with radio frequency specifications when used near your ear or at a distance of 0.4 in (1.0 cm) from your body. Ensure that the device accessories, such as a device case and device holster, are not composed of metal components. Keep the device away from your body to meet the distance requirement."
Samsung 3G Laptop Manual	"Usage precautions during 3G connection: Keep safe distance from pregnant women's stomach or from lower stomach of teenagers. Body worn operation: Important safety information regarding radiofrequency radiation (RF) exposure. To ensure compliance with RF exposure guidelines the Notebook PC must be used with a minimum of 20.8 cm antenna separation from the body."

Owlcam Manual with RF Instructions	"Caution exposure to radiofrequency radiation, to comply with FCC RF exposure compliance requirements for mobile configurations, a separation distance of at least 20 cm must be maintained between the antenna of this device and all persons."
PlayStation 3	"This equipment complies with FCC/IC radiation exposure limits set forth for uncontrolled equipment and meets the FCC radio frequency (RF) Exposure Guidelines in Supplement C to OET65 and RSS-102 of the IC radio frequency (RF) Exposure rules. This equipment should be installed and operated with at least 20 cm (8 in) and more between the radiator and person's body (excluding extremities: hands, wrists, feet and legs)."
Amazon Echo	"Information Regarding Exposure to Radio Frequency Energy…This device should be installed and operated with a minimum distance of 20cm between the radiator and your body. The remote control meets the RF exposure requirement of low power devices under portable operation. Nevertheless, it is advised to use the Products in such a manner that minimizes the potential for human contact during normal operation."
Panasonic DECT Home Cordless Phone	"FCC RF Exposure Warning: To comply with FCC RF exposure requirements, the base unit must be installed and operated 20 cm (8 inches) or more between the product and all person's body."
HP Printer	"In order to avoid the possibility of exceeding the FCC radio frequency exposure limits, human proximity to the antenna shall not be less than 20 cm (8 inches) during normal operation."
Apple Watch	"During testing, Apple Watch radios are set to their highest transmission levels and placed in positions that simulate use against the head, with 10mm separation, and on the wrist, with no separation. When placing Apple Watch near your face, keep at least 10mm of separation to ensure exposure levels remain at or below the as-tested levels."

Apple iPod Touch	"During testing, iPod radios are set to their highest transmission levels and placed in positions that simulate use near the body, with 5mm separation. To reduce exposure to RF energy, use the supplied headphones or other similar accessories. Carry iPod at least 5mm away from your body to ensure exposure levels remain at or below the as-tested levels."
Nokia 8110 4G Phone (2019 Manual)	"This device meets RF exposure guidelines when used against the head or when positioned at least 5/8 inch (1.5 centimetres) away from the body. When a carry case, belt clip or other form of device holder is used for body-worn operation, it should not contain metal and should provide at least the above stated separation distance from the body."

Apple Has Changed Their Text and No Longer Clearly Instructs Users to Keep the Phone at a Distance But Does Share the Test Distance

In 2015 the Apple iPhone 6 manual had the following statement, "Carry iPhone at least 5mm away from your body to ensure exposure levels remain at or below the as-tested levels." While this sentence was still on their website on March 2, 2017, it was removed by November 9, 2017. Similarly, the iPhone 7 was released in 2016, along with the same online instructions to carry it "5 mm away from your body" which disappeared from the Apple website by November 9, 2017.

Apple's website still includes information that cell phones are tested with a separation distance. However, the text is absent of clear instructions to consumers. Years ago, iPhone 3 filings to the FCC stated "iPhone's SAR measurement may exceed the FCC exposure guidelines for body-worn operation if positioned less than 15 mm (5/8 inch) from the body (e.g. when carrying iPhone in your pocket)." Apple clearly stated, "When using iPhone near your body for voice calls or for wireless data transmission over a cellular network, keep iPhone at least 15 mm (5/8 inch) away from the body."

Investigations Find Cell Phones Violate Cell Phone Regulatory Limits When the Phone is Tested at Body Contact

Chicago Tribune Cell Phone Radiation Tests
Tests paid for by the Tribune and conducted according to federal guidelines at an accredited lab, produced a surprising result: Radiofrequency radiation exposure from the iPhone 7 — one of the most popular smartphones ever sold — measured over the legal safety limit and more than double what Apple reported to federal regulators from its own testing. These tests measured radio frequency radiation SAR levels at 2mm from the body. Chicago Tribune Cell Phone Test Report

During Commission proceedings the CTIA countered that the FCC tested the phones the Chicago Tribune had reported to exceed SAR levels and released a report that found them to not to violate SAR limits. However, if you go to the FCC report on SAR measurements it shows that the FCC used a separation distance (on page 9)[66]. The Chicago Tribune report specifically investigated phones at a distance of 2mm from the body. The FCC Report did not replicate the Chicago Tribune tests at 2mm but instead used the manufacturers separation distances which vary from 5 mm to 15mm.

Canadian Broadcasting Corporation
A 2017 investigation by the Canadian Broadcasting Corporation found radiation levels higher than government standards after they tested popular cell phones in a US FCC certified laboratory.

French ANFR
Professor Om Gandhi, one of the engineers who developed radiofrequency limits years ago, published an analysis of the data from 450 cell phone models from the French government agency, ANFR, the national radiation assessment bureau, indicating that phones can emit 11 times over the US FCC limit and 3 times over European/ICNIRP limits.

3. Why have 1,000s of peer-reviewed studies, including the recently published U.S. Toxicology Program 16-year $30 million study, that are showing a wide range of statistically significant DNA damage, brain and heart tumors,

[66] FCC. *Results of Tests on Cell Phone RF Exposure Compliance*.; 2019. Accessed July 8, 2020.

infertility, and so many other ailments, been ignored by the Federal Communication Commission (FCC)?

There has not been a scientific review of the research by a US agency for more than two decades.

Just recently in December 2019, the FCC determined that there was no need to review the radiofrequency limits. The FCC based this decision largely on a letter by the FDA. In the spring of 2020, the FDA released a research review, but it was not a systematic full evaluation of health effects, but instead only focused on cancer and criticized studies that found effects. FDA has not done experimental research on impacts to humans, birds, bees, trees, and wildlife. The FDA review does not systematically evaluate RF levels and impacts to birds, bees, and trees.

Most importantly, as the FCC states, there are no federally developed safety limits[67] and there is no US health agency developing such safety limits in the US.

There is not a single health/safety/environmental agency investigating, researching or monitoring impacts to birds, bees, trees, and wildlife. In addition, regulatory limits for exposure to radiofrequency radiation have never been developed for birds, bees, trees, and wildlife. This is why the US Department of the Interior sent a letter to the National Telecommunications and Information Administration in 2014[68] reviewing several research studies showing harm to birds and concluding that "the electromagnetic radiation standards used by the Federal Communications Commission (FCC) continue to be based on thermal heating, a criterion now nearly 30 years out of date and inapplicable today."

A now retired US Fish and Wildlife Service wildlife biologist and former lead on telecommunications impacts, Dr. Albert Manville, has written to the FCC on impacts to birds and higher frequencies to be used in 5G and authored numerous publications detailing research showing harm to birds.[69, 70, 71] "Now as a private

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[67] Wireless Devices and Health Concerns | Federal Communications Commission. Accessed July 8, 2020.
[68] Washington DC, Veenendaal ME. Department of Interior Letter. *United States Department of the Interior OFFICE OF THE SECRETARY*.
[69] ECFS Filing Detail. https://www.fcc.gov/ecfs/filing/1060315601199. Accessed July 8, 2020.
[70] Albert M. Manville Ph.D. Former U.S. Fish and Wildlife Service Senior Biologist. "Memorandum on the Bird and Wildlife Impacts of Non-ionizing Radiation." *Environmental Health Trust*. Accessed July 8, 2020.
[71] Manville AM. "Collisions, Electrocutions, and Next Step : Bird Strikes And Electrocutions At Power Lines,

wildlife consultant and part-time adjunct professor for Johns Hopkins University, I also continue to study the impacts of radiation on human health, welfare and safety, including impacts from millimeter-wide radiation frequencies on humans from 5G. The race to implement 5G and the push by FCC to approve the related 5G license frequencies to industry are very troubling and downright dangerous."

He has testified[72] about the impacts of cell towers on birds that "the entire thermal model and all FCC categorical exclusions for all the devices we see today, rests on the incorrect assumption that low-level nonionizing nonthermal radiation cannot cause DNA breaks because it is so low power. The evidence to the contrary is clear and growing laboratory animals and wildlife."

Most recently Manville wrote the FDA regarding the FDA statements of "safety" in regards to cell phone radiation that, "as a certified wildlife biologist and Ph.D. environmental scientist who has studied the impacts of radiation on migratory birds, other wildlife, and humans since the late 1990s, the statement credited to the FDA is preposterous, without any scientific credibility, and at a minimum deserves a retraction by the FDA. There currently are well over 500 scientific, peer-reviewed papers addressing impacts of non-ionizing, non-thermal radiation on laboratory animals — many of the studies directly applicable to human health and safety."[73]

In addition, no "safe" level has been scientifically determined for long term impacts for children or pregnant women. While they are "designed" to address children, the reality is that no such research existed at the time of the limit development that actually considered children's unique vulnerability which includes their developing brain and immune system. The EPA clarified that current FCC limits do not account for long term exposures[74] in 2002 stating, "Federal health and safety agencies have not yet developed policies concerning possible risk from long term, nonthermal exposures." Current FCC human exposure limits "are thermally based, and do not apply to chronic, nonthermal exposure situations" and adequate scientific evaluations of the full impact on sensitive

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Communication Towers, And Wind Turbines: State Of The Art And State Of The Science - Next Steps Toward Mitigation."; 2002.

[72] Manville AM. IPCWB. Declaration of: Albert M. Manville, II, PhD, C.W.B.. Published 2018. Accessed July 8, 2020.

[73] Statement From Dr. Albert Manville On The FDA Report On Cell Phone Radiation. *Environmental Health Trust*. Accessed July 8, 2020.

[74] Washington DC. *United States Environmental Protection Agency*. 2002 http://www.epagov. Accessed July 8, 2020.

populations such as children, pregnant women, and the elderly has yet to be completed.

Background on US FCC Radiofrequency Human Exposure Limits
The FCC is not a health and safety agency and in fact never developed health based federal safety standards as we have with other environmental exposures.

Although there used to be a robust research effort in the United States in the '60s, '70s, and '80s, it was defunded. In fact, the US EPA was tasked to develop proper safety standards and was in process of developing two tiered guidelines on both thermal and biological effects in the mid-nineties. However, funding was cut and in 1996 the EPA was fully defunded from work on electromagnetic radiation. Then the FCC promulgated limits for human exposure to radiofrequency radiation based on the American National Standards Institute (ANSI), the Institute of Electrical and Electronics Engineers, Inc. (IEEE) – ANSI/IEEE C95.1-1992 guidelines and the National Council on Radiation Protection and Measurements (NCRP) NCRP Report 1986. The limits have remained largely unchanged since 1996.

In 2008 the National Academy of Sciences National Research Council Report "The Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices" documented critical research gaps and called for the need to increase understanding of any adverse effects of long term chronic exposure to RF/microwave energy on children and pregnant women.

In 2008 the Congressional hearing "Health Effects of Cell Phone Use" of the US House Oversight and Government Reform Subcommittee on Domestic Policy had testimony from several experts including David Carpenter, Ronald B. Herberman M.D., Robert Hoover, Darrell Issa, and Julius P. Knapp II.[75]

In 2009 a Senate Appropriations Subcommittee held a hearing on the "Health Effects of Cell Phone Use" and had testimony from several experts including John Bucher, Devra L. Davis, Thomas "Tom" Harkin, Dariusz Leszczynski, Olga Naidenko, and Siegal Sadetzki.[76]

[75] 2008 Congressional Hearing: Health Effects of Cell Phone Use
[76] 2009 Hearing link to transcript

A 2012 report by the Government Accountability Office "Exposure and Testing Requirements for Mobile Phones Should Be Reassessed" urged the FCC to "formally reassess and, if appropriate, change its current RF energy (microwave) exposure limit and mobile phone testing requirements related to likely usage configurations, particularly when phones are held against the body" because without such a reassessment, the "FCC cannot ensure it is using a limit that reflects the latest research on RF energy exposure." The report stated that the FCC RF limits adopted in 1996 did not reflect the way people use their phones, particularly when phones are held against and touching the body. The report led the FCC to launch an official inquiry[77] in 2013 to explore whether it should modify its radiofrequency exposure standards. The FCC noted, "we specifically seek comment as to whether our current limits are appropriate as they relate to device use by children." The FCC docket asked these important questions: Are US cell phone and cell tower radiation limits safe for humans? Do children need special protections? Should companies change the way they test the radiation from phones because phones are tested with a separation distance between the phone and the body? The FCC received over a thousand submissions.[78]

In 2019, the FCC issued a report and order[79] that closed the inquiry. It stated, "First, we resolve a Notice of Inquiry that sought public input on, among other issues, whether the Commission should amend its existing RF emission exposure limits. After reviewing the extensive record submitted in response to that inquiry, we find no appropriate basis for and thus decline to propose amendments to our existing limits at this time. We take to heart the findings of the Food & Drug Administration (FDA), an expert agency regarding the health impacts of consumer products, that "the weight of scientific evidence has not linked cell phones with any health problems."

Scientists are calling for the FDA to retract their report that is now used as proof of safety. Due to the fact that the FDA later in 2020 released a report criticizing studies that found harm and provided no research demonstrating safety, several expert scientists wrote to the FDA.

[77] Review of RF Exposure Policies | Federal Communications Commission
[78] ECFS filings results. Accessed July 8, 2020.
[79] FCC. *FCC 19-126*. https://www.fda.gov/Radiation. Accessed July 8, 2020.

“I find it shocking that the FDA would casually dismiss the carcinogenicity findings from the National Toxicology Program (NTP) studies on cell phone radiation in experimental animals, when it was the FDA that requested those studies in the first place ‘to provide the basis to assess the risk to human health,’ and when an expert peer-review panel carefully reviewed the design and conduct of those studies and then concluded that the results provided “clear evidence of carcinogenic activity,” stated Ronald Melnick PhD who led the design of the $30M NTP study. Melnick sent a letter to the FDA documenting the scientific inaccuracies in their review.

“When I worked as a wildlife biologist for the U.S. Fish & Wildlife Service for 17 years, I collaborated with the late Dr. Ted Litovitz in 2000. Dr. Litovitz and his colleagues studied the impacts of low-level, non-thermal radiation from the standard 915 MHz cell phone frequency on chicken embryos. In their laboratory studies, control/non-treated embryos suffered no effects, but some of the treated/irradiated embryos died — at levels as low as 1/10,000 the normal level of cell phone radiation exposure to humans. This was an eye-opener!” stated Albert M. Manville, II, Ph.D.; retired Senior Wildlife Biologist, Division of Migratory Bird Management, U.S. Fish & Wildlife Service, Washington.

“The FDA review omits an evaluation of the science on wireless radiation impacts to trees and wildlife. Electromagnetic radiation is a form of environmental pollution which may hurt wildlife. I have co-published research entitled “Radiofrequency radiation injures trees around mobile phone base stations“ finding harm to trees near base stations (cell antennas) in a long term field monitoring study in two cities, “ stated biologist Alfonso Balmori, BSc who sent a statement to the FDA.

Letters which have been sent to the FDA include:

- Letter calling for a retraction signed by several scientists.
- Ronald Melnick PhD’s letter to the FDA on the National Toxicology Program study
- Albert Manville PhD, retired Senior Wildlife Biologist, Division of Migratory Bird Management, U.S. Fish & Wildlife Service, Wash. DC HQ Office (17 years); Senior Lecturer, Johns Hopkins University

- Prof. Tom Butler of the University College in Cork, Ireland's letter to the FDA
- Igor Belyaev, PhD, Dr. Sc. Head, Department of Radiobiology of the Cancer Research Institute, Biomedical Research Center of the Slovak Academy of Science letter to the FDA
- Paul Heroux PhD, McGill University
- Alfonso Balmori, BSc statement to the FDA
- Additional Statements by Experts

The FCC is considered a Captured Agency with Undue Influence by Telecom
Several experts who provided testimony to the Commission detailing how several FCC Commissioners have industry ties. Several cited the Harvard Press Book "Captured Agency: How the Federal Communications Commission is Dominated by the Industries it Presumably Regulates" by Norm Alster which documents the financial ties between the FCC, Congress and industry and how wireless companies have bought "inordinate access to—and power over—a major US regulatory agency." The investigation puts forward that there is a "revolving door" between industry and regulators, meaning that persons are moving from positions in the wireless industry to positions in government and vice versa. In addition, the book documents the large financial Investment by telecommunications companies into public relations efforts, designing and publishing contradictory science, pushing for minimal regulation, lobbying via "non-profit" associations, and "hyper aggressive legal action and research bullying."

Examples of the revolving door at the Federal Communications Commission include:

- Tom Wheeler: In 2013, President Obama appointed Tom Wheeler to head the FCC. Wheeler, a fundraiser for Obama in the 2008 election, was a lobbyist and head of the Cellular Telecommunications and Internet Association (CTIA). As head of the wireless industry, Wheeler was accused of suppressing science. A 2003 inductee into the Wireless Hall of Fame (yes, there is such a thing), Wheeler laid the groundwork for 5G, pushing through regulations to strip local authority.

- Ajit Pai: In 2017, President Trump appointed Ajit Pai, a former Verizon Lawyer to head the FCC. Pai had already been a member of the commission, having been appointed by President Obama in 2011 — upon the recommendation of Senate Majority Leader Mitch McConnell — to fill a "Republican" seat on the five-member board.
- Brendan Carr: FCC Commissioner Brendan Carr was appointed by President Trump. He too is a former lawyer for Wiley Rein and helped sue the San Francisco over the city's cell phone ordinance. Carr's wife is the staff director for the U.S. House Ways and Means Committee's Oversight Subcommittee.
- Former FCC chairman Julius Genachowski is now a managing director of the U.S. buyout team at Carlyle Group. The team's focus is on acquisitions and growth investments in global technology, media, and telecom, including Internet and mobile.
- Meredith Attwell Baker: Former FCC Commissioner Meredith Attwell Baker is now head of the CTIA - The Wireless Association. She is a former lead lobbyist for Comcast.
- Michael Powell: Former FCC commissioner Michael Powell is now president & CEO of NCTA - The Internet & Television Association.
- Bruce Romano: Former legal chief in the FCC's Office of Engineering and Technology. Bruce Romano is now at the law firm of Wiley Rein, representing the CTIA.
- Thomas M. Johnson, Jr.: Thomas M. Johnson, Jr. is general counsel of the FCC appointed by Ajit Pai and previously worked for the law firm Gibson, Dunn & Crutcher LLP which represented the CTIA - The Wireless Association who sued the City of Berkeley in federal court, seeking to topple the city's recently enacted cell phone right to know ordinance mandating disclosure of possible radiation hazards associated with use of cellphones.

In addition, published research has documented conflicts of interest in the experts that governments refer to.

- The International Journal of Oncology published "World Health Organization, radiofrequency radiation and health – a hard nut to crack

(Review)"[80] in 2017 detailing conflicts of interest with ICNIRP and the WHO EMF Project, both started with industry support.

- The American Journal of Industrial Medicine published "Secret ties to industry and conflicting interests in cancer research"[81] in 2006 about industry funding of studies such as the Danish Cohort cell phone studies that are often put forward as showing no harm.
- Molecular and Clinical Oncology published "Appeals that matter or not on a moratorium on the deployment of the fifth generation, 5G, for microwave radiation"[82] in 2020 details how ICNIRP is referred to as "a private German non-governmental organization. ICNIRP [that] relies on the evaluation only of thermal (heating) effects from RF radiation, thereby excluding a large body of published science demonstrating the detrimental effects caused by non-thermal radiation."

4. Why are the FCC-sanctioned guidelines for public exposure to wireless radiation based only on the thermal effect on the temperature of the skin and do not account for the non-thermal, non-ionizing, biological effects of wireless radiation?

In 1996, just as the EPA was set to release their Phase 1 of safety limits, the EPA's RFR efforts were defunded, halting all EPA research. That year the FCC adopted RFR exposure limits based largely on limits developed by industry/military connected groups (ANSI/IEEE C95.1-1992 and NCRP's 1986 Report).

These FCC limits are only based on protecting against heating (thermal) effects from short-term exposures. They do not account for non-thermal biological effects or the effects of long-term, chronic exposures. Furthermore, adequate scientific data on children's unique vulnerability to RFR was not available at that time. The US still has no federally developed safety limits, and there has been no systematic review of the scientific research to develop safety limits that adequately protect the public from long-term exposures.

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[80] Hardell L. "World health organization, radiofrequency radiation and health - A hard nut to crack (Review)." *Int J Oncol*. 2017;51(2):405-413. doi:10.3892/ijo.2017.4046

[81] Hardell L, Walker MJ, Walhjalt B, Friedman LS, Richter ED. "Secret Ties to Industry and Conflicting Interests in Cancer Research." *Am J Ind Med*. 2006. doi:10.1002/ajim.20357

[82] Hardell L, Nyberg R. "Appeals that matter or not on a moratorium on the deployment of the fifth generation, 5G, for microwave radiation." *Mol Clin Oncol*. 2020;12(3):247-257. doi:10.3892/mco.2020.1984

Due to the lack of evaluation for long term safety and research that linked neurological impacts in firefighters to cell antenna exposure, the International Association of Fire Fighters has long opposed[83] cell antennas on fire stations stating that, "fire department facilities, where fire fighters and emergency response personnel live and work are not the proper place for a technology which could endanger their health and safety. The only reasonable and responsible course is to conduct a study of the highest scientific merit and integrity on the RF/MW radiation health effects to our membership and, in the interim, oppose the use of fire stations as base stations for towers and/or antennas for the conduction of cell phone transmissions until it is proven that such sitings are not hazardous to the health of our members." The International Association of Fire Fighters passed a resolution[84] that they oppose cell towers on fire stations in 2004 and it remains in effect today.

5. Why are the FCC radiofrequency exposure limits set for the United States 100 times higher than countries like Russia, China, Italy, Switzerland, and most of Eastern Europe?

The following countries have cell tower network radiofrequency radiation limits (maximum permissible limits) below ICNIRP and FCC limits: Belarus, Bulgaria, China, Lithuania, Poland, Russia, Belgium, Chile, Greece, India, Israel, Italy, Liechtenstein and Switzerland.[85] [86] [87] [88] [89]

The exposure guidelines developed by the FCC and International Commission on Non-Ionizing Radiation Protection (ICNIRP) were principally designed to protect against adverse thermal effects and were largely based on studies of short-term exposures to animals at high power levels. However, countries such as India,

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[83] Cell Tower Radiation Health Effects - IAFF. https://www.iaff.org/cell-tower-radiation/. Accessed July 8, 2020.

[84] https://ecfsapi.fcc.gov/file/109281319517547/20-Attachment%2020-%20Firefighters%20Inter%20Resolution%20Against%20Cell%20Towers.pdf

[85] https://apps.who.int/gho/data/node.main.EMFLIMITSPUBLICRADIOFREQUENCY?lang=en

[86] Wu T, Rappaport TS, Collins CM. "Safe for Generations to Come." *IEEE Microw Mag*. 2015;16(2):65-84. doi:10.1109/MMM.2014.2377587

[87] Chiang, Huai. "Rationale for Setting EMF Exposure Standards." Zhejiang University School of Medicine, Microwave Lab, China, as referenced by Wu 2015

[88] "Comparison of international policies on electromagnetic fields (power frequency and radiofrequency fields)." Rianne Stam, National Institute for Public Health and the Environment

[89] Mary Redmayne (2016). "International policy and advisory response regarding children's exposure to radio frequency electromagnetic fields (RF-EMF)." *Electromagnetic Biology and Medicine*, 35:2, 176-185, DOI: 10.3109/15368378.2015.1038832

China and Russia have much lower limits and are considered "science based." [90] They are well below any thermally significant levels to address their own countries research indicating adverse non-thermal health effects.

- USSR and Russian standards were based on many areas of research including impacts to the nervous system and immune system as documented in the "Scientific basis for the Soviet and Russian radiofrequency standards for the general public." Their exposure limits are set based on protecting against possible biological consequences which is different than limits by the FCC and ICNIRP, which bases their limits on the lowest RF exposure that causes any "established" adverse health effect. Russia limits consider children to be more sensitive to EMFs and in need of "special consideration when developing exposure limits." According to the ICNIRP, the following health hazards are likely to be faced in the near future by children who use mobile phones: disruption of memory, decline in attention, diminished learning and cognitive abilities, increased irritability, sleep problems, increase in sensitivity to stress, and increased epileptic readiness. For these reasons, special recommendations on child safety from mobile phones have been incorporated into the current Russian mobile phone standard.[91]
- China's cell tower limits are based on science showing effects which include behavioral, neurological, reproductive abnormalities, and DNA damage.[92]
- India dropped their RF limits by 1/10th of ICNIRP after a 2010 Government Report documented the majority of research studies found adverse effects to wildlife, birds and bees.[93] An August 2012 Advisory by the Ministry of the Environment and Forests refers to the "negative effects" and makes a series of recommendations to the government.[94] The findings of the report were later published in the journal Biology and Medicine which concludes that, "based on current available literature, it is justified to conclude that RF-EMF radiation exposure can change neurotransmitter functions, blood-brain barrier, morphology, electrophysiology, cellular metabolism, calcium

[90] Wu T, Rappaport TS, Collins CM. "Safe for Generations to Come." *IEEE Microw Mag*. 2015;16(2):65-84. doi:10.1109/MMM.2014.2377587
[91] "Scientific basis for the Soviet and Russian radiofrequency standards for the general public."
[92] Prof. Dr. Huai Chiang. "Rationale for Setting EMF Exposure Standards." Accessed July 8, 2020.
[93] "Report on Possible Impacts of Communication Towers on Wildlife Including Birds and Bees." Ministry of Environment and Forest, Government of India, 2010.
[94] Government of India Ministry of Environment and Forests Office. "Advisory on the use of Mobile Towers to minimize their impact on Wildlife including Birds and Bees." 2012

efflux, and gene and protein expression in certain types of cells even at lower intensities”.[95]

Many European countries have RF limits much lower than ICNIRP as part of their precautionary approach to decision-making. In 2011 the Parliamentary Assembly of the Council of Europe issued Resolution 1815: “The Potential Dangers of Electromagnetic Fields and Their Effect on the Environment”,[96] a call to European governments to “take all reasonable measures” to reduce exposure to electromagnetic fields “particularly the exposure to children and young people who seem to be most at risk from head tumors.” The Resolution calls for member states to:

- Implement “information campaigns about the risk of biological effects on the environment and human health, especially targeting children and young people of reproductive age.”
- “For children in general, and particularly in schools and classrooms, give preference to wired Internet connections, and strictly regulate the use of mobile phones by schoolchildren on school premises.”

Resolution 1815 specifically states that governments “Reconsider the scientific basis for the present standards on exposure to electromagnetic fields set by the International Commission on Non-Ionizing Radiation Protection, which have serious limitations, and apply ALARA principles, covering both thermal effects and the athermic or biological effects of electromagnetic emissions or radiation.”

6. Why did the World Health Organization (WHO) signify that wireless radiation is a Group B Possibly Carcinogenic to Humans category, a group that includes lead, thalidomide, and others, and why are some experts who sat on the WHO committee in 2011 now calling for it to be placed in the Group 1, which are known carcinogens, and why is such information being ignored by the FCC?

In 2011 wireless radiofrequency radiation was classified as a “Possible Human Carcinogen” by the International Agency for Research on Cancer (IARC) of the WHO based on research that found an increased risk for glioma, a malignant type

[95] Sivani S, Sudarsanam D. “Impacts of Radio-Frequency Electromagnetic Field (RF-EMF) from Cell Phone Towers and Wireless Devices on Biosystem and Ecosystem - a Review.” *Biology and Medicine* Vol 4.; 2012. www.biolmedonline.com. Accessed July 8, 2020.
[96] Resolution 1815: *“The Potential Dangers of Electromagnetic Fields and Their Effect on the Environment.”*

of brain cancer, associated with wireless phone use.[97] The WHO/IARC Class 2B classification includes wireless radiation from any transmitting source including cellphones, baby monitors, tablets, cell towers, radar, other Wi-Fi, etc. The classification applies to RF-EMF in the range of 30 KHz to 300 GHz emitted from any equipment- not just cell phones. This fact is detailed in the Lancet's published statement and in the related press release in 2011.

Precautions for cell phones were recommended by then IARC Director Christopher Wild in the WHO/IARC press release for the Class 2B Carcinogen classification with quotes from Wild as stating, "Given the potential consequences for public health of this classification and findings, it is important that additional research be conducted into the long-term, heavy use of mobile phones. Pending the availability of such information, it is important to take pragmatic measures to reduce exposure such as hands-free devices or texting."

After the 2011 classification, the WHO/IARC issued a monograph documenting all the research underpinning the 2011 classification.[98]

The 2013 published monograph also references children's higher exposures as compared to adults and states, "the average exposure from use of the same mobile phone is higher by a factor of 2 in a child's brain and higher by a factor of 10 in the bone marrow of the skull."

The reason that scientists are calling for a change to the classification is that since the 2011 classification, the evidence for adverse effects in the published research has increased. Cancer is only one of the issues that have been investigated. Here are some of the studies often mentioned by scientists:

- The National Toxicology Program studies on cell phone radiation in animals found clear evidence of carcinogenic activity, in male rats and DNA damage in the frontal cortex of the brain in male mice, the blood cells of female mice, and the hippocampus of male rats.
- The multicenter case-control study Coureau et al. 2014 found statistically significant positive association between brain tumors and cell phone use in the heaviest cell phone users when considering life-long cumulative duration.

[97] IARC classifies Radiofrequency Electromagnetic Fields as possibly carcinogenic to humans

[98] Monograph on Non-Ionizing Radiation, Part 2: Radiofrequency Electromagnetic Fields.

- An animal study Lerchl 2015 replicated a previous study that found at very low levels, radiofrequency can promote tumors.
- Falcioni et al. 2018 found a statistically significant increase in the incidence of heart Schwannomas in male rats exposed to radiofrequency radiation at levels below FCC limits.
- Yale research funded by the American Cancer Society[99] found thyroid cancer associated with cell phone use in people with genetic susceptibility.
- Additional Yale research[100] found prenatal radiofrequency radiation exposure led to higher hyperactivity, poorer memory, and altered brain function in mice,[101] corroborating prior published research findings of altered brain development after exposure.
- A 2018 study[102] looking at hundreds of adolescents found memory damage in the brain receiving some of the higher radiofrequency cell phone radiation exposures.
- A 2015 review study[103] found among 93 of 100 currently available peer-reviewed studies dealing with oxidative effects of low-intensity RFR, confirmation that RFR induces oxidative effects in biological systems.

The evaluation by some scientists that wireless is carcinogenic due to this increased body of published research can be found in Hardell and Carlberg 2017 and Miller et al. 2018.

Several scientists who were members of the WHO IARC 2011 monograph classification have publicly stated that the evidence on the carcinogenicity of RF has increased and that the classification of "possible carcinogen" is outdated and should be upgraded based on increased evidence of adverse effects.

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[99] Jiajun Luo et al. "Genetic susceptibility may modify the association between cell phone use and thyroid cancer: A population-based case-control study in Connecticut." *Environmental Research* (2019).
[100] Aldad, T., Gan, G., Gao, X., & Taylor, H. (2012). "Fetal Radiofrequency Radiation Exposure From 800-1900 Mhz-Rated Cellular Telephones Affects Neurodevelopment and Behavior in Mice." *Scientific Reports*, *2*(1). https://doi.org/10.1038/srep00312
[101] Cell phone use in pregnancy may cause behavioral disorders in offspring
[102] Foerster, M., Thielens, A., Joseph, W., Eeftens, M., & Röösli, M. (2018). "A Prospective Cohort Study of Adolescents' Memory Performance and Individual Brain Dose of Microwave Radiation from Wireless Communication." *Environmental Health Perspectives*, *126*(7), 077007. https://doi.org/10.1289/ehp2427
[103] Yakymenko, I., Tsybulin, O., Sidorik, E., Henshel, D., Kyrylenko, O., & Kyrylenko, S. (2015). "Oxidative mechanisms of biological activity of low-intensity radiofrequency radiation." *Electromagnetic Biology and Medicine*, *35*(2), 186-202.

- Dr. Lennart Hardell in Case-control study of the association between malignant brain tumours diagnosed between 2007 and 2009 and mobile and cordless phone use: “This study confirmed previous results of an association between mobile and cordless phone use and malignant brain tumours. These findings provide support for the hypothesis that RF-EMFs play a role both in the initiation and promotion stages of carcinogenesis.”
- Dr. Chris Portier: “A careful review of the scientific literature demonstrates there are potentially dangerous effects from RF,“ stated Portier, a recently retired CDC Director, Center for Environmental Health and the Agency for Toxic Substances and Disease Registry in his official call for invoking the precautionary principle with wireless radiation in a 2015 conference. See also a poster presentation he penned for the conference here.
- Dr. Igor Belyaev: “There are many publications showing health effects of radiofrequency radiations. Approximately half of all published papers show such effects.” (National Press Club, 2012. He has published findings of adverse effects in several publications.)
- Dariusz Leszczynski, WHO IARC expert, former Finnish government researcher stated in 2015 “The IARC-WHO classification of cell phone radiation is misrepresented by the industry. Classification of cell phone radiation as ‘a possible carcinogen to humans’ means that there are enough studies indicating that it might cause cancer and that we urgently need more research to clarify this issue. The strongest evidence that it might be causing cancer comes from three epidemiological studies. In 2011, only two sets of studies were available – EU’s Interphone study and a series of studies from Lennart Hardell’s group in Sweden. Recently, CERENAT study from France published in 2014, similarly indicated that persons using cell phones for more than ten years and for half hour per day are at a higher risk for developing brain cancer. In fact now the evidence is sufficient to consider cell phone radiation as a probable carcinogen – Group 2A in IARC’s scale of carcinogenicity.”
- Ronald Melnick, retired NTP staff scientist has written extensively on this topic and states in Health Physics 2020, “The NTP studies show that the assumption that RF radiation is incapable of causing cancer or other adverse health effects other than by tissue heating is wrong.”

- Anthony B. Miller, who served as an editorial reviewer of the IARC monograph, has also written that if an IARC panel were to review the science at this point they would conclude that it should be reclassified as category 1, a human carcinogen.

In 2019, an advisory group of the International Agency for Research on Cancer (IARC) of the World Health Organization, consisting of 29 scientists from 18 countries, released new recommendations to reassess as a “high priority” the cancer risks of radiofrequency radiation between 2020–2024. The recommendations were published in The Lancet Oncology on April 18, 2019.

7. Why have more than 220 of the world’s leading scientists signed an appeal to the WHO and the United Nations to protect public health from wireless radiation and nothing has been done?

Over 393 scientists and doctors from 35 countries have signed on to a declaration called the 5G Appeal,[104] sent to officials of the European Commission, calling for a moratorium on the increase of cell antennas for planned 5G expansion because “5G will substantially increase exposure to radiofrequency electromagnetic fields (RF-EMF) on top of the 2G, 3G, 4G, Wi-Fi, etc. for telecommunications already in place. RF-EMF has been proven to be harmful for humans and the environment.”

In addition, the 5G Appeal references the 2015 Scientistic Appeal to the United Nations published in the European Journal of Oncology[105] now signed by 253 scientists who have published research on electromagnetic radiation which states that, “numerous recent scientific publications have shown that EMF affects living organisms at levels well below most international and national guidelines. Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plant and animal life.”

[104] The 5G appeal – 5G Appeal 5G Appeal. Accessed July 8, 2020.
[105] EMFscientist.org - International EMF Scientist Appeal. Accessed July 8, 2020.

Why has nothing been done?
The Scientific Appeal states that "the various agencies setting safety standards have failed to impose sufficient guidelines to protect the general public, particularly children who are more vulnerable to the effects of EMF." The International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines do not cover long-term exposure and low-intensity effects, yet they are used by many governments as safety limits. The EMF scientists contend that the ICNIRP guidelines are insufficient to protect public health.

Dr. Lennart Hardell published a paper entitled, "Appeals that matter or not on a moratorium on the deployment of the fifth generation, 5G, for microwave radiation" explaining how ICNIRP is a private German non-governmental organization of 13 people that "relies on the evaluation only of thermal (heating) effects from RF radiation, thereby excluding a large body of published science demonstrating the detrimental effects caused by non-thermal radiation." He contends that ICNIRP has disregarded research and that their safety guidelines are obsolete and protect the industry, not health. Hardell describes the communications between decision makers and the scientists and concludes that "the majority of decision makers are scientifically uninformed on health risks from RF radiation." In addition, they seem to be uninterested in being informed by scientists representing the majority of the scientific community, i.e., those scientists who are concerned about the increasing evidence or even proof of harmful health effects below the ICNIRP guidelines (www.emfscientist.org). Instead, they rely on evaluations with inborn errors of conflicts, such as ICNIRP.

8. Why have the cumulative biological damaging effects of ever-growing numbers of pulse signals riding on the back of the electromagnetic sine waves not been explored, especially as the world embraces the Internet of Things, meaning all devices being connected by electromagnetic waves, and the exploration of the number of such pulse signals that will be created by implementation of 5G technology?

There are extensive data gaps regarding human exposure to wireless devices and the complexity of the waves we are exposed to. Most studies have not adequately explored all of these characteristics but instead only focus on power density.

“Adverse Health Effects of 5G Mobile Networking Technology Under Real Life Conditions”[106] published in Toxicology Letters states “the typical incoming EMF signal for many/most laboratory tests performed in the past consisted of single carrier wave frequency; the lower frequency superimposed signal containing the information was not always included. This omission may be important. As Panagopoulos states: “It is important to note that except for the RF/microwave carrier frequency, Extremely Low Frequencies - ELFs (0–3000 Hz) are always present in all telecommunication EMFs in the form of pulsing and modulation. There is significant evidence indicating that the effects of telecommunication EMFs on living organisms are mainly due to the included ELFs…. While ∼50 % of the studies employing simulated exposures do not find any effects, studies employing real-life exposures from commercially available devices display an almost 100% consistency in showing adverse effects” (Panagopoulos, 2019). These effects may be exacerbated further with 5 G: “with every new generation of telecommunication devices…..the amount of information transmitted each moment…..is increased, resulting in higher variability and complexity of the signals with the living cells/ organisms even more unable to adapt” (Panagopoulos, 2019).”

This is an area that requires adequate research before deployment.

[106] Kostoff RN, Heroux P, Aschner M, Tsatsakis A. “Adverse health effects of 5G mobile networking technology under real-life conditions.” *Toxicol Lett*. 2020;323:35-40. doi:10.1016/j.toxlet.2020.01.020

Appendix D

Sampling of Scientific Studies Pertaining to Cellphone Radiation

CANCER

2018 U.S. National Toxicology Program (NTP) & Italian Study Confirm Cell Phones Cause Cancer

- See the NTP website which indicates radiofrequency radiation is associated with "Clear evidence of tumors" -- the highest warning they can issue: https://ntp.niehs.nih.gov/whatwestudy/topics/cellphones/index.html?utm_source=direct&utm_medium=prod&utm_campaign=ntpgolinks&utm_term=cellphone
- In the following article, study designer and former NTP Senior Scientist Ronald L. Melnick, PhD., counters with facts the industry spin intended to downplay the NTP study findings:

  https://www.sciencedirect.com/science/article/pii/S0013935118304973?via=ihub
- In January 2020 the National Institutes of Environmental Health (NIEHS) published the following article from NTP scientist Michael Wyde, Ph.D., confirming brain, heart and adrenal tumors and that more research is underway to understand the impact of adding 5G millimeter waves to the existing exposures from 2G, 3G and 4G radiation: https://factor.niehs.nih.gov/2020/1/community-impact/5g-technology/index.htm
- See study findings by the Ramazzini Intstitute study in Italy, which corroborates the NTP study findings: https://www.sciencedirect.com/science/article/pii/S0013935118300367?via%3Dihub
- Longtime World Health Organization advisor Anthony B. Miller, M.D., and other experts, confirm radiofrequency (RF) radiation from any source now fully meets the World Health Organization criteria to be classified as a "Group 1 carcinogenic to humans" agent: https://www.sciencedirect.com/science/article/pii/S0013935118303475?via%3Dihub

- BioMed Research International published a peer-reviewed study by Michael Carlberg, MSc, and Lennart Hardell, M.D., Ph.D. concluding "RF radiation should be regarded as a human carcinogen causing glioma." https://www.hindawi.com/journals/bmri/2017/9218486/
- In 2018 IEEE Microwave Magazine published, "Clear Evidence of Cell Phone RF Radiation Cancer Risk" by Dr. James Lin: https://ieeexplore.ieee.org/document/8425056/?part=1

  Dr. Lin's article is also available in full here: http://www.avaate.org/IMG/pdf/lin_2018.pdf

INFERTILITY

- Dr. Martin Pall's 2018 paper, "5G: Great risk for EU, U.S. and International Health! Compelling Evidence for Eight Distinct Types of Great Harm Caused by Electromagnetic Field (EMF) Exposures and the Mechanism that Causes Them" indicates much of the damage from wireless radiation is cumulative and some becomes irreversible.

  His paper includes 16 scientific reviews (each referencing multiple individual peer-reviewed published studies) which include a wide variety of changes leading to lowered male fertility, lowered female fertility, increased spontaneous abortion, lowered levels of estrogen, progesterone and testosterone, and lowered libido.

  The European Academy of Environmental Medicine provides Dr. Pall's paper here: https://europaem.eu/attachments/article/131/2018-04_EU-EMF2018-5US.pdf
- See the 2018 paper, "Radiations and male fertility": https://rbej.biomedcentral.com/articles/10.1186/s12958-018-0431-1
- See also abstracts for eight review papers and links to 40+ studies as collected by Dr. Joel Moskowitz: https://www.saferemr.com/2015/09/effect-of-mobile-phones-on-sperm.html

- These studies address male fertility issues and wi-fi:
  http://www.ncbi.nlm.nih.gov/pubmed/22112647
  http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3778601/
  https://www.ncbi.nlm.nih.gov/pubmed/28967061
- A 2017 study, "Temporal trends in sperm count: a systematic review and meta-regression analysis" shows sperm counts dropping dramatically**:** https://academic.oup.com/humupd/article/doi/10.1093/humupd/dmx022/4035689/Temporal-trends-in-sperm-count-a-systematic-review
- Kaiser Permanente scientists completed a study that concluded non-ionizing radiation more than doubles the risk of miscarriage: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5727515/
- The EPA provides an understanding of how DNA mutations from radiation affect what we pass on to our offspring genetically: http://www.epa.gov/radiation/understand/health_effects.html
- The following link provides an audio track from a 2013 conference led by leading U.S. experts in, "Cell Phones & WiFi – Are Children, Fetuses and Fertility at Risk?" http://electromagnetichealth.org/electromagnetic-health-blog/summary-and-audio/
- Barrie Trower, PhD, "WiFi Report – Humanity At The Brink," September 2013, shows how wi-fi exposure now will affect fertility in the future: http://www.geoengineeringwatch.org/barrie-trower-wifi-report-humanity-at-the-brink/
- A quick search of the National Institutes for Health (NIH) PubMed database on "emf fertility" returns a multitude of other studies from around the world: http://www.ncbi.nlm.nih.gov/m/pubmed/?term=emf+fertility

ELECTROMAGNETIC SENSITIVITY

While adverse effects of long-term exposure to wi-fi radiation, like cancer, infertility and DNA damage may not surface in some for years, there are many who suffer immediate effects when exposed to wireless radiation. Health care providers are now learning to diagnose and treat environmentally induced electromagnetic sensitivity, or ES, also known as microwave sickness. Training for doctors, nurses, first responders and others will be proved in the continuing medical education (CME) accredited EMF Medical Conference 2021, https://emfconference2021.com/.

Those who suffer from ES can feel the radiation hitting various biological systems when they encounter cell towers, small cell antennas, routers, access points, cordless phones, smart meters, laptops, iPads, tablets, baby monitors, fluorescent lights or any other devices pulsing signal. Patients experience a myriad of immediate or latent symptoms that may include pain, tightening in the chest or skull, altered heartbeat, tinnitus or ringing in the ears, headaches, nosebleeds, insomnia, fatigue, diminished concentration, cognitive impairment, poor memory, behavioral issues, anxiety, depression, anger, suicidal ideation and more. Symptoms can disappear or diminish over time when exposure to electromagnetic fields (EMFs) is eliminated.

Following is a sampling of the science and actions being taken by the medical community, followed by recognition of ES by the Americans with Disabilities Act:

- Dominique Belpomme and Philippe Irigaray: "Electrohypersensitivity as a Newly Identified and Characterized Neurologic Pathological Disorder: How to Diagnose, Treat, and Prevent It," *Int J Mol Sci*. 2020 Mar; 21(6): 1915.
- "Electromagnetic Field Sensitivity," *Journal of Bioelectricity*: Vol 10, No 1-2.
- Replication of heart rate variability provocation study
- McCarty DE *et al*, (December 2011) "Electromagnetic hypersensitivity: evidence for a novel neurological syndrome," *Int J Neurosci.* 2011 Dec;121(12):670-6. Epub 2011 Sep 5 [View Author's abstract conclusions] [View on Pubmed]
- Nishimura T *et al*, (March 2011) "A 1-uT extremely low-frequency electromagnetic field vs. sham control for mild-to-moderate hypertension:

a double-blind, randomized study," *Hypertens Res.* 2011 Mar;34(3):372-7. Epub 2011 Jan 20 [View Author's abstract conclusions] [View on Pubmed]

- See other EHS papers at Physicians for Safe Technology: https://mdsafetech.org/science/es-science/
- The United States Access Board's IEQ Indoor Environmental Quality Project indicates electromagnetic sensitivities may be considered disabilities under the ADA: https://www.access-board.gov/research/completed-research/indoor-environmental-quality/introduction
- The Access Board recommends the following accommodations: https://www.access-board.gov/research/completed-research/indoor-environmental-quality/recommendations-for-accommodations
- Job Accommodation Network (JAN) is one of several services provided by the U.S. Department of Labor's Office of Disability Employment Policy (ODEP). JAN offers the following Accommodation Ideas for Electromagnetic Sensitivity: http://askjan.org/soar/other/electrical.html

VULNERABILITY OF CHILDREN

- Bioelectromagnetics expert Dr. Om Ghandi published in IEEE Access, "Yes the Children Are More Exposed to Radiofrequency Energy From Mobile Telephones Than Adults": http://ieeexplore.ieee.org/document/7131429/?reload=true&arnumber=7131429&contentType=Journals%20%26%20Magazines
- Pall, M. L. (2016). "Microwave frequency electromagnetic fields (EMFs) produce widespread neuropsychiatric effects including depression." *Journal of Chemical Neuroanatomy*, 75(Pt B), 43–51. https://doi.org/10.1016/j.jchemneu.2015.08.001
- Warnke, U., & Hensinger, P. (2013). "Increasing incidence of burnout due to magnetic and electromagnetic fields of cell phone networks and other wireless communication technologies." (Original: Steigende „Burn-out"-Inzidenz durch technisch erzeugte magnesche und elektromagnesche Felder des Mobil- und Kommunikaonsfunks, Umwelt·medizin·gesellschaft, 26(1), 31-38. http://avaate.org/IMG/pdf/warnke_hensinger_umg_1_2013_engl_df.pdf

- Martha Herbert, PhD, MD, a leading neuroscientist and autism expert, "Findings in Autism (ASD) Consistent with Electromagnetic Fields (EMF) and Radiofrequency Radiation (RFR)": https://bioinitiative.org/wp-content/uploads/pdfs/sec20_2012_Findings_in_Autism.pdf
- Dr. Toril Jelter, pediatrician and general practitioner, discusses EMF, Autism and Child Behavior in an 8-minute video. She prescribes a two-week trial with limited wi-fi exposure and patients often have remarkable results in just a few days: https://www.youtube.com/watch?v=O3iRrVQPDBk
- Hugh Taylor, MD, Yale University discusses ADHD symptoms seen in mice exposed to cell phone radiation: http://vimeo.com/73806192
- Studies have found adverse effects on offspring from prenatal exposure to wireless radiation: http://www.saferemr.com/2014/06/joint-statement-on-pregnancy-and.html
- Dr. Toril Jelter, pediatrician and general practitioner, discusses EMF, Autism and Child Behavior in an 8-minute video. She prescribes a two-week trial with limited wi-fi exposure and patients often have remarkable results in just a few days: https://www.youtube.com/watch?v=O3iRrVQPDBk
- Barrie Trower, a former physicist with the British Royal Navy and expert in radiation, explains in the following two-part lecture the dangers of using wi-fi radiation. He is particularly concerned for the welfare of children and fetuses:
  http://www.youtube.com/watch?v=5xgJmeQaQmc
  http://www.youtube.com/watch?v=UhcuSEHVOSM
- The American Academy of Environmental Medicine has issued an *Open Letter to the Superintendents* imploring them to protect our children.
- The American Academy of Pediatrics (AAP), representing 60,000 pediatricians, in December 2012 urged Congress to protect children from the dangers of wi-fi. "It is essential that any new standards for cell phones or other wireless devices be based on protecting the youngest and most vulnerable populations to ensure they are safeguarded through their

lifetimes." The full letter is published here: http://www.electrosmogprevention.org/cell-phone-safety-campaign/american-academy-of-pediatrics-supports-rf-protection/

In addition to the biological effects of radiation on children, science is showing excessive screen time is causing addiction, impairing our children's ability to function and is degrading family and social relationships. Here is a sampling of books that bring forth the science and safe technology solutions:

- Dr. Nicholas Kardaras, addiction expert, has clinically worked with more than a thousand teens. He published the book *Glow Kids* which shows how screen addiction is hijacking our kids and offers strategies to break the trance.
- Dr. Catherine Steiner-Adair offers *The Big Disconnect*, which takes one through technology's impact at each stage of child development. Basically, the left side of the brain where math and science are housed is still developing on point. The right side, however, is not in many children. This is where a child's ability to show empathy, employ coping strategies, make eye contact, and self-sooth are housed. In humans, we need regular human contact and deep meaningful interactions with loved ones and teachers to develop these properly. Children also need unstructured time for imaginative play to develop deep parts of our brains. Although well-intended parents think providing their children with technology will give them a leg up, the research is proving otherwise as we begin to see scores dropping after upping technology time, and behavioral and mental health issues are escalating.
- In *Reset Your Child's Brain*, Dr. Victoria Dunkley explains the myriad ways in which children can be harmed by electronic screen syndrome (ESS). Biologically, electronic screen exposure can cause a chronic fight or flight response, and hit the same opiate receptors in the brain as drugs and alcohol causing addiction. Children with attention issues and those with autism are at higher risk of addiction. If not given appropriate time to rest and regenerate, children begin to suffer chronically. Common symptoms are irritability, depression and mood swings. As ESS progresses, mood disregulation may combine with aggression causing some to be diagnosed with bi-polar disease. Others may develop obsessive-compulsive behavior, nightmares, panic attacks, tics, seizures, etc., as the effects take hold on the brain. Dr. Dunkley demonstrates how freedom from electronic screens can

change the brain and alleviate or significantly reduce many of these symptoms. She offers a four-week plan to reverse the effects of ESS. See also her article in Psychology Today.

- Paula Healy steps us through the psychological and neurological impact of screentime in this 37 minute talk, *How our Digital Obsession is Dumbing us Down*: https://www.youtube.com/watch?v=OM_lFijB9rA&feature=youtu.be
- Dr. Marilyn Wedge explains how screens are impairing development in *"Virtual Autism" May Explain Explosive Rise in ASD Diagnoses*:
- https://www.madinamerica.com/2017/08/virtual-autism-explain-rising-asd-diagnoses/?fbclid=IwAR0K7A5j36mbGDKdNdafUBPG0TNdHcC9hj4Id_tKJZx6GSf_pcZExVIgJZs

Additionally, Silicon Valley executives limit their own children's access to technology while promoting it to others' children:

- Apple's Steve Jobs and other technology executives limited their own children's technology exposure: *http://www.nytimes.com/2014/09/11/fashion/steve-jobs-apple-was-a-low-tech-parent.html?smid=fb-share&_r=1*
- The Digital Gap Between Rich and Poor Kids Is Not What We Expected: America's public schools are still promoting devices with screens — even offering digital-only preschools. The rich are banning screens from class altogether. https://www.nytimes.com/2018/10/26/style/digital-divide-screens-schools.html?action=click&module=RelatedLinks&pgtype=Article
- A Dark Consensus About Screens and Kids Begins to Emerge in Silicon Valley: "I am convinced the devil lives in our phones." https://www.nytimes.com/2018/10/26/style/phones-children-silicon-valley.html?action=click&contentCollection=undefined&contentPlacement=4&module=stream_unit&pgtype=collection&region=stream&rref=collection%2Fbyline%2Fnellie-bowles&version=latest
- Silicon Valley Nannies Are Phone Police for Kids: Child care contracts now demand that nannies hide phones, tablets, computers and TVs from their charges. https://www.nytimes.com/2018/10/26/style/silicon-valley-nannies.html

Appendix E

Challenges to the Radiation Exposure Standards
Set by U.S. Regulatory Agencies

Organizations Recommending Reducing Wireless Radiation Thresholds

5G Appeal to the European Union by Hundreds of Scientists

American Academy of Pediatrics – Letters Calling for Updating Radiation Standards

US Doctors and Experts National 5G Resolution

EMF Scientist Appeal

International Society of Doctors for Environment – Appeal for a 5G Standstill

The EMF Call – Protective Limits for Exposure to Electromagnetic Fields

Vienna Medical Association

Scientists Join Canadian Doctor Appeal on 5G

Ontario Doctors Appeal and former Microsoft Canada President

The European Scientific Committee on Health, Environmental and Emerging Risks

Worcester School's Standing Committee consulted with the Massachusetts Department of Epidemiology – Best Practices, Minimizing Exposure to RF

ANSES, France's National Agency for Food, Environmental and Occupational Health Safety – Recommends Moderate Use of Wireless Communication Technologies by Children

ANSES, France's National Agency for Food, Environmental and Occupational Health Safety – Recommends Limiting The Population's Exposure to RF

World Health Organization's International Agency for Research.

New Jersey Education Association – Minimize Health Risks from Electronic Devices

Environment and Human Health, Inc. – Technology, Exposures, Health Effects

Irish Doctors Environmental Association

Bioinitiative Working Group – 2012 Report on Biologically Based Exposure Standards

International Appeal to Stop 5G on Earth and in Space, Scientists (4,503), Engineers (8,036), Medical Doctors (2,593), Nurses (4,177),Psychologists, Psychotherapists and Social Workers(9,663)

German Environmental Organisation "Bund" – Petition to Stop 5G in Hamburg

German Doctors Delegation – Open Letter to Prime Minister Kretschmann

Hippocrates Electrosmog Appeal of Belgium – Over 550 Health Professional Signatures

Pancyprian Medical Association & Cyprus National Committee on the Environment and Child Health – Public Health Dangers from the 5G Network

California Department of Public Health – Reduce Exposure to Radiofrequency From Cell Phones

The BabySafe Project – Health Professionals Warn of Dangers of Wireless Radiation on Pregnancy

Turin Medical Association of Italy – Changes in the Law on Electromagnetic Radiation Needed

Department of Pediatrics at Hadassah Hebrew University Hospital – Statement by Dr. Eitan Kerem

The American Academy of Environmental Medicine – Recommendations, Letter to the FCC

Association for Consumer Protection in Romania

Cleveland Clinic

Swiss Physicians Association of Doctors for Environmental Protection – Apply The Precautionary Principle for Wireless Devices

Swiss Physicians Association of Doctors for Environmental Protection – Preliminary Draft for a Federal Law Protecting Against the Dangers of Non-Ionizing Radiation

African Cancer Organization – Advisory to Keep Children From Mobile Phones

The Cyprus National Committee on Environment and Child Health – Recommendations to Reduce Exposure to Children

Austrian Medical Association – Nicosia Declaration on Health Impacts from EMF and RF Radiation

Austrian Medical Association – Practical Rules to Decrease Wireless EMF Radiation Exposure

Santa Clara County Medical Association Magazine

Connecticut Department of Public Health – Cell Phone Safety Bulletin

Athens Medical Association – Measures to Protect Against Electromagnetic Radiation

Canadian Parliament Standing Committee on Health of the House of Commons

Pittsburgh Cancer Institute

LETTERS TO FDA

- Press releases from scientists challenging radiation limits
- Letter calling for a retraction signed by several scientists.
- Ronald Melnick PhD's letter to the FDA on the National Toxicology Program study
- Albert Manville PhD, retired Senior Wildlife Biologist, Division of Migratory Bird Management, U.S. Fish & Wildlife Service, Wash. DC HQ Office (17 years); Senior Lecturer, Johns Hopkins University
- Prof. Tom Butler of the University College in Cork, Ireland's letter to the FDA

- Igor Belyaev, PhD, Dr. Sc. Head, Department of Radiobiology of the Cancer Research Institute, Biomedical Research Center of the Slovak Academy of Science letter to the FDA
- Paul Heroux PhD, McGill University
- Alfonso Balmori, BSc statement to the FDA

LETTERS AND OFFICIAL BRIEFINGS ON 5G

Briefing on 5G Health Impacts by Dr. Martin Pall: "5G: Great Risk for EU, U.S. and International Health! Compelling Evidence for Eight Distinct Types of Great Harm Caused by Electromagnetic Field (EMF) Exposures and the Mechanism that Causes Them"

November 19, 2018 – Magda Havas, BSc, PhD, Trent University, Peterborough, Canada – Open Letter: Need to Consider Health Effects Associated with Radio Frequency and Microwave Radiation before Deployment of 5G

November 19, 2018 – Paul Héroux, PhD, Professor of Toxicology and Health Effects of Electromagnetism, McGill University Medicine, Montreal – Open Letter

November 21, 2018 – Yuri Grigoriev, Dr. Sc. Med., Professor, Academician of Russian Academy of Electrotechnical Sciences – Open Letter: From Electromagnetic Smog to Electromagnetic Chaos Evaluating the Hazards of Mobile Communication for Public Health

December 7, 2018 – David O. Carpenter, MD, Director, Institute for Health and the Environment, University at Albany, State University of New York – Open Letter to Ministers and Members of Parliament of the Brussels Capital Region

December 13, 2018 – Olle Johansson, PhD, associate professor / retired from the Karolinska Institute, Stockholm, Sweden, and the Royal Institute of Technology, Stockholm, Sweden – Letter of Concern, addressed to the decision-makers of the City of Brussels

May 15, 2019- Magda Havas, BSc, PhD, Trent University, Peterborough, Canada Affidavit on 5G to Canadian Parliament with non-profit EMF OFF.

LETTERS FROM ORGANIZATIONS AND OTHERS

Letter from Frank Clegg, former President of Microsoft, Canada

Letter from EMF 249 Scientists to Mr. Charles Parkinson/Mrs. Andrea Dudley-Owen President & Vice President of Economic Development, The States of Guernsey, Re: 5G

Letter from Jerry L. Phillips Ph.D. to Mr. Charles Parkinson & Mrs. A Dudley-Owen President & Vice President Of Economic Development, The States of Guernsey, Re: 5G

Letter from Paul Héroux, PhD to The States of Guernsey, Re: 5G

Health Effects of Electromagnetism (Detailed Report) submitted to The States of Guernsey by Paul Héroux, PhD

Letter from Anthony B. Miller, MD, FRCP to Gavin St Pier Esq, Chief Minister, The States of Guernsey, Re: 5G

Letter from Professor Colin Pritchard to The States of Guernsey, Re: 5G

Declaration to European Commission by 180 Scientists Calling for a Moratorium on 5G Cell Antennas, September 13, 2017

National Health Integrated Associates October 29, 2018 Letter to Montgomery County Council

Letter from Dr. Lennart Hardell To Governor Jerry Brown on SB649

Beatrice Alexandra Golomb, MD, PhD Lettter in Opposition to SB649

Letter from Dr. Martin Pall in Opposition to SB649

Attachment to Dr. Pall Letter – 142 Microwave Radiation Review Studies

Letter from Dr. Devra Davis to Chair Aguiar-Curry on SB 649, June 28, 2017

Letter from Dr. Devra Davis to Governor Jerry Brown on SB 649, September 17, 2017

Letter from Dr. Paul Ben Ishai in Opposition to SB 649, September 08, 2017

Letter from Dr. Cindy Russell in opposition to SB 649

Letter from Physicians For Safe Technology in opposition to SB 649

Article from Dr. Cindy Russell on Impacts of 5G Technology, January 2017

Santa Clara Bulletin, pg. 20-23, "A 5G Wireless Future: Will It Give Us a Smart Nation or Contribute to An Unhealthy One?" by Cindy Russell, January 2017

Letter from Dr. Joel Moskowitz To Governor Jerry Brown on SB 649

Beatrice Alexandra Golomb, MD, PhD Letter in Opposition to SB 649

Letter from Dr. Sam Milhelm

Letter from Dr. John West

Letter from Dr. Hugh Scully to the City of Toronto

Letter from Dr. Stephen Sinatra to Toronto City Councilors in Opposition to Item 26.21

Joint letter from 541 health, environment and justice advocates and organizations to US Senators and Representatives in opposition to bills on 5G and wireless radiation expansion – November 13, 2017

Ellie Marks Letter to Governor Brown SB 649

Letter from the Alliance of Nurses for Health Environments

Letter from Environmental Working Group June 26, 2017

Letter from Environmental Working Group July 26, 2017

8/20 National Institute for Science, Law & Public Policy Letter to Appropriations Committee

8/21 National Institute for Science, Law & Public Policy Letter to Assembly

8/24 National Institute for Science, Law & Public Policy Letter to Governor Brown.

Letter from the Sierra Club, August 15, 2017

Letter from Greenlining Institute, June 27, 2017

Letter from the American Association of Retired Persons (AARP), July 19, 2017

Letter from Law Office of Harry Lehmann "Mass casualties are likely in District 10 from passage of 648", July 6, 2017

Letter from Law Office of Harry Lehmann to State of California, "Liability for Damage From Microwave Radiation Exposure Sustained by Senate Bill 649 Will Be Shifted to California State", July 19, 2017

Letter from Law Office of Harry Lehmann, "SB 649 will disproportionately effect the poor in California", August 24, 2017

Letter from EMF Safety Network and Ecological Options Network, July 06, 2017

Letter by Susan Foster Assembly Appropriations Letter – Fire Station Exemption from SB 649, August 14, 2017

Letter from Susan Foster and Radiation Research Trust in of Opposition of SB 649, June 22, 2017

Scientists For Wired Technology, 5/30/17: front and back

Scientists For Wired Technology 5/31/17:front and back

American Planning Association Opposes SB 649

Berkeley City Council Opposition Letter, April 25, 2017

SCIENTIFIC COMMENTS TO THE FCC

Comments by Ronald M. Powell, PhD, to the FCC on Spectrum Frontiers

Comments by The Berkshire-Litchfield Environmental Council to the FCC on Spectrum Frontiers, July 12, 2016

Comments by Dr. Albert Manville to the FCC on Spectrum Frontiers, July 14, 2016

Comments by Dr. Joel Moskowitz to the FCC on Spectrum Frontiers, July 20, 2016

Comments by Dr. Yael Stein to the FCC on Spectrum Frontiers, July 09, 2016

Comments by Dr. Devra Davis to the FCC on Spectrum Frontiers

Comments by Susan Clarke to the FCC on Spectrum Frontiers, July 14, 2016

Comments by EMF Scientist Appeal Advisors to the FCC on Spectrum Frontiers, June 09, 2017

Letters by Scientists and Doctors on Small Cells and 5G

Appendix F

Wireless Exposure Limits in Different Countries

The exposure limits given below are from the website of Physicians for Safe Technology

Japan	600 microwatts/cm^2
U.S.A.	450 microwatts/cm^2
Canada	450 microwatts/cm^2
Australia	450 microwatts/cm^2
Austria	450 microwatts/cm^2
France	450 microwatts/cm^2
Germany	450 microwatts/cm^2
Hungary	450 microwatts/cm^2
Ireland	450 microwatts/cm^2
Luxembourg	450 microwatts/cm^2
Portugal	450 microwatts/cm^2
Spain	450 microwatts/cm^2
India	45 microwatts/cm^2
China	40 microwatts/cm^2
Russia	10 microwatts/cm^2
Italy	10 microwatts/cm^2
Bulgaria	10 microwatts/cm^2
Poland	10 microwatts/cm^2
Lichtenstein	10 microwatts/cm^2
Switzerland	10 microwatts/cm^2
Belgium	2.4 microwatts/cm^2
Ukraine	2.5 microwatts/cm^2
Cosmic	<0.00000000001 microwatts/cm^2

Appendix G

Captured Agencies and Conflicts of Interest

Alster, Norm, *Captured Agency: How the Federal Communications Commission Is Dominated by the Industries It Presumably Regulates,* Edmond J. Safra Center for Ethics, Harvard University. The report can be accessed here.

Conflicts of Interest Among Those Who Set Radiation Limits

- In Europe, the public radiation limits are set by the International Committee on Non-Ionizing Radiation Protection (ICNIRP). Investigate Europe, a team of investigative journalists expose that ICNIRP members have extensive conflicts of interest with industry. Dr. Joel Moskowitz chronicles their findings, and additional studies that show ICNIRP scientists are working for industry: *https://www.saferemr.com/2018/07/icnirps-exposure-guidelines-for-radio.html*
- The 98 page report, "*The International Commission on Non-Ionizing Radiation Protection: Conflicts of interest, corporate capture and the push for 5G*" was commissioned, coordinated and published in 2020 by two Members of the European Parliament – Michèle Rivasi and Klaus Buchner: https://www.saferemr.com/2018/07/icnirps-exposure-guidelines-for-radio.html
- Priyanka Bandara, Ph.D., and others in 2020 published *5G Wireless Deployment and Health Risks: Time for a Medical Discussion in Australia and New Zealand* which cites conflicts of interest with industry and current evidence of harm: https://www.researchgate.net/publication/343416307_5G_Wireless_Deployment_and_Health_Risks_Time_for_a_Medical_Discussion_in_Australia_and_New_Zealand

Conflicts of Interest at the World Health Organization

- In 2016 the authors of the BioInitiative Report, which summarizes thousands of peer-reviewed scientific studies showing wireless technology is harmful, submitted a No-Confidence letter to the WHO's EMF program manager because the committee no longer includes appropriate representation from non-industry funded EMF scientific experts:

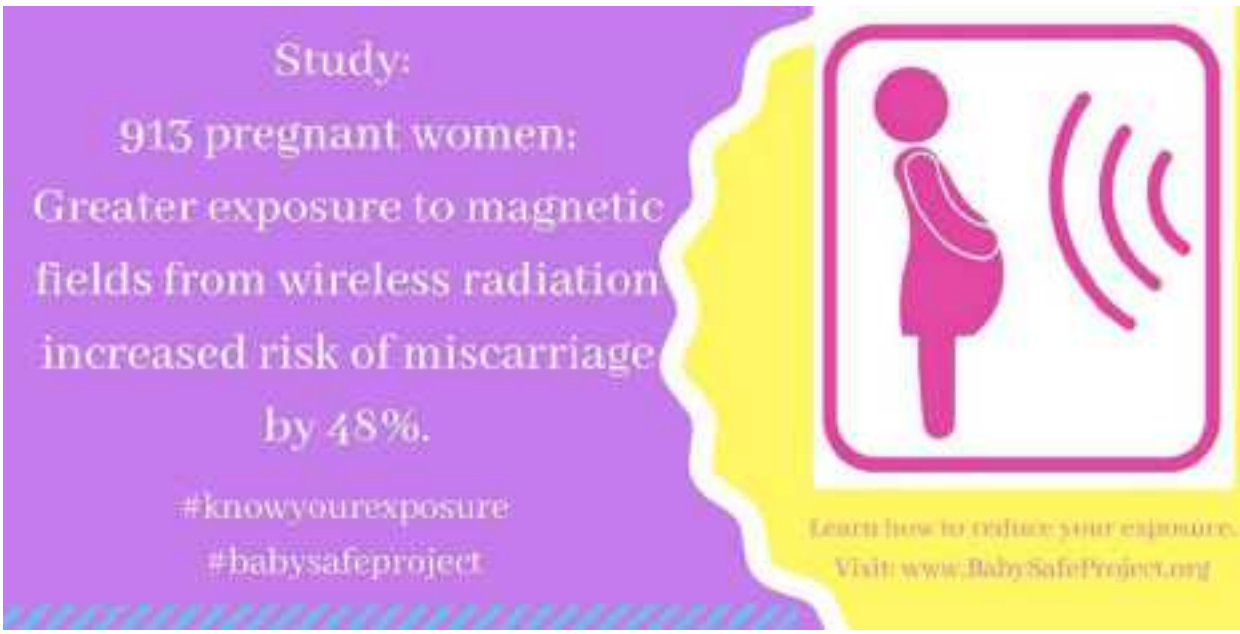
http://www.bioinitiative.org/bioinitiative-working-group-issues-a-no-confidence-letter-to-the-who-emf-program-manager/.

- The Russian National Committee on Non-Ionizing Radiation Protection issued a similar letter in March 2017.
- Over 250 of the world's leading EMF scientists and biologists have signed **a** formal appeal to the World Health Organization with a clear plan to inform and protect the public from wireless radiation: https://www.emfscientist.org/
- Columbia University's Dr. Martin Blank provides a three-minute introduction to the Appeal that summarizes the issue: https://vimeo.com/123468632
- The head of the WHO's "International EMF Project" has heavy ties to the telecom industry. Further, she does not have EMF scientific or medical credentials and is not listening to the scientists proving electromagnetic fields are hazardous. A former UN employee, Olga Sheean of Canada, submitted a petition to get qualified leadership in place: http://olgasheean.com/who-emf/.
- In 2017, the International Journal of Oncology published a report by Dr. Lennart Hardell explaining the WHO has conflicts of interest with industry and does not plan to take action to protect the public from non-thermal electromagnetic radiation, even though the scientific and epidemiological evidence of harm is well documented: https://www.spandidos-publications.com/10.3892/ijo.2017.4046
- In 2020, the WHO's "International EMF Project" reopened its investigation into Electromagnetic Fields: https://www.who.int/peh-emf/research/rf_ehc_page/en/index1.html

The WHO's "International EMF Project" is composed of those with close ties to industry and is separate from the another WHO group that in 2011 determined EMFs to be Group 2B: Possibly Carcinogenic to Humans. The latter group is the "International Agency for Research on Cancer (IARC)" which has non-industry funded scientific experts in the biological effects of EMFs. It remains to be seen what will come of the investigation launched in 2020: https://ehtrust.org/scientists-call-for-transparency-at-the-world-health-organization-emf-project/

Appendix H

Example of an RF radiation warning



Appendix I

Example of a symbol for use on poles and other structures located in public rights-of way that hold 5G antennae

Appendix J

Deleterious effects of impulsive radiation

While current FCC guidelines for non-ionizing radiation exposure are based upon heating effects, there is a growing body of research showing that the impulsive nature of high-speed data transmission can cause deleterious health effects at considerably lower radiation levels. Three references that document the effect of the impulsive radiation are given below:

[1] Belyaev, I., Dean, A., Eger, H. et al. "EUROPAEM EMF Guideline 2016 for the prevention, diagnosis, and treatment of EMF-related health problems and illnesses." *Rev environ Health.* 2016;31(3):363-397. Doi:10.1515/reveh-2016-0011.

[2] B. W. G. (2012). "Bioinitiative 2012: A Rationale for Biologically-based Exposure Standards for Low-Intensity Electromagnetic Radiation."

[3] McCarty, D. E., Carrubba, S., Chesson, A. L., Frilot, C., Gonzalez-Toledo, E., & Marino, A. A. (2011). "Electromagnetic hypersensitivity: P Evidence for a novel neurological syndrome." *International Journal of Neuroscience*, 121(12), 670-676.

Appendix K

Siting restrictions for wireless antennae

The siting restrictions for cell phone towers already in force in the world were intended to ensure the safety of vulnerable populations, like children and those with illnesses.

India already prohibits placement of cell phone towers near schools or hospitals, and Canada (Standing Committee on Health), as well as many European countries, are looking into similar restrictions.

CALIFORNIA FIREMEN

California firemen are exempted from the forced placement of towers on or adjacent to their stations, because of radiation health concerns.

> "The International Association of Fire Fighters' position on locating cell towers commercial wireless infrastructure on fire department facilities, as adopted by its membership in August 2004, is that the IAFF oppose the use of fire stations as base stations for towers and/or antennas for the conduction of cell phone transmissions until a study with the highest scientific merit and integrity on health effects of exposure to low-intensity RF/MW radiation is conducted and it is proven that such sitings are not hazardous to the health of our members."

https://ecfsapi.fcc.gov/file/109281319517547/20-Attachment%2020-%20Firefighters%20Inter%20Resolution%20Against%20Cell%20Towers.pdf

https://vimeo.com/122670207

https://web.archive.org/web/20150403040308/http://www.stopcellphonetowers.com/index.html%20

https://www.youtube.com/watch?v=61h_vuBujw0

http://cbsloc.al/2DNAYA5

https://sanfrancisco.cbslocal.com/2018/01/25/consumerwatch-5g-cellphone-towers-signal-renewed-concerns-over-impacts-on-health) https://ehtrust.org/wp-content/uploads/HARDELL-14-October-2014_1-1.pdf

This was codified in Government, section 65964.1. (f) as enacted by California's legislation AB 57 in 2015:

> "Due to the unique duties and infrastructure requirements for the swift and effective deployment of firefighters, this section does not apply to a collocation or siting application for a wireless telecommunications facility where the project is proposed for placement on fire department facilities."

A similar provision was included in California's SB 649 (2018), "Wireless Telecommunications Facilities" under item 65964.2.:

> "(a) A small cell shall be a permitted use subject only to a permitting process adopted by a city or county pursuant to subdivision (b) if it satisfies the following requirements: ….(3) The small cell is not located on a fire department facility."

On October 15, 2018, Governor Jerry Brown vetoed SB 649, the so-called small-cell bill, which would have usurped local authority over the siting of telecom equipment.

> To the Members of the California State Senate:
> I am returning Senate Bill 649 without my signature.
>
> This bill establishes a uniform permitting process for small cell wireless equipment and fixes the rates local governments may charge for placement of that equipment on city or county owned property, such as streetlights and traffic signal poles.
>
> There is something of real value in having a process that results in extending this innovative technology rapidly and efficiently. Nevertheless, I believe that the interest which localities have in managing rights of way requires a more balanced solution than the one achieved in this bill.
>
> Sincerely, Edmund G. Brown Jr.

ESTABLISHING SETBACK

To increase wireless data rates, the 5G industry seeks higher frequencies. These frequencies distribute energy in a smaller fraction of the body and need higher field intensities because of (1) poor penetration into structures, (2) absorption of radiation by oxygen and water, (3) shrinking antenna apertures, as well as (4) noise from an increasing number of extraneous sources.

For human users, this means increased power density exposures. In addition, exposures will become more irregular because of beam-forming, as well as originate from multiple sources (Multiple-Input Multiple-Output architecture).

Since there is no epidemiological or animal data, and very few laboratory results using 5G, cautionary setbacks should be established by the municipalities based upon past 3G and 4G systems.

The verdict on animal studies is expressed in reports by (1) the US National Toxicology Program, (2) the Ramazzini Institute, and by older studies by (3) Chou (1992) and (4) Repacholi (1997).

The verdict on epidemiology is expressed in two reports (ELF and RF) from the *International Agency for Research on Cancer* ("possibly carcinogenic"), which Agency is scheduled to review evidence on RF carcinogenicity between now and 2024.

Senator Blumenthal:
https://www.radiationresearch.org/articles/us-senator-blumenthal-raises-concerns-on-5g-wireless-technology-health-risks-at-senate-hearing-youtube/

US National Toxicology Program – Impact of Cell Phones:
https://ntp.niehs.nih.gov/results/areas/cellphones/index.html

Ramazzini Institute – Impact of Base Stations:
https://www.ncbi.nlm.nih.gov/pubmed/29530389

International Agency for Research on Cancer – ELF*:*
https://monographs.iarc.fr/wp-content/uploads/2018/06/mono80.pdf
https://www.iarc.fr/wp-content/uploads/2018/07/pr208_E.pdf

International Agency for Research on Cancer – RF:
https://publications.iarc.fr/Book-And-Report-Series/Iarc-Monographs-On-The-Identification-Of-Carcinogenic-Hazards-To-Humans/Non-ionizing-Radiation-Part-2-Radiofrequency-Electromagnetic-Fields-2013
https://www.iarc.fr/wp-content/uploads/2018/07/pr208_E.pdf

Chou, 1992: *https://onlinelibrary.wiley.com/doi/abs/10.1002/bem.2250130605*

Repacholi, 1997: *https://www.ncbi.nlm.nih.gov/pubmed/9146709*

As vulnerable individuals are exposed involuntarily every day in society to RF-radiation, caution should be universally used and set according to the Largest Observed Adverse Effect Distance (LOAED), using the experience from past and current 2G, 3G, and 4G networks. A conservative LOAED should include all observed health effects.

Best engineering practice would therefore apply a set-back requirement for new cellular towers, including 5G micro-towers.

From the 17 documents referred to in this appendix, shown below in historical order, this set-back for all new cell towers should be 500 meters which translates to 1,640 feet.

All of these studies have been given support by a recent animal study from the Ramazzini Institute that links to them, as well as to the US National Toxicology Program result on cell phones.

REFERENCES

Paola **Michelozzi**, Alessandra Capon, Ursula Kirchmayer, Francesco Forastiere, Annibale Biggeri, Alessandra Barca, and Carlo A. Perucci.
"Adult and Childhood Leukemia near a High-Power Radio Station in Rome," Italy. *American Journal of Epidemiology*, Vol. 155, No. 12, (2002) 1096-1103.
Michelozzi et al 2002 describe an increased risk for childhood leukemia at distances up to 6 km from the powerful Vatican Radio transmitters near Cesano, Italy, which led to compensation by decision of Italy's Supreme Court (relative risk of 7 for lymphomas and myeloma, and 5 for non-Hodgkin's lymphoma and leukemia).
https://pubmed.ncbi.nlm.nih.gov/12048223/

R. **Santini**, P. Santini, P. Le Ruz, J. M. Danze, and M. Seignel. “Survey Study of People Living in the Vicinity of Cellular Phone Basestations.” *Electromagnetic Biology and Medicine*. Vol. 22, No. 1, pp. 41-49, 2003.
Santini et al 2003 surveyed by questionnaire 530 people living or not in proximity to cellular phone Base Stations (BSs) in France. Eighteen different symptoms (Non-Specific Health Symptoms-NSHS), described as radiofrequency sickness, were studied. Certain complaints are experienced only in the immediate vicinity of BSs (up to 10 m for nausea, loss of appetite, visual disturbances), and others at greater distances from BSs (up to 100 m for irritability, depressive tendencies, lowering of libido, and up to 200 m for headaches, sleep disturbances, feeling of discomfort). In the 200 m to 300 m zone, only the complaint of fatigue is experienced significantly more often when compared with subjects residing at more than 300 m or not exposed (reference group). For seven of the studied symptoms and for the distance up to 300 m, the frequency of reported complaints is significantly higher ($P<0.05$) for women in comparison with men.
https://www.tandfonline.com/doi/abs/10.1081/jbc-120020353

Michael **Kundi**, Hans-Peter Hutter. “Mobile phone base stations—Effects on wellbeing and health.” *Pathophysiology* 16 (2009) 123–135.
Kundi and Hutter 2009 comment that studying effects of mobile phone base station signals on health have been discouraged by authoritative bodies like the WHO. As a result, only few investigations of effects of base station exposure on health and wellbeing exist. But two ecological studies of cancer in the vicinity of base stations report both a strong increase of incidence within a radius of 350 and 400 m, respectively. It is suggested that power densities around 500–1000 $\mu W/m^2$ must be exceeded in order to observe an effect.
https://pubmed.ncbi.nlm.nih.gov/19261451/

Vini G. **Khurana**, Lennart Hardell, Joris Everaert, Alicja Bortkiewicz, Michael Carlberg, Mikko Ahonen. “Epidemiological Evidence for a Health Risk from Mobile Phone Base Stations.” *International Journal of Occupational and Environmental Health*. July 2010;16:263–267. DOI: 10.1179/107735210799160192.
Khurana et al 2010 provides a review of 10 BS proximity and neurobehavioral effects, and three investigations of cancer. Eight of the 10 studies reported increased prevalence of adverse neurobehavioral symptoms or cancer in populations living at distances < 500 meters from BSs.
https://pubmed.ncbi.nlm.nih.gov/20662418/

Adilza C. **Dode**, Mônica M.D. Leão, Francisco de A.F. Tejo, Antônio C.R. Gomes, Daiana C. Dode, Michael C. Dode, Cristina W. Moreira, Vânia A. Condessa, Cláudia Albinatti, Waleska T. Caiaffa. "Mortality by neoplasia and cellular telephone base stations in the Belo Horizonte municipality, Minas Gerais state, Brazil." *Science of the Total Environment* 409 (2011) 3649–3665.
Dode et al 2011 provides the most detailed information. Belo Horizonte is the third largest city in Brazil. It was been selected by the Population Crisis Committee of the United Nations (UN, 2007) as the metropolis with the best quality of life in Latin America. Its health system is considered very good, according to the Atlas of Human Development (2000/United Nations Development Program).

In 2011, a 10-year study on cell phone antennas was released by the Municipal Health Department and several local universities. The study was conducted in a broad environmental context, aiming to verify if there is a spatial correlation between the cellular telephony system BS location and the cases of death by neoplasia during the period between 1996 and 2006. Three data banks were used: 1. death by neoplasia documented by the Municipal Health Department; 2. BS documented in ANATEL (Telecommunications National Agency); and 3. census and demographic city population data obtained from official archives provided by IBGE (Brazilian Institute of Geography and Statistics). The results show that approximately 856 BSs were installed through December 2006.

Between 1996 and 2006, 7191 deaths by neoplasia occurred and, within an area of 500 m from the BS, the mortality rate was 34.76 per 10,000 inhabitants. Outside of this area, a decrease in the number of deaths by neoplasia occurred. The greatest accumulated incidence was 5.83 per 1000 in the Central-Southern region and the lowest incidence was 2.05 per 1000 in the Barreiro region. During the environmental monitoring, the largest electric field measured was 12.4 V/m and the smallest was 0.4 V/m. The largest power density was 407,800 µW/m², and the smallest was 400 µW/m².
https://pubmed.ncbi.nlm.nih.gov/21741680/

Ermanno **Affuso,** J. Reid Cummings, Huubinh Le. "Wireless Towers and Home Values: An Alternative Valuation Approach Using a Spatial Econometric Analysis." *Journal of Real Estate Finance and Economics* (2018) 56:653–676. DOI 10.1007/s11146-017-9600-9.

Affuso et al 2018 examines the economic impact on home values. For properties located within 0.72 kilometers of the closest tower, results reveal significant declines of 2.46% on average, and up to 9.78% for homes within tower visibility range compared to homes outside tower visibility range.
https://link.springer.com/article/10.1007/s11146-017-9600-9

Falcioni L., L. Bua, E. Tibaldi, M. Lauriola, L. De Angelis, F. Gnudi, D. Mandrioli, M. Manservigi, F. Manservisi, I. Manzoli, I. Menghetti, R. Montella, S. Panzacchi, D. Sgargi, V. Strollo, A. Vornoli, F. Belpoggi.
Report of final results regarding brain and heart tumors in Sprague-Dawley rats exposed from prenatal life until natural death to mobile phone radiofrequency field representative of a 1.8 GHz GSM base station environmental emission. *Environmental Research* 165 (2018) 496–503.
Falcioni et al 2018 conclude: the Ramazzini Institute findings on far field exposure to RFR are consistent with and reinforce the results of the NTP study on near field exposure, as both reported an increase in the incidence of tumors of the brain and heart in RFR-exposed Sprague-Dawley rats. These tumors are of the same histotype of those observed in some epidemiological studies on cell phone users. These experimental studies provide sufficient evidence to call for the reevaluation of IARC conclusions regarding the carcinogenic potential of RFR in humans.
https://www.avaate.org/IMG/pdf/belpoggi-heart-and-brain-tumors-base-station-2018.pdf

J.M. **Pearce**. "Limiting liability with positioning to minimize negative health effects of cellular phone towers." *Environmental Research* 181 (2020) 108845.
Pearce et al 2020 provides the most recent assessment and promotes a 500 m set-back to limit future liabilities of the cell phone industry, based on correlation with headaches, dizziness, depression and other neurobehavioral symptoms, as well as increased cancer risk. It is almost inevitable that such economic impacts will increase in the future.
https://www.sciencedirect.com/science/article/abs/pii/S0013935119306425

Other References

Buchner K et al. (2011): [Modification of clinically important neurotransmitters under the influence of modulated high-frequency fields - A long-term study under true-to-life conditions]. In German. Abstract translation below.

This long-term study over one and a half years shows a significant activation of the 60 participants´ adrenergic systems after the installation of a regional mobile telephone transmitting station in the village of Rimbach (Bavaria).

The values of the stress hormones adrenaline and noradrenaline grow significantly during the first six months after starting the GSM transmitter; the values of the precursor substance dopamine decreases substantially after the beginning of the radiation (Wilcoxon test, $p<0,0002$). The initial condition is not restored even after one and a half years. Due to the not regulable chronic difficulties of the stress balance, the phenylethylamine (PEA) values drop until the end of the research period (Wilcoxon test, $p<0,0001$). The effects show a dose effect relation and are situated far under the valid limits for technical high-frequency stress. Chronic dysregulations of the catecholamine system have substantial health relevance and cause health damages in the long run.

Wolf R, Wolf D. "Increased incidence of cancer near a cell-phone transmitter station." *Int J Canc Prev* 2004; 1 (2): 123-128. Publication unavailable online.

Conclusion according to the authors: Of the 622 people of area A, 8 cases of different kinds of cancer were diagnosed in a period of one year (from July 1997 - June 1998). The cancer incidence rate was 129 cases per 10,000 persons per year in area A compared to 16/10,000 in area B and 31/10,000 in the town of Netanya. Relative cancer rates for females were 10.5 for area A, 0.6 for area B and 1 for Netanya. The authors conclude that the study indicates an association between increased incidence of cancer and living in proximity to a mobile phone base station.

Eger H, Hagen KU, Lucas B, Vogel P, Voit H. [Influence of proximity to mobile telephony transmitters on cancer incidence]. Umwelt-Medizin-Gesellschaft 2004; 17 (4): 326-332. In German. Author's conclusion translated below.

320 of 967 residents of Naila have been living in the inner circle at a distance to the next base station of less than 400 m. The results showed an increased risk for malignant tumors for patients living closer than 400 m to the mobile telephony transmitter compared to patients living further away.

In the years 1999 - 2004 the risk for malignant tumors tripled for patients living in the proximity of the mobile telephony transmitter.

Appendix L

Measurement of RF intensities
within frequency ranges throughout state

The majority of the Commission suggests this data include location, frequency ranges, peak, and average power intensities of total combined RF emitted by sources such as 3G, 4G, or 5G cellphone networks, Wi-Fi, smart meters, IOT devices, and similar devices. The data should be collected in such a way as to identify possible areas of notably high RF exposure, places where RF signal for wireless communication is inadequate (dead spots), and places where RF is unusually low (white zones) that are sought by people who wish to minimize their exposure.

RF data collected and mapped should be archived and published on a state website, accompanied by state-wide and regional aggregated averages for both peak and 24-hour integrated microwatts/meter squared intensities. The state should also publish benchmarks for comparison: a few readings from low-intensity underdeveloped areas, and nearby some strong high-intensity sources (base of a tower) for min-max comparison. The Bioinitiative 2012 recommends that human peak exposure not exceed an RF intensity of 1,000 microwatts/meter squared.

One use of this data will be buyers/renters of property or the public in general using these benchmark values to make comparisons and form their own decisions based on their comfort level. After a while, an extensive NH RF database will exist to provide useful maps and data for future public health investigations.

Appendix M

The enabling technology and scientific rationale
for automatically stopping cell phones from
operating when held against the body

The FCC testing procedure for certification of cell phones aims for a power injection into the head below 1.6 Watts per kilogram of tissue. The accuracy of SAR determinations is not very high (variation between laboratories), and some cellular phones have been found to exceed this limit (https://www.chicagotribune.com/investigations/ct-cell-phone-radiation-testing-20190821-72qgu4nzlfda5kyuhteiieh4da-story.html).

A major problem is that the FCC testing procedure allows the phone to be tested up to 0.98 inches (2.5cm) from the head, at which distance injection of energy into the head is much reduced compared to when held against the head as is done routinely by users. "Small print" instructions already present in many cell phone manuals instruct users to hold cell phones at a distance from the head, in full knowledge that this is not likely to be done.

In France, measurements by the National Frequency Agency (ANFR) revealed that 9 out of 10 mobile phones tested in 2015 under real use conditions (in contact with the body) exceeded the legal limit, leading to extensive recalls (https://www.phonegatealert.org/en/phonegate-scandal-where-are-we-three-years-after-the-alert-was-launched).

We provide here a simple change expected to reduce the number of glioblastomas and other tumors in cell phone users by mandating that cell phones turn off their radiation when held right against the head or body.

IMPLEMENTATION
A reliable method to reduce head exposure to radiation is to configure the phone itself to automatically shut off, protecting the user's brain. Cellular phones already contain a small device called a *proximity sensor* (shown at right is the miniature

Sharp GP2AP002S00F), usually located at the top of the phone. The element on the left of the sensor sends out pulsed infrared which is detected by the element on the right, if the phone is near an object. The image sequence at right shows how a finger turns off the screen.

In present Android devices, the proximity sensor triggers as the user's face is close to the screen, switching off the screen and preventing any errant soft-button presses by the skin as well as saving battery power.

Some Android devices can report the distance to another object in centimeters, whereas others will simply report minimum and maximum values to denote *near* and *far*, respectively. These functions are accessed through *SensorManager* and *Sensor* classes from the Android Application Programming Interface (API).

Similarly, the iPhone proximity sensor (also using infrared) is designed to detect any object near the screen and is used to put the display to sleep when the iPhone is against the head, preventing unintentional display triggering.

Assigning to the user the task of keeping the phone away from the head is not practical. The phone itself should disable its RF emissions if proximity is detected. This means that the user could use the phone away from the head, in his hand, or on a table in front of him. At the cost of a small change in personal habits, this measure would instantly remove high SAR exposures from cell phone usage and would remove the need for sophisticated assessment of exact SAR measurements in close body proximity. Note that this phone adjustment does not prevent alerting the user to incoming calls. But it does prevent the unit from autonomously sending out data when held against the body. A number of applications ("apps") have in recent years contributed to user exposures by radiating data even without user intervention. This automatic data traffic tends to increase and should only be permitted if the device is held away from the body. Essentially, this software adjustment is an automated "Airplane Mode", designed to protect users from radiation.

JUSTIFICATION

For cellular phones, commonly held against the head, prolonged use has led to an increase in a lethal form of brain cancer, glioblastoma, as well as with a more benign tumor, acoustic neuroma, in 9 peer-reviewed studies, including one cohort study.

- Brain Tumours: Rise in Glioblastoma Multiforme Incidence in England 1995–2015 Suggests an Adverse Environmental or Lifestyle Factor. Alasdair Philips, Denis L. Henshaw, Graham Lamburn, and Michael J.O'Carroll. Journal of Environmental and Public Health Volume 2018, Article ID 7910754, (https://doi.org/10.1155/2018/7910754),
- Use of mobile phones and cordless phones is associated with increased risk for glioma and acoustic neuroma. Lennart Hardell, Michael Carlberg, Kjell Hansson Mild. Pathophysiology 20 (2013) 85–110. https://www.sciencedirect.com/science/article/abs/pii/S0928468012001101

Recent studies have also linked cell phone use to cancer.

The US National Toxicology Program,
https://ntp.niehs.nih.gov/results/areas/cellphones/index.html,

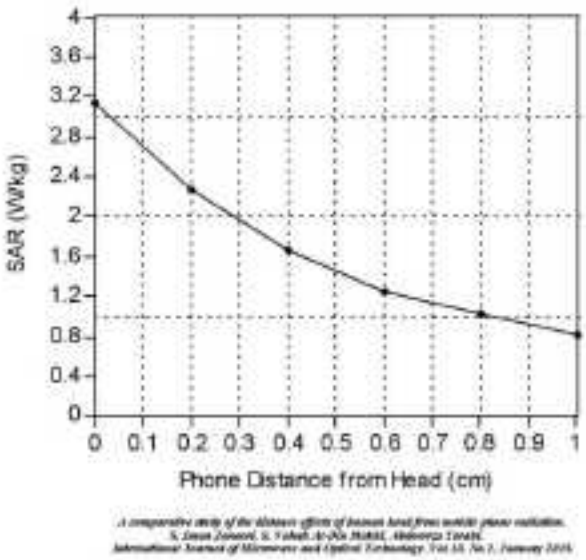
the International Agency for Research on Cancer,
https://publications.iarc.fr/Book-And-Report-Series/Iarc-Monographs-On-The-Identification-Of-Carcinogenic-Hazards-To-Humans/Non-ionizing-Radiation-Part-2-Radiofrequency-Electromagnetic-Fields-2013,

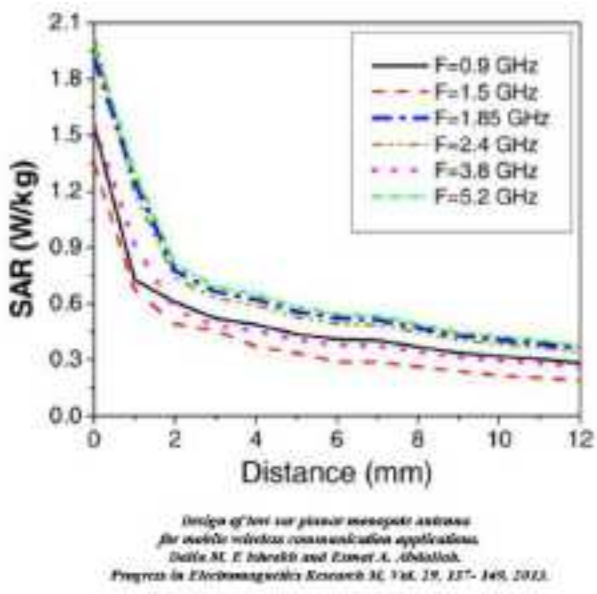
as well as individual large studies by Chou,
https://onlinelibrary.wiley.com/doi/abs/10.1002/bem.2250130605,

Repacholi,
https://www.ncbi.nlm.nih.gov/pubmed/9146709,

as well as a collective opinion of scientists,
https://bioinitiative.org/.

Engineering analysis indicates that the dose delivered to the brain decreases rapidly as distance between cellular phone and head rises. As shown below, it decreases by as much as 4 to 5 times, according to two separate analyses, as the phone is moved 1 cm (0.4”) away.





While walkie-talkies of the past were used more distantly from the head, the recent trend has been to reduce the size of cellular phones and to promote a style of use identical to that of the telephone which is pressed against the ear. An unfortunate consequence has been to deliver large doses of EMR to tissues of the nervous system which have been shown to be adversely affected, as stated above.

Without altering the function of cellular phones, it is technically possible to seriously reduce exposure to the brain of users by altering how the phones are held when emitting radiation, specifically by holding them away from the body.

Appendix N

Research on the effects of wireless radiation on trees, plants, birds, insects, pollinators, and wildlife

FCC limits were not developed to protect our flora or fauna. Wireless radiation "safety" limits for trees, plants, birds, insects, pollinators, and wildlife simply do not exist. No US agency nor international authority with expertise in science, biology or safety has ever acted to review research and set safety limits on these non-human species.

The Department of Interior wrote a letter in 2014 detailing several published studies showing impacts of wireless radiofrequency radiation (RFR) to birds. It stated the following:

> There is a growing level of anecdotal evidence linking effects of non-thermal, non-ionizing electromagnetic radiation from communication towers on nesting and roosting wild birds and other wildlife in the U.S.
>
> However, the electromagnetic radiation standards used by the Federal Communications Commission (FCC) continue to be based on thermal heating, a criterion now nearly 30 years out of date and inapplicable today.
>
> … third-party peer-reviewed studies need to be conducted in the U.S. to begin examining the effects from radiation on migratory birds and other trust species.
>
> Study results have documented nest and site abandonment, plumage deterioration, locomotion problems, reduced survivorship, and death (e.g., Balmori 2005, Balmori and Hallberg 2007, and Everaert and Bauwens 2007). Nesting migratory birds and their offspring have apparently been affected by the radiation from cellular phone towers in the 900 and 1800 MHz frequency ranges- 915 MHz is the standard cellular phone frequency used in the United States.
>
> In laboratory studies, T. Litovitz (personal communication) and DiCarloet al. (2002) raised concerns about impacts of low-level, non-thermal electromagnetic radiation from the standard 915 MHz cell phone frequency on domestic chicken embryos- with some lethal results (Manville 2009, 2013a). Radiation at extremely low levels (0.0001 the level emitted by the average digital cellular telephone) caused heart attacks and the deaths of some chicken embryos subjected to hypoxic conditions in the laboratory while controls subjected to hypoxia were unaffected (DiCarlo et al. 2002).

Albert Manville, former senior biologist of the US Fish and Wildlife Service wrote "A BRIEFING MEMORANDUM: What We Know, Can Infer, and Don't Yet Know about Impacts from Thermal and Non-thermal Non-ionizing Radiation to Birds and Other Wildlife" published in Wildlife and Habitat Conservation Solutions, 2014 on the impacts of RFR to birds and bees. India dropped their RF limits by 1/10th after a research review documented the majority of research studies found adverse effects to wildlife, birds and bees.

Regarding bees and pollinators, the study "Exposure of Insects to Radio-Frequency Electromagnetic Fields from 2 to 120 GHz" published in Scientific Reports found insects (including the Western honeybee) can absorb the higher frequencies that will be used in the 4G/5G rollout, with absorbed power increases up to 370%. The researchers warn, "This could lead to changes in insect behaviour, physiology, and morphology over time…." Research also has found impacts to bees from wireless frequencies including inducing artificial worker piping (Favre, 2011), disrupting navigation abilities (Sainudeen, 2011; Kimmel et al., 2007), reducing colony strength (Harst et al., 2006), and impacts to honey bee physiology (Kumar et al., 2011).

Research on trees has found that trees are harmed by RFR. A 9 year field study (Waldmann-Selsam, C., et al 2016) found significant impacts to trees near cell antennas and an investigation of 700 trees found damage starts on the side of the tree with highest RF. A review on impacts to plants entitled, "Weak radiofrequency radiation exposure from mobile phone radiation on plants" concluded, "a substantial amount of the studies on RF-EMFs from mobile phones show physiological and/or morphological effects." A study on aspen seedings found ambient RF in a Colorado setting were high enough to cause necrotic lesions on the leaves, decrease leader length and leaf area, and suppress fall anthocyanin production (Haggarty, 2010).

The European Scientific Committee on Health, Environmental and Emerging Risks states, "The lack of clear evidence to inform the development of exposure guidelines to 5G technology leaves open the possibility of unintended biological consequences." Several literature reviews warn that non-ionizing EMFs are an "emerging threat" to wildlife (Balmori, 2015, Curachi, 2013, Sivani, 2012).

Research Studies

Waldmann-Selsam, C., et al. "Radiofrequency radiation injures trees around mobile phone base stations." *Science of the Total Environment* 572 (2016): 554-69.

Breunig, Helmut. "Tree Damage Caused By Mobile Phone Base Stations An Observation Guide" (2017).

Sivani, S., Sudarsanam, D. "Impacts of radio-frequency electromagnetic field (RF-EMF) from cell phone towers and wireless devices on biosystem and ecosystem - a review." *Biology and Medicine,* Volume 4, Issue 4, Pages 202–216, 2012.

Haggerty, Katie. "Adverse Influence of Radio Frequency Background on Trembling Aspen Seedlings." *International Journal of Forestry Research,* 2010.836278 (2010).

Halgamuge, M. "Weak radiofrequency radiation exposure from mobile phone radiation on plants." *Electromagnetic Biology and Medicine*, vol. 36, no. 2, 2017, pp. 213-235.

Martin Pall. "Electromagnetic Fields Act Similarly in Plants as in Animals: Probable Activation of Calcium Channels via Their Voltage Sensor." *Current Chemical Biology*, Volume 10, Issue 1, 2016.

Shikha Chandel, et al. "Exposure to 2100 MHz electromagnetic field radiations induces reactive oxygen species generation in Allium cepa roots." *Journal of Microscopy and Ultrastructure,* 5.4 (2017): 225-229.

Halgamuge, M., Skafidas, E., Davis, D. "A meta-analysis of in vitro exposures to weak radiofrequency radiation exposure from mobile phones (1990–2015)." *Environmental Research*, 2020;184:109227. doi:10.1016/J.ENVRES.2020.109227.

Halgamuge, M., Davis, D. "Lessons learned from the application of machine learning to studies on plant response to radio-frequency." *Environmental Research*, 2019. doi:10.1016/j.envres.2019.108634

Gustavino, B., et al. "Exposure to 915 MHz radiation induces micronuclei in Vicia faba root tips." *Mutagenesis* 31.2 (2016): 187-92.

Halgamuge, Malka N., See Kye Yak, and Jacob L. Eberhardt. "Reduced growth of soybean seedlings after exposure to weak microwave radiation from GSM 900 mobile phone and base station." *Bioelectromagnetics* 36.2 (2015): 87-95.

"Tree Damage from Chronic High Frequency Exposure Mobile Telecommunications, Wi-Fi, Radar, Radio Relay Systems, Terrestrial Radio, TV etc" by Dr. Volker Schorpp (2011).

Shepherd et al. "Increased aggression and reduced aversive learning in honey bees exposed to extremely low frequency electromagnetic fields." *PLoS One*, 2019 Oct 10.

Balmori, Alfonso. "Anthropogenic radiofrequency electromagnetic fields as an emerging threat to wildlife orientation." *Science of The Total Environment* 518–519 (2015): 58–60.

Balmori, A. "Electrosmog and species conservation." *Science of the Total Environment*, vol. 496, 2014, pp. 314-6.

Cucurachi, C., et al. "A review of the ecological effects of radiofrequency electromagnetic fields (RF-EMF)." *Environment International*, vol. 51, 2013, pp. 116–40.

Kumar, Neelima R., Sonika Sangwan, and Pooja Badotra. "Exposure to cell phone radiations produces biochemical changes in worker honey bees." *Toxicology International*, 18, no. 1, 2011, pp. 70–2.

Favre, Daniel. "Mobile phone induced honeybee worker piping." *Apidologie*, vol. 42, 2011, pp. 270-9.

"Briefing Paper on the Need for Research into the Cumulative Impacts of Communication Towers on Migratory Birds and Other Wildlife in the United States." Division of Migratory Bird Management (DMBM), U.S. Fish & Wildlife Service, 2009.

"The potential dangers of electromagnetic fields and their effect on the environment." Council of Europe Parliamentary Assembly, Resolution 1815, 2011.

Engels, S. et al. "Anthropogenic electromagnetic noise disrupts magnetic compass orientation in a migratory bird." *Nature*, vol. 509, 2014, pp. 353–6.

Balmori A. "Possible Effects of Electromagnetic Fields from Phone Masts on a Population of White Stork (Ciconia ciconia)." *Electromagnetic Biology and Medicine*, vol. 24, no. 2, 2005, pp. 109-19.

Balmori, A. "Mobile phone mast effects on common frog (Rana temporaria) tadpoles." *Electromagnetic Biology and Medicine*, vol. 29, no. 1-2, 2010, pp. 31-5.

Appendix O

Meeting Minutes

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS OF EVOLVING 5G TECHNOLOGY

Meeting held:
9/16/19
9:00-10:00 am
LOB 202

Meeting called to order by Rep Abrami at 9:00 am.

In attendance: (9) (*Each member discussed their backgrounds*)
Rep. Patrick Abrami-speaker of the house appointee
Senator Tom Sherman-president of the senate appointee
Rep. Ken Weeks- speaker of the house appointee
Kent Chamberlin-UNH-appointed by the chancellor
Carol Miller-NH Business & Economic Affairs Dept
Denise Ricciardi-public-appointed by the governor
Michelle Roberge-DHHS- Commissioner of DHHS appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee

Excused: (1)
Dr. Paul Heroux- Professor of Toxicology, McGill University- speaker of the house appointee

To be filled: (6)
AG or designee
2 members of the NH High Tech Council
1 member of NH Medical Society, specializing in environmental medicine/electromagnetic radiation
1 member of cell phone/wireless industry
1 member of Business and Industry Association

Agenda: (*attached*)

I. Member introductions and background

II. Election of Chair:
- Rep. Patrick Abrami was nominated by Senator Tom Sherman, seconded by Rep Gary Woods. Vote was unanimous.

III. Guiding Principles: (*see attached and attached HB522*)
- Senator Sherman: committee decorum protocol, ask permission of chair to speak or rebut.

IV. Statement of Purpose and Goals: (*see attached*)
- Rep. Abrami: Why do we need state level? Fed is not doing much. States are pushing back against the Federal government as small cells are rolled out in front of homes. Because we cannot see it or feel it, except those who are sensitive, doesn't mean it is

not an issue for health and the environment. A sixth goal was added to communicate conclusions to all federal agencies with jurisdiction and the Office of the President.

V Questions Needing Answers: *(see attached)*

-Senator Gray: We need to look at all radiation, not just 5G. Is it good or bad? Is is frequency? Intensity? How much is too much? Think broadly, not just 5G.
-Senator Sherman: Applying Precautionary Principle is most important. We are not looking for proof positive, but risk. Lack of knowledge does not equal safety. Is there potential harm here? Public health policy is not black and white. The goal is to protect public health.
-Rep Woods: we need a good understanding of baseline ambient level and levels relative to that.
-Kent Chamberlin: Concerns of cybersecurity and military issues and from sources not under U.S. control, not just biological.
- Denise Ricciardi: Health epidemic avoidance, constitutional privacy issues, data collection. Our job is to get to the truth for public health.
-Rep Abrami: Let it take us where it leads us. Root discussion is RF radiation. We cannot talk about 5G without RF in general.

VI List of organizations in which testimony will be requested. (see attached)

-Rep Abrami: There will be no problem bringing in people with tremendous science credentials. I am hoping to get someone in to refute that. We need back and forth discussion. The harder problem will be in getting people to testify rebutting findings. Joel is research resource for the commission.

Discussion:

- Rep Abrami: US National Toxicology findings, WHO, FCC. We need to understand FCC standards and why they only test for thermal effects, ignoring biological effects. We may need to skype people in as we do not have a budget for this
- Senator Sherman: who is making decisions at the FCC? Are they biased? What are their qualifications? Request background on decision makers setting regulations state and fed levels both
- Kent Chamberlin: limits are set very high compared to other countries who do look at biological effects. What can we, as a state do if fed level decision makers aren't qualified to be making those decisions?
- Carol Miller: We should have an industry report for NH. Where are we at for 5G deployment? How can we help mitigate for our constituents?
- Rep Woods: in hearing testimony, has study been repeated? Look beyond credentials of presenter.
- Rep Abrami: Would like to hear from Industry on this. And insurance?
  Kent Chamberlin: Can we look at where policies are done because of exposure to radiation?

- Senator Gray: Insurance writes exclusions because it's an issue or may exclude on Rumor?

VII. Meeting frequency, time & length

-every 2-3 weeks, initially.

two hours typically

- next meeting: Thursday, October 10,2019 8:30-10:30

- Kent Chamberlin will do brief presentation on waves.

- will need projector for slides.

- Dr Heroux may present if he is able to be at the next meeting.

VIII. Public comments:

– Jennifer White (Hancock,NH):

1. Jen and her son are RF sensitive. She manages two businesses out of her home. Agree with Senator Gray it is a greater issue than just 5G. However, the issue with 5G is we can no longer have control over the safety of our home/property environment. If that right is taken away, they will both suffer, as their own home will no longer be a safe place.
2. Response to Senator Gray's statement about some radiation is helpful ie. Killing cancer.. Jen's mom had cancer. The radiation did kill that. But she lived 3 years longer but died from Leukemia caused by the radiation to kill the cancer.

-Cherylyn Randolph LeBrun: (Loudon, NH): She has background in public health nursing. Her concern is for children and our future children. Please consider the long term effects on exposure to children who will have a much longer exposure than we have. Autism is a big issue. Please focus on pediatric neurology.

IX. Meeting Adjourned at 10:05 am.

HB 522 - VERSION ADOPTED BY BOTH BODIES

2019 SESSION

19-0261
05/01

HOUSE BILL *522*

AN ACT establishing a commission to study the environmental and health effects of evolving 5G technology.

SPONSORS: Rep. Abrami, Rock. 19; Sen. Sherman, Dist 24

COMMITTEE: Science, Technology and Energy

ANALYSIS

This bill establishes a commission to study the environmental and health effects of evolving 5G technology.

- -

Explanation: Matter added to current law appears in ***bold italics.***
Matter removed from current law appears [~~in brackets and struckthrough.~~]
Matter which is either (a) all new or (b) repealed and reenacted appears in regular type.
19-0261
05/01

STATE OF NEW HAMPSHIRE

In the Year of Our Lord Two Thousand Nineteen

AN ACT establishing a commission to study the environmental and health effects of evolving 5G technology.

Be it Enacted by the Senate and House of Representatives in General Court convened:

1 New Subdivision; Commission to Study the Environmental and Health Effects of Evolving 5G Technology. Amend RSA 12-K by inserting after section 11 the following new subdivision:

Commission to Study the Environmental and Health Effects of Evolving 5G Technology

12-K:12 Commission Established. There is established a commission to study the environmental and health effects of evolving 5G technology, which includes the use of earlier generation technologies. Fifth generation, or 5G, wireless technology is intended to greatly increase device capability and connectivity but also may pose significant risks to humans, animals, and the environment due to increased radiofrequency radiation exposure. The purpose of the study is to examine the advantages and risks associated with 5G technology, with a focus on its environmental impact and potential health effects, particularly on children, fetuses, the elderly, and those with existing health compromises.

12-K:13 Membership.

I. The members of the commission shall be as follows:

(a) Three members of the house of representatives, including one member from the house science, technology, and energy committee, and one member from the health, human services and elderly affairs committee, appointed by the speaker of the house of representatives.
(b) Two members of the senate, appointed by the president of the senate.
(c) A member of the public, appointed by the governor.
(d) The attorney general, or designee.
(e) Two members of the New Hampshire High Technology Council, appointed by the council.
(f) One member representing the Business and Industry Association, appointed by the association.
(g) One member of the New Hampshire Medical Society who specializes in environmental medicine and is familiar with electromagnetic radiation, appointed by the society.
(h) One member representing the university system of New Hampshire knowledgeable in radiofrequency radiation, appointed by the chancellor.
(i) One member of the cell phone/wireless technology industry, appointed by the president of the senate.
(j) The commissioner of the department of health and human services, or designee.
(k) One public member with expertise in the biological effects of radiofrequency radiation, appointed by the speaker of the house of representatives.
II. Legislative members of the commission shall receive mileage at the legislative rate when attending to the duties of the commission.
III. The members of the commission shall elect a chairperson from among the members. The first meeting of the commission shall be called by the first-named house member. The first meeting of the commission shall be held within 45 days of the effective date of this section. Seven members of the commission shall constitute a quorum.
12-K:14 Duties and Reporting Requirement.
I. The commission shall:
(a) Examine the health and environmental impacts from radiofrequency (RF) radiation emitted from the waves in the 30-300 gigahertz(GHZ) range of the electromagnetic spectrum, which falls somewhere between microwaves and infrared waves, and which are required with the rollout of 5G technology.
(b) Assess the health and environmental impacts of 5G technology, which requires small cell towers to be placed at a distance of 250 meters from each other at telephone pole height from the ground and will operate in conjunction with the 3G and 4G technology infrastructure.
(c) Receive testimony from the scientific community including but not limited to physicists and electrical engineers, the medical community including but not limited to cellular experts and oncologists, the wireless technology industry including but not limited to cell phone businesses and businesses working on the development autonomous vehicles which will rely on 5G technology, as well as other organizations and members of the public with an interest in 5G technology.
(d) Consider the following questions and the impact on New Hampshire citizens, municipalities, and state government of:
(1) Why the insurance industry recognizes wireless radiation as a leading risk and has placed exclusions in their policies not covering damages caused by the pathological properties of electromagnetic radiation?
(2) Why do cell phone manufacturers have in the legal section within the devise saying keep the phone at least 5mm from the body?
(3) Why have 1,000s of peer-reviewed studies, including the recently published U.S. Toxicology Program 16-year $30 million study, that are showing a wide-range of statistically significant DNA damage, brain and heart tumors, infertility, and so many other ailments, being ignored by the Federal Communication Commission (FCC)?
(4) Why are the FCC-sanctioned guidelines for public exposure to wireless radiation based only on the thermal effect on the temperature of the skin and do not account for the non-thermal, non-ionizing, biological effects of wireless radiation?
(5) Why are the FCC radiofrequency exposure limits set for the United States 100 times higher than countries like Russia, China, Italy, Switzerland, and most of Eastern Europe?

(6) Why did the World Health Organization (WHO) signify that wireless radiation is a Group B Possibly Carcinogenic to Humans category, a group that includes lead, thalidomide, and others and why are some experts who sat on the WHO committee in 2011 now calling for it to be placed in the Group 1, which are known carcinogens, and why is such information being ignored by the FCC?

(7) Why have more than 220 of the worlds leading scientists signed an appeal to the WHO and the United Nations to protect public health from wireless radiation and nothing has been done?

(8) Why have the cumulative biological damaging effects of ever-growing numbers of pulse signals riding on the back of the electromagnetic sine waves not been explored, especially as the world embraces the Internet of Things, meaning all devices being connected by electromagnetic waves, and the exploration of the number of such pulse signals that will be created by implementation of 5G technology?

II. The commission shall prepare and publish an interim and final report of its findings and recommendations. The reports shall:

(a) Outline the advantages of, and risks associated with, 5G technology running in conjunction with the 3G and 4G technology infrastructure.

(b) Develop a strategy, if deemed necessary, to limit RF radiation exposure from 5G or lesser generation technology relying upon electromagnetic waves

(c) Include a public policy statement on 5G wireless systems, which either declares the technology safe or outlines actions required to protect the health of its citizens and environment

(d) Consider alternatives to 5G technology that will accelerate information flow speeds and volumes without the use of electromagnetic waves that emit high levels of radiation

(e) Provide any recommendations for proposed legislation developed by the commission.

III. The commission shall submit the interim report required under paragraph II to the speaker of the house of representatives, the president of the senate, the house clerk, the senate clerk, the governor, and the state library on or before November 1, 2019, and shall submit the final report on or before November 1, 2020

2 Repeal. RSA 12-K:12 - 12-K:14 and the subdivision heading preceeding RSA 12-K:12, relative to commission to study the environmental and health effects of the evolving 5G technology, are repealed.

3 Effective Date

I. Section 2 of this act shall take effect November 1, 2020.

II. The remainder of this act shall take effect upon its passage.

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS
OF EVOLVING 5G TECHNOLOGY

Meeting held:
10/10/19
8:30-10:30am
LOB 202

Meeting called to order by Rep Abrami at 8:30am.

In attendance: (13) (Each member discussed their backgrounds)
Rep. Patrick Abrami-speaker of the house appointee
Senator Tom Sherman-president of the senate appointee
Rep. Ken Wells- speaker of the house appointee
Kent Chamberlin-UNH-appointed by the chancellor
Carol Miller-NH Business & Economic Affairs Dept.
Denise Ricciardi-public-appointed by the governor
David Juvet-Business and Industry Association
Brandon Garod-AG designee, Asst. AG Consumer Protection
Bethann Cooley-CTIA , trade association for wireless industry and manufacturers
Michelle Roberge-DHHS Commissioner of DHHS appointee
Dr. Paul Heroux- Professor of Toxicology, McGill University- speaker of the house appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee

Not present (1)
Frank MacMillan ,Jr. MD-NH Medical Society Environmental Medicine

Agenda: (attached)

I. Approval of minutes from 9-16-19
-minutes were approved with changes to be made for Rep. Wells name to be corrected and to correct quote attributed to Kent Chamberlin in error.

II. Commission in agreement to broaden out to RF effects beyond just 5G.

III. Dr. Kent Chamberlin Presentation: Electromagnetic Spectrum Physics: (see attached 6 pages)

- All information/data is transmitted merely as 1s and 0s.
- Everything is electrical in the data transmission system.
- Data rate= how fast you can send information= bandwidth, etc.
- The higher the data rate, the higher the frequency.

- Frequency is inverse relationship to wavelength. Increase frequency, the shorter the wavelength.
- The data rate can be no faster than half the speed of the oscillator for acoustic transmission. Therefore, data cannot be sent very quickly at low frequencies.
  Two fields are generated: Electric and Magnetic fields in electromagnetic transmission.
- Antenna converts voltage to E/M waves or the reverse.
- Wavelength is distance from peak to peak of the wave. The lower the frequency, the greater the wave length, the larger the antenna needed. Need high frequency, shorten wavelength to have smaller antenna.
  We need high frequency for high data rate for small antenna for mobile devices.
- 2.45 Ghz Industrial scientific Medical band.
- 800 Mhz-2.7 Ghz currently for cell phones same as microwave oven frequency.
- 5G is proposed to be 86 Ghz, significantly higher, close to the invisible spectrum.
- Photon Energy =frequency x Planck's constant= to find energy in photons of the frequency.
- Wave particle duality which is part of quantum physics is important to look at for health effects.

Sherman: why doesn't my cell phone fry my hand like a microwave oven if I put my hand in it?

Chamberlin: 1.5 Kw for a microwave is more watts of power than your cell phone. Power drives the heating. Increased power increases photons but energy remains constant. We need to look at Quantum Physics and photons

Rep Abrami: non ionizing vs ionizing?

Chamberlin: We need to look at photons for that EMR can be represented as discrete packets of energy called photons. If photon energy is great enough to detach electrons from molecules, you have ionizing radiation or heating, if power is great enough. It is a fuzzy line between ionizing vs non ionizing radiation. You will have heating if thermal radiation from microwaves is strong enough.

Sherman: if visible light is that far along the spectrum, why isn't it damaging?

Chamberlin: We know that it is. You are also exposed to UV rays in light like sun or tanning beds.

Woods: Can it be damaging but non-ionizing?

Wells: yes , an example of an egg frying.

Woods: Proton tunneling- protons go from one side to other of DNA which creates a misread or error. Non-ionizing is in that category because hydrogen bonding can be flipped during proton tunneling. Quantum physics. There is a probability it can go through the energy barrier. Be aware, because there are other mechanisms by which energy levels can be damaging but non-ionizing.

Chamberlin: EMF simulation- if we increased the wavelength and it strikes something like wet wood, some of the energy reflects back like radar. Some of it gets transferred into the wood or object. The wave is getting smaller as it enters because it gives up heat and warms the wood. You get heating from within and you do get heating from the outside.

Sherman: Does impact of reflected wave change the amplitude of the incoming wave?

Chamberlin: Yes. It causes a partial standing wave.

-High frequency supports higher data rates and allows for designs of convenient sized devices.

-Relatively (600 mw to 3 watts) low power of cell devices, supposedly won't cause heating.

- Signal loss increases with increasing frequencies which is why they need to be so close to towers.

-Cell phones adjust power output as needed. Cell works harder if signal is weak or antenna is covered. It will pump more EM energy into the user. (22-45 miles) typical cell power distance ranges.

The closer your cell phone is to your body, the power is significantly greater. What goes through someone's head while talking on cell phone? It uses your head as a ground plane before radiating outside, standing waves and resonances within cavities like sinuses. This isn't good. We need to ask. If it's harmful, what can we do about that?

Sherman: Are you saying that human tissue becomes part of antenna or diffuses power into tissue?

Chamberlin: Yes. Your head acts as antenna or ground plane. It excites current inside your skull and causes heating. Is it significant heating? I don't know.

Abrami: original studies in 1990s studied thermal effects. Studies say potential biological effects. As a Commission, we will be about science, not speculation.

Wells: Besides ionizing or non-ionizing radiation, other photo chemical reactions are at play. For example, vitamin D or Plastic beach balls out in the sun. The red ones fade from photo chemical reactions. It is consequential.

Sherman: Seacoast terrible cell service. Does that mean cellphones work at higher level then Manchester? If that's the case, are we getting more of one kind of EMR from cell tower? Or cell phone?

Chamberlin: If cell tower is far away, will not get constant radiation. However, your cell phone will give off higher radiation because it works harder to find the signal. But, we can choose to have a cell phone off or not radiation constantly.

Cooley: with small cells, your phone battery is not working as hard to find signal and works at lower power

Sherman: what are you getting in exposure from that closer infrastructure?

Chamberlin: which is worse? Short high bursts? Or constant low level doses?

Roberge: On your slide, the higher the red in the brain, the higher the intensity?

Chamberlin: yes.

Denise: Does that explain the rise in brain cancer?

Chamberlin: It's a correlation but is that causation? I don't know that answer. We need to look at epidemiology.

Wells: Brain Cancer and reproductive organs don't require big voltage to affect.

Woods: much of our tissue is ionized and that is a natural state. Your bones don't grow or heal unless you have an ionized state. Biological tissue can operate in an ionized state.

Abrami: Some say it's safe because it's non-ionizing. But is that a true statement? That's why I bring that up.

IV. <u>Dr. Paul Heroux Presentation, Biological Effects of RF Radiation:</u> *(see attached 6 pages)*

- Occasionally, we make mistakes in public health with uncertainty. Because we did not recognize accurately the danger, In 2007, we changed chromium 6 from 100 to 5 which is a factor of 20 that we misjudged safety. Workers under the old limits have 35% chance of cancer from exposure. The new limits reduced to 4.5%.

-Risk is a part of life. We cannot have zero risk. Important to realize that legal exposure limits are what is known at the time, for the exposed population, and if there are the alternatives should be part of risk assessment for an agent

-EMR standard came about after second WW. U.S. was the only country to produce a standard because they were the only ones who had that capability. The military was the source of deciding that heat would be the criteria.

- Navy, Air Force, Army EMR enormous importance in time of war .. would need radar to survive. Applications involving military were given high priority at that time.
Colonel George Knauf of USAF and Dr. Herman Schwann, bio-physicist, were those making decisions. At that time, it was perceived as non- patriotic to suggest any ban of use of Emfs because of Cold War with what was considered a nefarious power. People gave green light to military which was understandab e at that time.

Debating the danger of microwave: 1960-1990. There was a rift in science at that time.

-Biophysicist, Dr. Herman Schwann, using physics thermal guidelines for heating experiments with short 30 minute exposures. His understanding was limited at that time.
-Biologist Allan Frey used biology based guidelines, microwave hearing, blood-brain barrier leakage and chronic 24x7 exposure. Some research was fabricated to discredit his work.

Military point of view: yes there is doubt to risk but people in service get hurt all the time. So we err on side of keeping armed forces with best technology available. Lots of things are acceptable in times of war.

USAF standard from 1960 survived more or less in this form as standard today in the US. Interestingly, USAF was 10mW/cm2; General Electric was 1mW/cm2;Bell labs was .1mW/cm2 and the Soviets .01mW/cm2.

Soviets based their standard on nervous system disturbances, not heating. They provided two standards; a higher standard for their military and much lower standard for domestic applications.

The US did not accept this difference USAF, ANSI, IEEE, FCC...standards still based on heating... as being the only dangerous agent. It's not easy to measure real exposure in high frequency. This limited capabilities for biologists to be part of this process.

1966 Health Standards were ultimately developed by 15 people 10 from military,1 oil,1 space, 1 General Dynamic, 1 US Treasury and only 1 from Public Health.

Very heavily biased to applications vs biological affects.. are exposures for fighter pilot in F16 appropriate for children in classrooms today?

In commerce and engineering, people are highly motivated to promote product. If someone says, maybe there is a subtle affect related to your product that you have not investigated, most companies will not have the desire nor resources to do so. This is not a recent story. Adam Smith...warned if merchants have their way, they will act in such a way to promote their product... beware. This has lead in the past to public health issues:

-Air pollution is one of these. Air pollution is visible. However, no one realized it until 1952 when 12,000 people died in four days...and that was what finally motivated people because it was obvious.

-Lead: 1930s. They knew at the time it was toxic and GM could have decided to use ethanol in fuel but they knew it could not be patented and you could not make more money. The company decided to use lead instead. You may not die immediately, but your civilization will be inferior as a result... 15 million US children lost 10 IQ points as a result of that decision.

-We should use alternatives, if they exist for public health.

Today an average of three hours a day are spent on mobile phones, texting and internet access. The cell phone has been an incredible success. Schwann or the Colonel did not anticipate the situation we are in right now. This explosion in constant exposure should have changed the risk assessment today.

-We are being exposed to chronic man made waves in a very short span of time. The reason we adapted to the radiation of light is we have had millions of years to adapt. What is less certain is if we are resistant to other forms of radiation like man made technological radiation.

-RF exposure and Low Frequency exposure: all signals that carry data, function in bursts. Many biological effects we detect, refer to modulation at LOW FREQUENCY (non thermal and non ionizing). This is important.
What evidence do we have that this radiation is biologically active?

*Altered enzyme activity, biochemical changes, Oxidative Stress (ROS), pathological cell changes, neuro behavioral effects, DNA damage, Altered Gene Expression, Brain wave changes. (hundreds of research papers)

- Currently, 44% of the world is living under much lower standards vs. US and much of the western world which have the highest standards allowed.

-How did IEEE react to these facts?

Engineers had the notion that public health people are trying to get grants based on the success on the telecom industry. There was a great deal of suspicion as they used research unfamiliar to them. Public health people, doctors and biologists realized they could not bridge the gap between engineering and health.

Dr. Carpenter designed the Bioinitiative Report to establish a better standard. But this group is lightweight compared to interests of industry. Academics are a loose group with very limited means and the results had very little influence. The situation is starting to change in Europe in particular in allowing the exposure to humans.

What is 5g? What does it mean?

-Slice spectrum into tiny bands changing 12.5 times per second your cell phone can change frequency.
- Time domain multiple access in bursts.

-Space segmentation...instead of broadcasting in every direction use narrow beams, 3-10 degrees in width. Tom Wheeler of FCC said it's a wonderful new idea...but Russians had in 1981 most sophisticated radar... already in military long time ago but what is new is beam steering and beam focusing. This results in a lot more radiation and information being broadcast for the Internet of Things. (IOT)

- Noise is important. IOT seems like a great idea but it will be a self-fulfilling prophecy. It will be difficult to extract information from all the noise from all the waves constantly radiating.

-Some people think less penetration in the body will result from 5G...but UV causes skin cancer at penetration of .1mm which is less penetration than 5g.

Abrami: pulsing?

-Amplitude modulation... allowed us to send voice over large areas... modulated with voice of person. When FM came along, this allowed us large amount of stations but you had to allow more power. Then, we changed from analog to digital or data as it can be compressed. Now, it is sent as pulses. Are pulses more negative affect than waves? All indications are that they are more biologically active. The irregularity of the pulse creates a challenge to the organism. The organism is hit vs being pushed. Irregularity of the challenge to organism is important.

-3G/4G cell phones...we had a lot of exposure to these pulses. These bursts are so useful that this was not taken into account. You do not want your phone to use high frequency all the time so you can save power.

Sherman: The difference between 10Ghz and 50Ghz is less penetration but is there increase in intensity of penetration?

Heroux: Yes.You will have more concentration of energy.

-Caution: Phone industry wants to get rid of SAR because they won't be able to sell them because that concentration will raise the SAR above the limits. They will be illegal. They will say power density should be the new standard. All that will do is change the location of the cancer in the body as it will be more concentrated. Regulators are coming from the industry to set standards for their products.

- RF in cars is a public health threat. They will become radiation intensive. Companies are more concerned about "features" in car vs the biological effects.

-IOT is dream of engineers to put RF in anything that you can get information from. But they are also taking information from people without authorization.

-We want the capacity but should a company be able to put that in a product without my authorization or knowledge? It has to be controlled.

Abrami: Can you touch on autonomous vehicles? Colleges have grant money to look at it.

- It is **NOT TRUE** you need 5g for autonomous vehicles.
-Vision and laser scanning are being done at MIT. You need very rapid scanning but it is being developed.

-Engineers are smart. If we tell them to do it safely, they will.
-You don't need 5g for remote medicine although they will say you do because of low latency.
-In terms of humans, low latency does not mean much. It means a lot in a process in a plant or with robots, but not humans.
-Is it possible to non thermally affect cancer cells? Yes. Dr. Heroux's research
ALL cancer cells react to artificial EMFs.
-Low level radiation, similar to cell phone at low frequency have same or higher power of oxygen that can affect the body. O2 is fuel for body that generates ROS but we need O2. However, fields that produce larger effects like cell phones, we can CHOOSE not to have.
-Organs that need the most oxygen are most affected. Cells die more by necrosis than aptosis.
In 1900s rates of disease and chronic disease very different than what we have now.

Abrami: has your research been replicated? Yes... there are hundreds of research papers to support this.

Cell necrosis vs fibrosis:

Sherman: necrosis (cell death) to fibrosis (scarring)

Tissues most at risk ..are brain, pancreas which has high levels of ROS already, diabetes.

-Non thermal effects... RF changes behavior of cells..... which is why we talk about children and digital RF exposure in their lifetime. There are places now eliminating wifi from schools.

-Pregnant women, infants, children: cells replicate quickly, developing tissues are vulnerable, microwaves penetrate young brains more deeply.

- Reproduction and sperm counts are very serious subject but I do not have time to cover all effects.

-You don't need energy to affect biology, they are already ionized.

- According to Prof Martin Blank: DNA becomes unstable from EMR.

Our bodies are electrical machines...the movement of protons tunneling and effect on ATP synthase, which is one of the most sensitive places in the body result from EMR.

-Importance of cell phones are so great people are not willing to act on risk. We need to find a way to maintain function and minimize the risk

-If you expose brain to EMR; penetration of albumin in brain= egg white which carries toxins so now you have toxins carried into the brain. Alan Frey detected permeation of blood brain barrier. The lesions were occurring have pattern have no connection to simulation by a physicist. It means there is penetration of albumin into the brain. 50% of protein in blood is albumin. It is used to capture toxicants of all sorts so your body is not affected too rapidly. It captures it and releases slowly so you aren't shocked. When albumin goes into brain, it carries all toxins that you carry in body into your brain. It is not a good thing and happens in a very short time.

Ramazzini & NTP studies.... Yes... DNA damage & cancer particularly in nervous system.

Wells: EMR studies with plants? Yes...There is a lot of literature even with visible light. The visible light is not a grave problem because we have evolved over millions of years... tissues can adapt over time...rapid changes we cannot adapt to.

Abrami: We ran out of time. Dr. Heroux, you may finish your presentation at our next meeting.

Next meeting will be Thursday, Oct 31st at 9 am.

Nov 1st, first draft report due

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V. Meeting Adjourned at 10:30 am.

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS OF EVOLVING 5G TECHNOLOGY

Meeting held:
10/31/19
9:00-11:15am
LOB 202

Meeting called to order by Rep Abrami at 9:00 am.

In attendance: (12)
Rep. Patrick Abrami-speaker of the house appointee
Senator Tom Sherman-president of the senate appointee
Rep. Ken Wells- speaker of the house appointee
Kent Chamberlin-UNH-appointed by the chancellor
Denise Ricciardi-public-appointed by the governor
David Juvet-Business and Industry Association
Brandon Garod-AG designee, Asst. AG Consumer Protection
Bethanne Cooley-CTIA , trade association for wireless industry and manufacturers
Michele Roberge-DHHS- Commissioner of DHHS appointee
Dr. Paul Heroux- Professor of Toxicology, McGill University- speaker of the house appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee

Not present: (2)
Frank MacMillan, Jr. MD-NH Medical Society Environmental Medicine
Carol Miller-NH Business & Economic Affairs Dept.

Agenda: (*attached)*

I. Approval of minutes from 10-10-19:
-minutes were approved with changes to be made for proper spelling of Bethanne Cooley and Michele Roberge.

II. Webex (NIEHS) National Toxicology Program Study Presentation

Presented by Dr. Michael Wyde, toxicologist and Dr. John Bucher senior scientist and former Director of NTP Division, in the Division of the National Toxicology Program at the National Institute of Environmental Health Sciences (NIEHS), which is a part of the National Institute of Health.

- Interagency program (NTP) was established in 1978 with the: National Institute of Environmental Health Sciences, National Institute of Occupational Safety and Health, FDA (National Center for Toxicology Research).

- The NTP's mission is to evaluate agents of public health concern by developing and applying tools of modern toxicology and molecular biology.
- Their scope of work includes: research and testing agents of public concern; conduct literature-analysis activities to identify cancer and non-cancer human health hazards; develop new approaches to better predict how agents affect biological responses and communicate results to multiple stakeholder groups through technical report series, journal publication and the NTP website. (https://ntp.niehs.nih.gov)
- In 1999, the USFDA nominated radiofrequency radiation (RFR) of wireless communication devices to NTP for study.
- At that time, there were 100 million users. Today there are over 310 million Americans and 5 Billion worldwide, exceeding the number of people.
- Biological effects have been reported in cell-based tests and in laboratory animal studies. However, animal studies have not consistently demonstrated increased incidence of tumors at any site associated with exposure to cell phone RFR in lab animals.
- There are challenges and logistical issues associated with RFR study.
- According to FCC, RFR limit is 1.6W/kg. Needed to design a new way to expose to RFR for research. Study focused on 2G and emerging 3G technology at the time.
- Used reverberation chambers as recommended by National Institute of Standards and Technology (NIST): shielded room with RF antenna distributing frequency into the room with uniform exposure. The benefit is that they could control and monitor the exposure.
- Three phase study: 5 day, 28 day and 2 year, alternating on/off for ten minutes at a time and exposed to GSM and CDMA signals for both mice and rats.

NTP Findings:

- NTP's study on cell phone RFR is the most comprehensive assessment of health effects in rats and mice from exposure to 2G and 3G cell phone RFR.
- There was **CLEAR EVIDENCE** that exposure to cell phone RFR caused malignant schwannomas (heart tumors) in male rats.
- There was **SOME EVIDENCE** that exposure to cell phone RFR caused malignant gliomas (brain tumors) and pheochromocytomas (adrenal gland tumors) in male rats in addition to positive findings of DNA damage to hippocampus and equivocal findings in frontal cortex.
- In mice, equivocal evidence of carcinogenic activity in both male and female and positive findings for DNA damage in the brain in males and blood cells in females.
- Positive findings for lower weight babies exposed in utero for rats and at five weeks for mice.
- NTP uses a 4 level scale: no evidence, equivocal evidence, some evidence, clear evidence.

- Final conclusions represent the consensus of NTP and a panel of external scientific experts who peer reviewed the studies at a public meeting on March 26-28, 2018. Two technical reports: TR 595 (2018) and TR 596(2018) Note: these findings should not be directly extrapolated to human cell phone usage because they were done at higher exposure and to the whole body during research.
- NTP Publications published in journals: 2017 in IEEE and in Bioelectromagnetics in 2018.

Goals for further study:

- Address issues raised in peer review and do follow up studies.

-Smaller scale exposure facility and quicker time frame to get data out.

-Use newer technology: 3G and 4G

- 5G uses different modulation schemes and frequencies above 60Ghz which behave differently.

- Evaluate DNA damage, establish biomarkers of exposure and probe biological mechanisms for RFR induced effects.

-What role does DNA damage and repair play?

Questions:

Abrami: Was the level 1.6W/kg in 1999? Is it the same today?

Wyde: Yes. It is based on acute exposure based on tissue heating. NO changes have been made in twenty years to the standard.

Abrami: If current standard is 1.6W/kg, where did damage start at the three levels you tested?

Wyde: Heart tumors were significant at 6W/kg showing clear evidence with some at lower exposures.

Abrami: That is well above the standard of 1.6W/kg and I am assuming phones are lower.

Wyde: Theoretically, 1.6 W/kg is the limit for phone which is what device is allowed not the exposure to people. New evidence is that SAR from phones is actually higher than 1.6W/kg. Part of that is because phones are not supposed to be next to your head.

Chamberlin: Reverberation chamber to have homogeneous 1.6 W/kg exposure, but how does that correlate to holding phone next to your head for a human?

Wyde: You have pin point exposure to the head but we don't have data on what that exposure is to all areas of the body at the same time. This is why we can't directly apply results to humans.

Chamberlin: Frequencies for 5G. You mention 60Ghz but I heard 87-100Ghz which is much higher. That is significant. We also have Beth here from industry.

Wyde: I defer to the expert. I am not aware of any intention to move above 60Ghz.

Cooley: I am not allowed to be privy to future deployment plans as a rep for CTIA. I only have information that the public has because of antitrust laws.

Sherman: When we are in a network of wifi/phones like we are right now, is there a certain level of radiation we are exposed to without even using our cell phone?

Wyde: Yes. That is one of our concerns in an increasingly wireless world. What is our background level of exposure when we are sitting in a room surrounded by people with cell phones or a school with wifi? The way we use devices has changed. It's not just a cell phone. Actual exposures is important, not just what a device emits.

Sherman: So to get to 6W/kg in a human holding a cell phone to their ear, could they get to that level or exceed it? Or is it well beyond any potential exposure a human would have?

Wyde: That exceeds what a device is capable of. But independent studies have looked at that showing it exceeding 1.6W/kg.

Sherman: Does exposure increase with increasing 2G, 3G,4G and 5G capable phones?

Wyde: no. the G means generation. (Woods, Heroux shaking heads…YES it does)

Gray: Does the energy emitted by antenna that is absorbed fall off as a cubed function?

Wyde: No, not cubed but squared.

Gray: Area is two planes, three dimensional is cubed. I would think it would fall between those two planes. I will explain later why I asked the question.

Wyde: That is not our area of expertise.

Chamberlin: I am not sure it's relevant.

Wells: Talking about intensity of field as opposed to photon energy. Photon energy definitely goes up as frequency increases.

Ricciardi: DNA damage was found without a degree of body temperature change which means non thermal effect. The FCC limits say that one degree of body heat is considered thermal heating. So what does that say about the FCC limit? Does that mean that this is harmful?

Bucher: That's one of the things we need to look at in the future. One idea is that there is an inhibition of the repair process. DNA damage happens all the time and is RFR slowing rate of DNA repair? We need to look at that.

Ricciardi: I am still not clear. Your study was designed to test non heating damage. You found damage so doesn't that mean that FCC assumption that only heating can cause damage is incorrect and no longer accurate? Would you agree?

Wyde: A lot of people believe unless you heat tissues, you won't see health effects with RF. This study disproves that as we did not have over heating but we did see damage.

Abrami: Dr. Chamberlin hopefully will bring in someone from IEEE to help us understand how they developed those standards.

Sherman: Was there any way to determine cumulative exposure rather than dose related? Or did you not look at that?

Wyde: We did not look at that when we designed studies.

Woods: Question on the structure of cages? What was it made of? Were they metal? They look like a faraday cage. Where was RF measured?

Wyde: That's a very good question. The chamber is stainless steel. Anything in the chamber was non metal so it did not affect the signal. We did not want to heat anything or cause problems for the animals. NIST took measurements to make sure there was uniformity in the whole space.

Abrami: what is a faraday cage?

Woods: Faraday cage is a metal mesh network that prevents RFR exposure to what is inside.

Woods: Why did you use rats and mice? Why were rats started in utero and mice at five weeks? Any animal is much more sensitive in utero to damage. How much of result was attributed to in utero?

Bucher: Traditionally, all cancer studies use both rats and mice. We only use in utero exposure with rats because it's harder to use hybrid mice in utero. By using both, we get more information than we would normally.

Wyde: Part of the reason for in utero, is it mimics human exposure in utero.

Roberge: Were you able to see the difference where health effects occurred, with regard to various levels, knowing your exposure was above the 1.6W/kg that a device is permitted to emit?

Bucher: We need to backup and understand what we were trying to do. We needed to make sure we did not use thermal limits more than one degree of body temperature that animals could tolerate. Different sized animals absorb different amounts. Rats because they are larger, could only be exposed to lower levels because we saw the largest response on the largest animals. They were affected more with strongest responses to RFR.

Roberge: Are you looking at synergistic effects of multiple frequencies in your future studies? Does that influence exposure?

Wyde: yes that is part of what we are looking at. How are people's exposures going to change with 5G? That's very important as we move forward.

Chamberlin: Are the signals realistic by alternating regular modulation, since it's not realistic compared to the pulsed or bursts we are exposed to now. Cell phones don't radiate continuously. Did you look at that?

Wyde: We tried to create scenarios with spikes and ten minute on and off exposures. We had modulating patterns that would mimic conversation on cell phones. We tried to create relevant exposure scenarios.

Bucher: We used actual GSM and CDMA signals that spike. GSM modulation when signals are sent only 1/8 is the spike. That is what we used.

Abrami: Legislators are being faced with push back on small cell towers with 5G at street level and every 250 meters apart with millimeter waves.

Bucher: We are keeping close eye as 5G emerges.

Heroux: NTP study was designed quite a long time ago. Our situation is that we deploy things and the time to assess health impacts is much larger than rapidly evolving technology.

Sherman: Can you recreate background daily exposure to what we might anticipate by increased number of 5G towers in a neighborhood using this model? I would like to know BEFORE deployment.

Wyde: The technology is not capable of doing that with 5G frequency.

Bucher: Our exposure depends upon how we are positioned with respect to antenna. To study 5G and combine with lower level exposure, is an enormously difficult scenario to recreate.

Wells: For base station towers 250 feet apart, the energy density is 5x higher than a cell tower. The depth of penetration in tissue, the higher the frequency have higher photon energy, the amount of energy being absorbed in a thin layer is significantly higher. Would you agree?

Bucher/Wyde: yes. We would agree. But power levels are lower.

Ricciardi: power levels are lower but it's in close proximity 24 hours a day, which is microwave radiation. Would that not heat tissues over time? If so, would we assume 5G would not be safe?

Wyde: No. Our exposure is a function of distance and power levels and other factors .At this point, we don't' know.

Chamberlin: Your category, Clear Evidence. Can you compare that to relative risk?

Wyde: No. clear evidence is a descriptor we use in our cancer studies. It does not relate to relative risk in the human population.

Chamberlin: Are you using P value of .05 as statistically significant value?

Wyde: We look at .05 as cutoff as statistical significance but often the clear evidence findings have a lower P value.

Sherman: We should get their peer reviewed articles. They may have more data in them.

Chamberlin: It would be nice if they could compare it to smoking or something.

Ricciardi: There is an online library at: https://onlinelibrary.wiley.com They just published new findings in October.

Woods: We need to be cautious because we cannot make one to one correlations with humans when we look at these studies. For example: if aspirin (djoxin) was tested today, it would be banned because it causes cancer in mice and rats. So we need to be careful when looking at these studies. Is there a significant difference between a rat and a mouse?

Sherman: We have to be cautious before we extrapolate to humans but we can't test humans without a long period knowing their cumulative exposure. You can't recreate it because it takes 20 years for people to die before we know anything. Hopefully, we will take as much evidence as we have. Because what we have seen in other industry settings with contaminants, we don't know until a lot of people die. They cannot recreate this in a lab. It's a warning on both sides.

Woods: We have to be able to say, we don't know. Some of the other literature, they were criticized for poor standards.

Ricciardi: Ramazzini Institute studies duplicated that study, using very low standards.

Wells: These are very difficult studies to do. The human body is an antenna. Larger animals are more exposed. Humans are much larger than mice or rats. They are studying critters smaller than the wavelength. When we talk about base stations for 4G transmitting at 100watts but KM away, that is much less than the magnitude of intensity from 10's of meters away of 5G antenna, even if it's only 7 watts. A flaw in this study is that they are treating them as chemical exposures. The room has a uniform feel but when it hits the skin, it's no longer uniform. Penetration depth is important. With 5G that's a very thin piece of tissue getting a lot of penetration. It's difficult to study.

Heroux: Mice and rats are only superficially similar. They are used because they are cheap, easy to handle. We know they are different and provide different information. Toxicologists know about these things. That is why they design a model on how to use animals in these experiments, which is extremely complex.

Cooley: What is on the towers is not line of sight technology. Small cells are. They are not beam forming. We will talk about this at future meetings as well.

Sherman: I have a comment on autonomous vehicles. People claim you need 5G for those. My nephew is one of the lead engineers for the Google vehicle, Waymo and he said the very definition of "autonomous" is autonomous. It does not or should not need wireless or power networks to depend upon. I don't think the ongoing claim that autonomous vehicles need 5G, is true.

Heroux: I agree MIT as well has a car that does not rely on 5G. There are many ways autonomous vehicles can operate using: vision, laser scanning, ultrasound. EMR is not required.

III. General Discussion:

We will hear from Prof. Eric Swanson, U. Pittsburgh provided from Bethanne Cooley at the next meeting: Thursday, November 21st at 8:30am.

Interim report: Agreed upon with correction for non-ionizing statement to reflect properly Ken Chamberlin's opinion from his presentation.

IV. Frank Clegg Video: Framing the Issue:

- Former CEO of Microsoft Canada, 40 years in technology sector.
- Current implementation of wireless is not safe.
-5G is not tested.
-Millimeter waves are used by the military for crowd control.
-We are advocates for safe technology, not, no technology.
-FCC is made up of previous telecom, lawyers and engineers not doctors.
-No oversight provided by FCC. Telecom industry is self-policing.
-1996 Telecom act prevents anyone from suing Telecom for health injury.
- Countries like China, Russia, Italy and Switzerland have safety limits 100x safer for citizens.
- Today we have significant exposure in our homes, schools, work and public spaces.
-Many states and cities are questioning safety, while the Federal Govt and some other states are fast tracking 5G.
-Many health and mental health effects, including permanent DNA damage.
-Individual, state and local rights are being passed over to telecom industry. That is a significant and historic power shift in rights. Telecom has over 500 lobbyists.
-Swiss RE has designated 5G as a significant insurance risk.
-Convinced there are safer alternatives available so we can have technology safely.
- We need to advocate for change to allow industry to become more responsible.
-Most important thing you can do is to get educated and educate your family, friends, co-workers, state, local and school officials. Knowledge is power and your power is in your hands.

Abrami: If anyone has any questions for Frank Clegg, we can contact him to talk with us.

That video encapsulates a lot of the issues we are dealing with here.

V. Dr. Heroux Completion of Presentation of Biological Effect:

-Human evidence: two documents that are very detailed human evidence: ELF (power systems) and RFR(communication). Both classified both high and low as possibly carcinogenic Class 2B. IARC repeats old notion that there is no mechanism that supports this. They are great epidemiologist but not cognizant of other things. Anthony Miller is worried about rollout of 5G because he is seeing an increase in student 15-19 increase 1%/year in lethal brain tumors. He would like IARC to go back to reclassify because IARC said there was a lack of animal studies but there are many studies which was the reason for the Class 2B. How many will they ignore? He would like it classified as a class I carcinogen.

-Another study shows with a cell phone one and off, that glucose metabolism is increased in the brain when cell phone is on. This is not thermal or heat related but it is an effect.

- Also troubling evidence on increasing gray matter changes.

-Hypersensitive: those who feel its impacts. In Finland, there is software to plot a path from where they live to where they want to go to minimize exposure to radiation. This software has been downloaded 200,000 times. These people are very real. Contrary to what a lot of the medical community is telling them, it's not in their mind. They are physical reactions and not everyone has same effect, nor should they. That is typical of medicine. One of the reasons is that many of them have variants in Glutathione enzyme which is a major detoxifier. EHS people have variations in this enzyme 10x higher than non EHS. Genes will not allow them to produce effective versions of glutathione transferase. The next generation will likely be more sensitive if both parents have this variant. You see a lot of people with EHS, who also have multiple chemical sensitivities because they share the same detoxification mechanisms.

- Proton tunneling: basic mechanism of action of EMR on tissues. Ionizing argument is beside the point. Biological systems are ionized. This is relevant. Stability of materials is an illusion. Every molecule of water decomposes and recomposes. PH of pure water is 7. This is based on the mobility of protons. In every living system, mobility of protons is very important.

- - Oxidative phosporylation is arguably the most important process in the body. Science did its work on this very quickly after concerns of EMFs on this process. Essential mechanisms of action were discovered of EMFs but ignored. A group of enzymes from 1-5 synthesize ATP. Protons and electrons have to move through our body. EMFs affect the movement of theses affects function of enzymes. When protons and electrons are free, they are vulnerable to EMR especially ELF components. Within Mitochondria, you have a PH of 1. You have the highest electric field. If you apply EMF to this system, you disrupt the flow of electrons and mainly protons. Entry channel is completely hydrophilic. It has the same structure as ice and the way enzymes work is proton tunneling. Through this, the proton is vulnerable to fields as small as 20 nano-tesla as confirmed in experiments. This is very vulnerable to EMR. The semiconductor industry has devices that work on the same principle. If you reduce ATP activity, electrons have to jump across distances and are vulnerable. There are 400 publications that talk about these effects on enzymes from EMF. These electrons form ROS (reactive oxygen species) and have a hard time functioning. The jumping of charges from one place to another creates a lot of room to interfere with propagation of electrons that support metabolism of cells. The science behind tunneling mechanism is… If you have a quantum of energy of any frequency, you are going to have a change in probability to jump from one place to another. This happens at levels way below thermal levels of FCC.

At Duke University in 1985, research showed changes the function of mitochondria but he was ignored. Nobody reads science or a paper unless someone needs them. The mechanisms and science are there but they are unknown.

I agree with Frank Clegg. We can get everything we want. You don't to fear you will lose your cellphone or go back to the dark ages. We can do this very well. We know engineers can do this.

Woods: Buran zones are happening at mitochondria level.

Sherman: Can we get the digital link to the slideshow?

Abrami: We have a website now where all info is posted.

Sherman: When you talk about impacts at exposure much less than our limit, does is increase cell death in terms of end organ damage?

Heroux: Biology is an electrical motor. We are electrical. Any field is possibly going to interfere with this.

Heroux: I exposed cells to radiation and see how cells died. It's not to kill them but does it change how they die by being exposed to EMF. If you compare the power of fields in everyday life, their ability to kill cells is higher than oxygen, creating ROS. ELF component of Telecommunication signals is a significant component.

It increases cell death and diverts cells toward necrosis vs apoptosis. The cell doesn't have enough (energy) ATP and it gives up and goes into necrosis. EMF has power to increase ROS leading to chronic diseases with inflammation like Alzheimer's and Diabetes. So why add on to the load we already have with ROS? We can control electric and magnetic exposure. If you ask at a hospital how many Parkinson's, are related to EMF exposure? They say none and claim EHS people don't exist at all. It is a part of chronic illness. I am not saying it's all of it but it is a part. We have just gotten used to these illnesses. If you can decrease diabetes 20% by reducing this effect, you will save a lot of money in medical care if you address this issue.

V. Meeting Adjourned at 11:15 am.

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS OF EVOLVING 5G TECHNOLOGY

Meeting held:
11/21/19
8:30-10:35am
LOB 202

Meeting called to order by Rep Abrami at 8:30 am.

In attendance: (11)
Rep. Patrick Abrami-speaker of the house appointee
Rep. Ken Wells- speaker of the house appointee
Kent Chamberlin-UNH-appointed by the chancellor
Denise Ricciardi-public-appointed by the governor
Brandon Garod-AG designee, Asst. AG Consumer Protection
Bethanne Cooley-CTIA , trade association for wireless industry and manufacturers
Michele Roberge-DHHS- Commissioner of DHHS appointee
Dr. Paul Heroux- Professor of Toxicology, McGill University- speaker of the house appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee
Carol Miller-NH Business & Economic Affairs Dept.

Not present: (3)
Frank MacMillan, Jr. MD-NH Medical Society Environmental Medicine
David Juvet-Business and Industry Association
Senator Tom Sherman-president of the senate appointee

Agenda: (*attached)*

I. Approval of minutes from 10-31-19:
-minutes were approved with comment from Rep Woods.

II. Dr. Eric Swanson: University of Pittsburgh, Professor of Physics Presentation
(*Here at the request of CTIA but the opinions are his own)*

- There is a lot of misinformation and misunderstanding out there + fear of the unknown= trouble.
- Fear of the unknown is what links past worries like power lines and radio waves causing cancer cellphones killing honey bees to the current ones about 5G and cellphones.
- Millimeter waves (similar to 5G) are used in Russia therapeutically for over 50 diseases.
- It is not plausible that the same radiation can both cause and cure 50 diseases. It does neither. It does nothing.
- It does not affect living things: and I have two main points.

Ricciardi: Experiments with 5G on bees show that bees are affected. Bees absorbed more with higher frequencies.(Scientific Reports: 2Ghz-120Ghz). This could lead to changes to insect behavior over time. Can you confirm based on scientific evidence that these frequencies are safe for pollinators? What credentials do you have to speak to this?

- Swanson: It's scientifically not plausible that these waves have any effect on ANY living thing. Biochemical response of a bee cell to EMR is the same as a rat cell and a human cell. That is my scientific opinion. It's true that EMR does not do nothing.

- As far as credentials… There are two aspects:
- 1. The radiation itself: we understand perfectly since 1875. There are no questions and no ambiguity. This is where I come from.
- 2. The biological response: it's difficult to measure. It's complex and messy. We can explain it all with general physics terms, not fancy biological terms.

Heroux: The IEEE standard is based on resonance between dimensions of humans and for example (70MHz) frequency of radiation. Frequencies that match the size of the bees, the transfer of power will be increased by a large factor. These parameters have been recognized by engineers, physicists, etc. not just biologists. They fly everywhere, not walk on the sidewalks and are likely to go to areas where power densities are very high. In my opinion, you are not showing much concern for the small pollinators that we need to survive.

Swanson: I disagree with everything you said. If you want I can go into details of why. Resonance is in fact related to size of important bio mechanical mechanisms inside of cells. There is a famous paper by Robert Gadera (sp?) from twenty years ago showing these resonance effects just cannot occur. These are not relevant to biology and cannot occur inside of cells. You said bees are attracted to these things. I would love to see the study saying bees are attracted to radio transmitters. Bees are actually attracted to flowers. It's true they don't walk on sidewalks. Transmitters are built where people live, not bees. That means they are even more removed, not closer.

Woods: I want to clarify your idea that the Bees are like rats and humans. We know if we test djoxin/aspirin today, rats get cancer but people do not. Can you please clarify what you mean that they are the same? That seems to break down there.

Swanson: This is a good point. You have to be careful about comparison and I was talking about the cellular level.

Woods: But chemicals are processed at the cellular level.

Swanson: If you are feeding aspirin to a rat vs to a human and if they normalize for the size, I would expect the response of test subjects to be very similar. But it's not what we are talking about here. Chemical reaction is far more energetic than reactions that are relevant to cellphones. Chemicals are like taking a hammer versus a gently tweaking it, like a cellphone does.

Chamberlin: On the previous slide, you mention exposure in some cases provides positive therapy. You are saying that it can't be both helpful and harmful. I disagree. For example, sunshine is a form of radiation. It is both beneficial like Vitamin D, etc. and harmful like skin cancer, depending upon exposure. I disagree with the premise stated there.

Swanson: You are right. There is room for something like this to happen. Like I said, I don't find this plausible and I have a reason why I don't find it plausible but I will get to that.

Abrami: On your electric towers slide, you said were definitive studies disproving health effects . We are trying to get at is, are there definitive studies RF in general whether it's 3G, 4G or 5G. Right now I don't know of any definitive studies saying whether 5G is good or bad. As a legislative body, we are trying to understand. We are blessed with having people in the room who understand these things. We have to be responsible to our public. If a small cell tower appears in front of their house, they will want to know, where is the definitive study showing its safe?

Swanson: Valid question. But those studies were specific to those towers. I completely respect that as a question.

<u>Electromagnetic Basics:</u>

- Electromagnetic radiation is the best understood phenomenon in the universe.
- It is not nuclear radiation.
- It is completely described by three numbers (intensity, frequency, and polarization) which makes it so well understood and so simple.
- Electromagnetic spectrum is a continuum from zero to infinity.

Ricciardi: Are you saying that you do not believe a potential mechanism exists for non-ionizing radiation to harm us?

Swanson: I will get to that in a minute. Do you mind?

Abrami: Let him cover non ionizing radiation and then ask your question.

<u>Health Effects:</u>

- You are well aware that there are health effects on this spectrum.
- UV radiation is dangerous. It's not good to get too many x rays. There are two scanners at the airport and you should go through the mm wave scanner not the x ray scanner because x rays are dangerous if you expose yourself to too many.
- Gamma rays are very dangerous. They will outright kill you.

- Ionizing radiation is damaging because of how it damages things. Your body responds by producing more melanin. DNA regulates reproduction of cells. You could mess with the reproduction of your cell and you get cancer. You don't want to damage your DNA.
- Shorter wavelength waves carry more energy.
- Visible light is just below UV light. Threshold effect between UV light and visible light. We can be in visible light all day and never get cancer because visible light is lower in energy. It is only a bit lower. There is no gradual tailing off. There is a threshold. This threshold effect between UV light and visible light was explained by Einstein in 1905. He won the Nobel Prize for this. That's called non ionizing radiation.
- There is a threshold 1.77ev and 2.25ev or minimal energy needed.
- The important thing: is that there is a photo electric effect.
- You need ionizing energy to remove an electron off its atom.
- When we talk about non ionizing radiation, there is no cumulative effect and there is no intensity effect and no effect on cancer.
- Ionizing is above the threshold effect. Non- ionizing is below on the spectrum.
- It doesn't matter how far below the threshold. Something could be just below threshold or far below threshold. It doesn't matter. The threshold is only thing that matters.
- Non Ionizing radiation has no known effect on the human body other than heat.
- Heat is just heat and motion of molecules.

Abrami: I understand water vibrates to heat in microwave but you wouldn't put your head in a microwave would you?

Swanson: I actually intend to put my head in a microwave next week.

Abrami: You are pulling my leg now, right?

Swanson: no. I am not going to have it at full power and will probably put my hand in. My point is, it's regular heating and what I will feel is my hand getting warm and then I will take it out. It's just like putting your hand on a radiator.

Wells: If radio frequencies that are non-ionizing have no effect, can you explain how radios work?

Swanson: they have no known health effects on tissue except for heating. EMR is absorbed by your skin. About half of it is reflected by the body. Metals are special because the electrons are mobile. Our electrons are attached to a molecule. They are hard to move except the salty water part of the cell. The signal in the radio just turns into heat.

Ricciardi: Thank you for explaining that. Before I ask my question, I want to understand what you said. It sounds like what you were saying is due to oxidative stress not heating. Did I understand that correctly?

Swanson: No. I didn't say any of those things.

Ricciardi: Well then. Are you saying there is no real potential harm for non-ionizing radiation?

Swanson: To the degree that you don't cook yourself, yes.

Ricciardi: There are several studies and if you can debunk them. I have a copy for you.

Abrami: Dr Swanson, can you address these later for time sake during your section on studies?

Swanson: Yes. I will address generic, not these particular studies later.

Chamberlin: I just want to say it's quite a statement and in preparation for service on this commission, I did a lot of work reading published peer reviewed journals and a lot of them DO say there are biological effects. So I am assuming you will address those.

FCC Regulations:

- I want to clarify misconceptions about the FCC.
- The FCC does not conduct experiments. It sets regulatory limits based on the evaluation of relevant literature made by many nation and international agencies.
- One of these agencies is: IEEE which has a rigorous policy creation process.
- I was very impressed with their methodology for how they come to their decisions.
- They are very thorough. They have various working groups where reports go into a committee called sub- committee four.
- Sub-committee four has 125 members in it. They have a broad swath of expertise.
- They looked at 2,200 papers.
- 5G is just part of the spectrum. It's the 30Ghz part of the spectrum. 5G is new. The physics and biology of 5G is not.
- You don't have to do studies at 5Ghz. Where do you draw the line? The difference between 4G and 5G is essentially meaningless when it comes to the response of humans to this radiation.
- FCC has two primary measures: Thermal behavior. IEEE determines thresholds of watts/kg.
- FCC sets its limit 50x lower than the limit detected on animal studies. Based on that they get the SAR (Specific Absorption Rate which should be less than 1.6w/kg) That is an extremely conservative number. I mentioned a heating pad earlier that is roughly 100w/kg.
- Another method is the MPE (maximum permissible exposure) Effects on humans start at 100x higher than the limit.
- Why are there two standards? BC at higher frequencies like 5G that does not penetrate as far in the body so it's hard to measure so they use MPE.
- 5G is called small cell because they are low power and closer together and about 30 feet high.
- Your exposure is about .4% of the extremely conservative limit if you stand at the base.
- It occurred to me that light is EMR and what would happen if the FCC regulated light? Or the sun? They don't for obvious reasons. We can see light. They expect us to react responsibly.
- For a 100W light bulb six feet away, you are at a quarter of the FCC allowable limit in terms of thermal exposure. Three feet away, you are at the FCC limit.
- If you stand outside in the sun, you are at 1600% of the FCC standard for exposure limit.

- The sun would be outlawed if the FCC regulated it.
- Should we worry about standing under a 5G tower? I would say no.
- Another example is the brain. It is a radio transmitter transmitting at the thermal end of the spectrum far higher in energy than 5G. Your body is 85W machine. The brain is 15W. It uses a lot of energy. The brain weighs about 1 kg. So I estimate an SAR of 15w/kg. So thinking would also be outlawed by the FCC whose limit is 1.6w/kg.
- Let's get to what is does to you. It heats the skin up. The higher the frequency, the less it penetrates the skin and 5G is at the very surface.
- 10W/m2 is the FCC limit. Temperature rise at the surface of the skin. According to this model (The Human Body and MM Wave Wireless Communication Systems accepted2015 IEEE International Conference) which shows a rise in temperature for different energy densities. The SAR limit of 10W/m2 results in about .1 degree temperature rise.
- You would have to climb the 5g pole and hug and wait for your skin to rise .1 degrees.
- It would create more heat just in the energy to climb the pole. It's not magical stuff. It's just heat energy.
- Stepping outside or drinking a cup of coffee, you get a larger rise in temperature than irresponsible behavior of climbing and hugging a 5G pole.

Cooley: When you showed the heights of the various towers and small cells, because there will be 5G on towers as well. Can you speak to the difference of towers at 100-200 ft vs the small cells at 20-50 ft. Can you talk about the exposure based on the higher it is, the exposure decreases? I am making an assumption. If you use an average 150ft tower vs a 40ft small cell.

Swanson: If you are asking what would happen if the tower was 40ft instead of 20, then all of those numbers would go down. If you double the height, you go down by a factor of 4 if you are standing right under it. It's not that clean cut. With a higher tower, you have more powerful equipment. It's the same thing with 5G. If it's a 40ft tower, there will be more powerful equipment on that small cell. You have to take that into account. I am speculating that when engineers design the towers, they figure how to get down to 1/1000th of the FCC limit. According to research I just read, there are countries that measured levels at 1/1000th of the FCC limit. It wouldn't surprise me if it ends up being a wash if you double the height.

Cooley: Please clarify a term you used, lens opacity. What is that?

Swanson: It's the beginnings of cataracts.

Roberge: When was the FCC limit set?

Swanson: This is an ongoing thing. I can partially answer this. I know that the IEEE did this in 1996 and did it again in 2005. I believe the FCC monitors these new standards as they come out .But I don't know that they had an official meeting to incorporate all of that. I believe there is something in the news about reinstating a meeting.

Abrami: Yes. We have a paper on this.

Swanson: I believe you know more than I do about this.

Roberge: When they set this, they were only looking at heat effects on the body. Do you know when they look at this again and will that include other biological effects?

Swanson: I wouldn't quite put it that way. They looked at 2,200 papers. They don't just go, oh this one deals with other effects and throw it into the garbage. They take all of it into account. Of course, the things that you focus on are thermal effects because those are easily measurable. Other effects are random.

Heroux: You describe the review process of the IEEE in glowing terms.

Swanson: Yes. It was glowing. I was very impressed.

Heroux: Were you there?

Swanson: Was I there? No.

Heroux: Are you a member of SC3 or SC4?

Swanson: No.

Heroux: You don't go to IEEE meetings?

Swanson: Nope

Heroux: So in other words, your description of this review process is based on what you were told.

Swanson: That's correct and from what I read. Yes.

Heroux: Ok. I was there. I can tell you that this process is far from impartial. I have personal experienced it and if you want, I can tell you how it happened. At the time, I had designed an instrument that measured pulsed EMF. I was part of an epidemiological study at McGill. It was found that all the underground workers exposed to these fields and smoked, systematically died of lung cancer. …All of them. This was done by Armstrong a biostatistician who is now in London. I was charged with informing IEEE of this. I was a member of SC4. I went when Eleanor Adair was presiding and I unfolded what had happened. Eleanor Adair said we will form a committee and we will look at this. There was a separate meeting. They wanted three members to join the president to study this. I was the one who designed the instrument and the only one at the time who knew of the epidemiological study determining this. At that meeting when they asked for volunteers, I raised my hand. Since only two other people did, I thought I am going to be able to discuss this openly in an IEEE committee. I was never called. This reflects the fact that your selection of the people controlling these committees and the literature that you review is very partial. It's not for some conspiracy but because of the fact that there is a natural tendency to assemble similar opinions in a given location. Are you aware that Eleanor Adair, who was president of SC4 for years and yea, at the time that she was supposed to be a judge on whether non thermal effects occur, simultaneously published a paper in the open literature promoting the idea that we should heat the people rather than houses.

Abrami: Dr. Heroux, is there a question you want to ask?

Heroux: Yes. The review process is very difficult to control and hard to be impartial. I have lived through these difficulties. When you haven't lived through the process, it's very difficult isn't it? to be entirely certain that it's entirely impartial? Would you agree?

Swanson: That is way too generic for me to agree.

Abrami: We are hoping to hear from IEEE, so we can form our opinion on that.

Swanson: Personally, if I formed a subcommittee I would not want one of the paper's authors on the subcommittee. It would be biased.

Wells: can you give us an idea of the wattage of a 5G transmitter and handset?

Swanson: The handsets will be similar to current handsets that operate around a watt. The 5G transmitters are much smaller than 4G. I ask this question many times and I always get the run around. The reason is because different sites and different manufacturers have different specs. Roughly speaking, it's 10-20 watts for the transmitter.

Wells: The function of 5G is communications so how would you relate data rate to intensity and frequency?

Swanson: Those are good questions. One of the major goals of 5G is to increase data rates. Apparently, everyone wants to watch their videos on their cellphones. That's why this higher frequency is needed. The reason these need to be closer together is higher frequencies have trouble penetrating wet air. The more humid it is, the harder it is to penetrate. So they tend to be closer together, low power, high frequency.

Wells: The power density in w/ square meter. Is that a parameter that affects data rate?

Swanson: Yes. Actually it is. The stronger the signal, the more data you can push through. Dr. Chamberlin can probably address this better.

Chamberlin: I wanted to get clarification on the setting of limits. You mention two ways. One is the IEEE going through publications to find out what other people have established as safe limits. You also mention there was an animal study where you expose some sort of animal to increasing amounts of radiation until you saw a change in their behavior. Then, you use a factor of 50 below. Which is it? Do they use both together?

Swanson: I didn't see a conflict there. Part of what IEEE is doing is looking at animal studies. That's one of the things they look at. That's what the IARC looked at as well, animal studies. So they are looking for any effect.

Abrami: But, isn't it just thermal effects they are looking at?

Swanson: No. they look at everything under the sun. These guys review what scientists look at and the only thing that actually sees something definitive is the thermal effects.

Chamberlin: But these are short term studies and that's my concern.

Swanson: They vary.

Swanson: I touched on it before and I will talk about this again on a famous NTP study later.

Ricciardi: I just wanted to clarify something on the FCC. I have a couple of documents stamped from the federal government in 1985. A letter written from the EPA to the FCC and it says they have done the studies on the heating of tissues and explained to the FCC that they needed to do studies on non thermal effects because it can heat chronically low over time. Heating of tissues vs non heating of tissues and only heating was studied when the EPA wanted to go further. The FCC responded by saying they were taking this out of the hands of the EPA and putting it into the FCC's hands. So we no longer have a health agency representing us doing those studies. The FCC is not a health agency.

Swanson: That's right. They are not. They have a committee and listen to what they tell them. They know what they are talking about.

Ricciardi: I think these scientists that have done peer reviewed studies know what they are talking about. How many peer reviewed studies have you done?

Abrami: we are going to get to the next topic.

<u>Studies:</u>

-Everything I have been telling you is consensus, mainstream science.

-There is no fringe aspect, controversy or conspiracy theories.

-In the internet age, it is possible to find a "respectable" source that says anything, from silly to ludicrous to dangerous. There is the flat earth society, pizzagate, and we all know of black helicopters coming in the night to take us all away. It is important to search out consensus views.

-Statements from National Bodies: FCC, FDA, Cancer Institute, Cancer Society (see slide)

-Statements from International Bodies: European Commission, WHO, Health Canada, UK Health Protection Agency, Swedish Council for Working Life and Social Research, Norwegian Institute for Public Health, Australian Radiation Protection and Nuclear Safety. (see slide)

- The Swedes and Norwegians say this is safe. They are most sensible people in the world.

-Here is the upshot. The rate of glioma, which is a rare brain tumor, has gone down in the US. The rate of cellphone use has increased. There is no correlation at all. That is a very powerful statement.

-There is a difference between doing physics and chemical studies and health and nutritional studies. Health studies are very difficult to do and have them be reliable. There are conflicting claims. I can't tell you how many times I have heard eggs are good for you, then they are bad for you then they are good for you. I don't want to give you the idea that science is useless or these people are dumb. Neither of these is true. It's just difficult to do studies on humans. Humans are not great subjects.

- Amgen tried to reproduce 53 landmark studies on cancer. They were only able to reproduce six of them. Bayer Health was only able to reproduce 25% of 67 studies. It's just really difficult to do this stuff.

- Most cited paper of all time in medicine: Dr. John Ioannidis studying studies. He found that 80% of non-randomized studies turn out to be wrong. There are many reasons for this: study biases (to make splashy result), lack of blinding, difficulty working with human or animal subjects, the rarity of effects being sought (trying to tease up very subtle stuff), the expense of dealing with many test subjects. Example: NTP study

- One important aspect is the problem of Multiple Comparisons:

- For example, I am going to examine a lot of outcomes from smoking. I have to conduct my experiment at a certain level of acuity. That's called a P-value. Industry standard for P-value is 5%. The P-value is the probability of observing the effect seen, or greater, given that the null hypothesis is true. Let's say you decide that cigarette smoke is not dangerous. That is the null hypothesis. Then you find your rats are getting lung cancer. Then you would say the probability of rats not getting lung cancer is very low. That implies that you are seeing something. I am going to assume a much tougher standard in my experiment with a P-value of 1%. That means that if I have 100 subjects, one of them has to have the outcome.

What happens in the real world with P-values much higher than 1% is that you could have three studies and they all have outcomes. You could have several different outcomes, not just the one you are testing. What is then reported, are all of the outcomes when in fact it should be none. For example…news clip about powerlines causing brain cancer, leukemia, breast cancer, birth defects, reproductive problems, fatigue, depression, and many others. It's implausible that a single thing causes many things.

- A single exposure causing many outcomes is a sure sign of the multiple comparisons problem! All of these studies find different things. If they don't start replicating each other, you shouldn't pay attention to them.

<u>NTP Study-the claim:</u>

- There is clear evidence that RFR causes heart tumors in male rats
- There is some evidence that RFR causes brain tumors in male rats
- There are problems with the NTP Study: (see slides for detail)
- The problem with the NTP study is the Multiple Comparison Effects.

Heroux theory:

He claims that electric fields from cellphones disrupt proton transfer in water, thereby "influencing the properties of water and the stability of DNA"

- This is a valid scientific question. We should delve into it.
- So what is going on here is something called the acid-base reaction which creates H_3O molecules. There is about 1 H_3O molecule per 10 million H_2O molecules. The extra proton can hop along chains of water molecules. This is called the Grotthuss mechanism. This is normal and is a chemical reaction. What is the effect of an electric field on chemical reactions?
- There is a study by Boxer at Stanford using fields from 2,000,000 V/cm to 100,000,000 V/cm to see a reaction. Cellphones max out at 1V/cm!
- So the physics of it and the chemistry of it say its fine but the magnitude of it says it's not something to worry about. A cellphone is not sufficient to cause any chemical reactions.
-

Chamberlin Presentation: I need to correct or point out what he said.

Chamberlin claim: power per unit area becomes alarmingly large.

- Significance of 1/r2 Power relationship. The implication that having a cellphone in your sports bra (per slide) is definitely not a good idea, I have a problem with. This is misleading.
- There is something called the Frauenhofer distance. The near field and the far field have different laws.
- You need to compare to IEEE localized MPE at 30 Ghz. It's well below that.
- I have to say this is not what is actually going to happen. What is actually going to happen is very complicated. You have to simulate these on computers.

Abrami: We are running out of time. We need time for questions and responses from Dr. Heroux and Dr. Chamberlin on your remarks. We may take you up on your offer to dial in at a future date. You mentioned the WHO but the WHO categorized RF as a group 2B carcinogen. Can you tell me how that works? You said the WHO said there is no problem but they have graded it like lead and thalidomide.

Swanson: Sure I can address. First a technical point. The reason there seem to be these conflicting statements is it is actually the IARC which is a sub portion of the WHO that made that statement.

Abrami: There are many articles saying WHO.

Swanson: Just because they ascribe it to WHO, it's really IARC a sub portion. They do categorize it like lead like you said but also things like coffee, sawdust are in that group.

Abrami: Ok . You made your point on that.

Swanson: This committee (IARC) like IEEE only smaller looked at literature and concluded Group 2B. The standard for that is a very low bar. They made this on two things. The first is a data point on the interphone study in Europe and a collection of studies from Swedish researcher Hardell. The other studies find no effect. I actually wrote to them and asked them, what are you doing??? What they said was, we are applying the Precautionary Principle.

Abrami: Dr. Sherman would bring that up, the Precautionary Principle.

Swanson: I have written about this. I am fine with the principle. But you can go overboard. It would be prudent not to go outside, not to get on a plane but I do it and accept the risks associated. One thing about the data points on the phone study. They self -reported that the numbers are unreliable.

Abrami: So why then is there a legal notice on RF in your cellphone telling you to keep it away from your body?

Swanson: It's not science. It's precautionary with a flavoring of legalese is what that is.

Abrami: So you are saying there is no science behind that legal notice?

Swanson: Correct. Yes.

Abrami: Let's talk about insurance industry. They recognize wireless radiation as a leading risk and place exclusions not to cover it. What does the insurance industry know that we don't know?

Swanson: I am not qualified. I don't work in industry and don't talk to them.

Heroux: You make a great point of giving a lot of influence to the concept of ionization vs non ionization. So if I take a copper atom in space and I want to extract an electron from it, it will take me a fair amount of energy. Is that right?

Swanson: Yes.

Heroux: We call this the extraction energy from the atom. But if I take a group of copper atoms together, how much field do I need to move the electrons in them?

Swanson: You don't need much. It's easy.

Heroux: It's called the degenerate fermi gas. The fact that you bring these atoms together changes considerably the electrical properties of the material. So you agree with me that if you have a material that has closely packed atoms and the electrons or protons move through the material then a small electric field can influence the motion of charges.

Swanson: Yes. But so we are not confused. We are talking about metal and of course people are not metal. There is an analogous effect on people though that I rarely ever mention where cooperative effects can cause something below the ionization. However, it's extremely rare and I don't feel like I was lying to you.

Chamberlin: I feel epidemiology is going to play an important part in the decisions of this commission. Your slide on gliomas vs cellphone usage is pretty convincing and that may not be the issue. But something that does concern me in the same time frame (1989-2005) is a 32% decline in male sperm count. That is major and significant. If you look at the studies that have been done, they are pretty convincing even exposing people at low levels below .1W/kg. They are getting statistically significant effects. I am not talking about P-values of .05 but of .001. I am wondering if you are aware of these and it correlates very strongly to wireless networks and cellphones.

Swanson: There are a lot of studies who are going to see an effect and some are going to be statistically significant. The real question is, are they reproducible? I don't look through all of these but every time I do look at one, I see problems and I don't see reproduction every single time. It's just amazing. I thought the NTP study…wow, this is a going to be a good study. Oh my god…they had problems. This always happens. The existence of these studies doesn't surprise me and would concern me if they could be reproduced but they can't. So I have to look at the consensus.

Chamberlin: There were 16 studies where statistics looked good and they all say the same thing. It's global epidemiology 32% sperm count decrease.

Swanson: Let me address sperm count. I use this in my class. There is a problem with studies. They are not based on same criteria or same subjects. About four years ago, the Danish Army did a study and they completely debunked this. There was no effect.

Wells: The Boxer lab slide is that a static field not an RF?

Swanson: Yes. I believe it's a static field.

Ricciardi: You just made a comment that you don't buy into these studies because they aren't reproduced. Many of these have been including the NTP study which was reproduced twice. What peer reviewed studies have you done?

Swanson: I have not done animal studies. I do theoretical studies.

Ricciardi: I find it difficult that you can dismiss all these studies showing biological health effects from cellphone radiation. The international EMF scientist appeal. That's 2,000 reproduced papers of studies over and over again with 240 scientists studying the fields on biology and health. How do you argue that health and regulatory agencies state that there is a scientific consensus that cellphones are safe when so many experts disagree?

Swanson: That's a good question. This thing is called the 5G appeal. These are scientists and doctors in Europe and North America saying let's slow down on 5G. So how many scientists and doctors are there in Europe and North America? They have 260 people out of 26,000,000 that have signed. That's not consensus.

Ricciardi: You misunderstood me. I wasn't talking about a petition. I was talking about 260 scientists doing studies.

Abrami: I think he stated his position already. We are short on time.   If you could spend some time later on the phone or webex maybe in a few months. We may have more questions for you and you can finish. (He ended his presentation just before Nasim and Kim).

Next meeting: Friday, December 13^{th} . 8:30 was agreed upon. We will have one speaker and then talk through where we want to go next.

V. Meeting Adjourned at 10:35 am.

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS OF EVOLVING 5G TECHNOLOGY

Meeting held:
12/13/19
8:30-10:35am
LOB 202

Meeting called to order by Rep Abrami at 8:30 am.

In attendance: (10)
Rep. Patrick Abrami-speaker of the house appointee
Rep. Ken Wells- speaker of the house appointee
Kent Chamberlin-UNH-appointed by the chancellor
Denise Ricciardi-public-appointed by the governor
Michele Roberge-DHHS- Commissioner of DHHS appointee
Dr. Paul Heroux- Professor of Toxicology, McGill University- speaker of the house appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee
Carol Miller-NH Business & Economic Affairs Dept.
Senator Tom Sherman-president of the senate appointee

Not present: (4)
Frank MacMillan, Jr. MD-NH Medical Society Environmental Medicine
David Juvet-Business and Industry Association
Bethanne Cooley-CTIA , trade association for wireless industry and manufacturers
Brandon Garod-AG designee, Asst. AG Consumer Protection

Agenda:

I. Approval of minutes from 11-21-19:
Minutes were approved.

II. General Discussion:

Abrami: Recommendations will be based on general consensus.
Minority reports can be written by anyone if there is disagreement.
Focus: things that we can do as a state: from as simple as warnings…to ordinances.
There are things going on in our state right now. Dr. Sherman and I are cosponsors in smart meter bill allowing opt out without having to pay a fee to do so.

A. The electromagnetic spectrum discussion on terms such as: frequency, wave length, photon, electron volts, etc. and comparison from radio to Gamma. Frequency is the inverse of wave length.

B. Energy. Radio waves are the lowest electron volts. Gamma Rays are highest at 1.24MeV.Where is the break point? None of this is linear. Science says ionizing radiation which expels electrons from atoms or molecules, doesn't happen until UV rays. However, we have learned that it's actually doing damage below that. The question is: Is the science still out on damage beyond "heat", which is the FCC's standard? It seemed from one presentation that they looked at papers beyond heat so we still want the FCC to talk with us. I will see what we can do.

Sherman: We may be able to inspire them with a nudge from one of our Senators. I would be happy to do that.

Abrami: Kent, I took this from your presentation!

B. Photons: EMR can be represented by discrete packets of energy called Photons.

1. Increasing transmission power will increase the number of photons (although the energy in each photon remains constant).
2. The energy in each photon is proportional to the frequency of the transmission.
3. If the photon energy is great enough to detach electrons from atoms and molecules, it is referred to as ionizing radiation.
4. All the charts that I look at say that happens at UV level.

Wells: When you are ionizing radiation and you remove an electron, you are breaking a chemical bond but you can break a chemical bond at much lower energies. That's why we can see. This is also why humans can photo-synthesize vitamin D. They do it at energies much lower than UV.

Woods: Along those lines, we have to remember, and this is important. This is isolated episodes. However, biological systems work collectively. They diffuse their base energy around parts of a molecule. There is thermal activity already and sometimes can cause a disruption of a bond without anything occurring from anything external. We have to remember that these are terms that we are learning but they are for isolated singular entities. Some electrons are shared by biological systems and are a very different process. We have to go from a single item to a collective and that's a big jump. These are some of the experiments that Dr. Heroux is working with that tries to address that biologic collective entity.

Sherman: One factor…..Transmission power: If I remember correctly, people in industry were saying that each tower would be lower in power because there would be so many, is that correct? My question is: if you increase power, there are more photons but the energy in the photon is proportional to the frequency. So when you increase frequency to 5G but decrease transmission power, you will have fewer photons but they will each be higher energy. What does that mean to us on the receiving end?

Wells: And the antenna is closer. As 5G single transmitter power density goes down but the number of them is much larger and they are much closer. It's like little Christmas tree lights around the room instead of just one bright one.

Sherman: Does that mean that the total amount of exposure will go up?

Wells: Yes.

Sherman: Because of the proximity of the antenna?

Wells: Yes.

Sherman: even though the power is down?

Wells: Yes.

Sherman: The photons will have more potency and you are closer to them.

Wells: They will have larger numbers. The total power of a 5G system has five orders of magnitude which is 100,000 times more intense than a 4G system!

Abrami: This is something we have to focus on. Kent, do you have something to add to that?

Chamberlin: No. I agree with what's being said.

Heroux: Basically with the beam forming you tend increase the directionality. It's more focused. With the old systems, they broadcast to a very wide area. So it's true that the new system 5G will be less power input into the antenna. But the beams will be much more focused and the cellphone will also have the ability. You are talking about very narrow beams that will be directed to you when you use the system so that means increased levels of radiation because of this concentration. The antenna is spending less power because it is not broadcasting everywhere.

Sherman: You just said something that I don't' think I put this together until now. When the cellphone is 5G capable, is the antenna putting out the same level of radiation?

Heroux: It's going to put out the same type of radiation. They are miniaturized antenna in a chip that is implanted inside the phone which you will hold so you will direct the beam to wherever it wants. You will have a more concentrated energy coming from your phone. The radiation pattern will be fundamentally different.

Sherman: So will it be 5G level radiation be coming out of your phone?

Heroux: Yes.

Abrami: Ken wants to talk about antennas after we get through this.

C. Specific Absorption Rate: power absorbed by mass of tissue=energy is absorbed by the human body when exposed to RF/EM field=Watts/kilogram. US cell phone standard is: 1.6Watts/kilogram or less.
D. IEEE/ICNIRP 209 standards are still the same basically what the FCC uses.

Dr. Swanson said that the FCC reviews biological standards as well, not just heat. We really need to speak with FCC on this.

Chamberlin: I thought my question to Dr. Swanson was pretty direct. I asked him which of the two approaches setting standards, did they use. One he described was on animal studies exposed to increasing radiation until their behavior changed, divide that by fifty and you come up with a standard. That was one way. He also said they relied on publications written but he didn't say which did they use? He said both but I don't feel like I got my question answered. If it's the behavior in animals, then that is a short term phenomena and does not address the concerns that we are looking at in this commission where people are going to be bathed in electromagnetic radiation 24x7. I am really unhappy with where we are, with finding out that piece of information.

Abrami: Dr. Heroux, I know you went back and forth with him on this and you were involved.

Heroux: Yes. The FCC cannot try to implement a national standard for radiation without claiming it is taking everything into account. Yet, they don't have biologists on their staff. They have a tradition of being a spectrum allocating agency which is very important for coordination in the country but they are not biologists. A better body to ask is the IEEE. Again, the IEEE is heavily influenced by engineering tradition and I would reinforce the argument of Dr. Woods. All of these things about physics are entirely true and entirely valid. What what we cannot forget are that biological systems, the fact that we think and we act are processes. These processes involve manipulations of electrical charges in our body. These processes fundamentally move electricity around in our body. Those are unstable processes that can be influenced by vanishingly small amounts of energy. Energy is an immensely valuable concept. But the complexities of biology have been underestimated by engineers eager to serve the public with applications and by the FCC eager to serve commerce.

Roberge: I asked Dr. Swanson a question related to the FCC standard as well. I thought I remembered a conversation about the standard being focused strictly on heating rather than other biological effects. That was my question with him, to understand are they strictly looking at effects of heat or are they looking at other biological effects? I am not clear on his answer. I am not clear if the standard evaluated other studies or just heat. I also thought it has been awhile since they set the standard.

Chamberlin: I would like to interpret what I heard him say. As long as you are below UV Ionizing radiation, the only factor is heating. There is a question about how much heating you can tolerate. That has been the industry mantra on radiation exposure for as long as I have been in the field. I believe that is what they are using as the criteria.

Abrami: That standard hasn't changed much over time, is my understanding.

Sherman: I apologize. I could not be here for that meeting. We are talking about human health effects. This bathing 24x7 is not just on the human environment. It's on the entire environment. Do any of you know if there are any studies on plants or animals and others exposed to this?

Chamberlin: Yes. There is a study that shows that tree and plant health near cell towers is degraded considerably. I have a paper that says that.

Ricciardi: There are many studies and a big study on the damage to bees. I did ask Dr. Swanson because he dismissed the fact that it harms bees. So I handed him the study. It has a huge impact on the environment.

Abrami: Let's pause on that one. There was a study done on bees using twelve hives. Half of the hives, they put cellphones in and in all six, they did not come back to the hive. They got confused and you wonder …why is that? It must have to do with their navigational system. I always thought they had sensors that pick up the Earth's magnetic field. All of a sudden we are going to cloud the Earth's natural magnetic field with man-made different frequencies.

Ricciardi: This one is the exposure of insects to radiofrequency electromagnetic fields from (2-120Ghz), published in Scientific Reports which is the first study to investigate into how insects including the Western Honey bee absorb the higher frequencies to be used in 4 and 5G. The simulation showed increases in absorbed power from 3% to 370% when insects were exposed. This could lead to changes in insect's behavior, physiology and morphology, over time. I did ask Dr. Swanson, can you confirm that these frequencies are safe for pollinators and what credentials he had to speak to this? I don't feel my question was answered at all.

Abrami: This is one I feel we need to follow up on. I found studies on bees at low levels that impacted the number of queen bees produced by 40% something like that, which is significant. Bees are our health, food, etc. It's navigation, which can also be biological. I don't want any of us to sound like alarmists. We want the facts to come out and we want to understand this. But on my list, I think bees and probably migrating birds as well are important.

Wells: there has been a lot of work on homing pigeons, migrating birds and bees. They also use iron to determine which orientation the EM field is. The effect is if you hit the frequency that will make that move, you will make that sense blurry or obliterate the usefulness. There haven't been a lot of studies determining what those frequencies are. However, if you confound the major pollinators, that puts all of plant life in jeopardy.

Abrami: yes…that's oxygen and food.

Woods: It's important for us to ferret out in these studies which include 5G because our charge is 5G. We know that that the photon energy is different. The comment that I heard him say was, how many G's do you need to study? We need to study 5G. As we go through this, we need to make sure studies include 5G. The energy is definitely different and we talked about that. Some of the studies do not include 5G.

Ricciardi: There is a recent study this year on 5G in France and Netherlands. They meaured the RF from small cells increased radio emissions from the base stations while decreasing the radio emission from the user. They found that in the area human sickness is well documented and has increased since it's been installed. This is all involuntary exposure hanging in front of people's homes. With your phones, you have the choice to turn off or not own. I have issues about choice and it's a privacy thing, too.

Abrami: The 1/R2 rule. Meaning the further away you are is a physics principle we need to talk about too.

Issues:

- Biological effects of non-ionizing radiation.
- We need to make sure these studies are not flawed.
- We need to find studies that are replicated.
- We need to understand the FCC approach to standard setting. Are biological effects included or not?
- Impact on navigation of bees, birds and other living things such as interference with Earth's magnetic field used for guidance (non-biological).
- Energy level from cell towers and small cells based upon distance. What other factors?
- Legislative activity, ordinances and the courts around the country and the world.
- RF Communication security. It's scary what's going on in China. Facial recognition, etc. Pretty soon you won't need any devices.
- Insurance Issues: why is it insurance companies won't insure this stuff?
- Smart meters on homes.
- Precautionary Principle. Dr. Sherman, I know you think this should apply here.
- Final report will have recommendations for future legislation or public health warnings based upon solid facts. We will come to a consensus. Anybody can write a minority report on any part they disagree with.

Sherman: One thing to consider is looking at all this frequency and power. Are we already beyond the safe level? Is 4G not safe? Is what's out there now unsafe even before 5G?

Abrami: well, we are not going to take people's cell phones. That's not going to happen. To industry, it means money. There are not definitive studies on 5G that there are not health effects. I asked Swanson that. Where are the studies that say 5G is going to be safe? Show us the definitive studies.

Ricciardi: I asked him, are you saying that 4 and 5G are not harmful? He said yes. To Dr. Sherman's comment about already being dangerous, your cell phones already have warnings buried in your phone to not put them close to your head or ear. People really don't know that. It is dangerous. We aren't going to get rid of phones. One solution we may want to consider a right to know law at the point of sale because people will still buy them but they may use them more carefully, just like cigarettes are still sold with a warning.

Sherman: That's my point. If this commission finds out that maybe we have crossed that threshold into what may be dangerous, I think transparency in sharing that knowledge is important. Also with 5G, one of the concerns is everyone will be exposed whether you own a phone or not. Are we already at that point with 4g whether you own a phone or not and is that exposure potentially toxic? That is something where we can at least raise the question.

Ricciardi: Very good.

Heroux: I have a number of comments. I have been in this business for a long time and I want to emphasize the importance of what has happening here and the influence that you are going to have. You are not the FCC. You are not the IEEE. You are not the Chinese government. But, you are a public body that has NO conflict of interest. You can claim that engineers have a conflict of interest because they are pushing products. You can claim that the FCC has a conflict of interest. This body apparently has none. It is looking at data and reality. The discussions that we are having today are incredibly rare. They are usually held in private between individuals. Although New Hampshire has limited power implementing laws and regulation, what you will recommend, will be heard. That can have tremendous influence on the future. I see that responsibility on the shoulders of this committee, as huge…. planet wide, in my opinion. First point!

The frequency range of 5G can be very wide because industry is very flexible in what it does. Some frequencies used in 5G are lower than some used in current systems. Some that have been allocated are much higher. As Tom Wheeler would say, if someone tells you that they know what 5G is, run the other way because not even industry, itself knows. So, we are forced to evaluate electromagnetic radiation as a whole.

About scientific studies: All scientific studies are flawed. You would have to have unlimited money and time to produce one that is not. The weakness of the overall process is that because you can criticize ANY study, a committee that has a philosophy, can get rid of studies it doesn't like. This is a reality that is inescapable. The philosophical attitude of the people assessing science is absolutely tantamount.

Another problem is that the reproducibility of experiments that you are familiar with in engineering or in science is higher than what you have in biology. This is because biological objects are inherently extremely variable. So when you impose the same standards of reproducibility on biology to those of engineering or science, it's extremely unproductive, in my opinion.

The physicists have to bear the guilt of the atomic bomb. I am sorry to say this but electrical engineering will have to bear the responsibility of 5G. In a sense, it's electrical engineering's atomic bomb. Probably the people who can attenuate and manage this are here.

III.Ken Wells: Presentation on 5G malign applications:

Culture of Safety:

It has been said in this room, that little research has been published on the hazard or the safety of these frequencies. I have been involved in hobby auto racing as a driver, pit crew and safety corner worker. I am used to cooperative safety culture that asks, what is the worst thing that could happen? Then you work together to make sure that is very unlikely or impossible. I don't see that 5g is progressing that way. I think we would be wise to take that same approach with high frequency radio frequency.

Is it possible for radio frequency to cause harm?

There is an RF weapon that's called "active denial system: that uses 3.25mm or 95 Ghz band of 5G. In testing, it was able to create a burning sensation in the people it was aimed at in a tenth of a second. It was able to create 1st and 2nd degree burns in less than a second. In one case a subject was hospitalized for two days. So, yes RF radiation can cause harm. From this military experiment, we have evidence that RF can cause pain and injury. I would like to explore what could happen if instead of a cooperative safety culture that I spoke about, that a maligned player either foreign or domestic wanted to pursue a nefarious use of this RF against a civilian population. In theory, could a 5G network of small cells, IOT and devices be weaponized? I think so. This is the worst thing that can happen scenario that we must render impossible.

Physical descriptors of RF. There are three major ones are used universally.

1. Photonic Energy that you can categorize in terms of frequency or wavelength.

2. The intensity of radiation: The brightness if you will. It expresses how much energy strikes an area in a given time.

3. Duration of exposure. The IEEE standard 95.12019 is substantial and you should look in to that document. The research in that describes a quantity called fluence which describes field strength times the time you are exposed to it. It implies that pulses of RF should be separated by a few tens of seconds to avoid damage. That is not currently incorporated in the standard but something I think we need to pay attention to.

Absorption: waves transmit energy from place to place. EMR interaction with matter is frequency dependent. It has three ways it shows that dependency. The first one is heating. Second, is quantum effects with sharp bands particular frequencies that are strongly absorbed by particular atoms and molecules. That is not so well studied.

Third, you have anisotropic effects. Those are not uniform in all directions. Those include things like polarized emission and absorption, tunneling, and we don't really understand the biological role very well. We know they are very important. We know that we can point to these in chlorophyll and DNA.

Membrane bound biological processes like photosynthesis, oxidative phosphorylation (respiration), reproductive fertilization and neurological processes are all things where we think these electronic reactions are happening. There is even some theory by Roger Penrose and others doing research that the human brain might even enlist what is not well understood called quantum entanglement. There could be a role of chaos theory. As Dr. Herox said, very small electrical fields are involved in these biological effects.

On page three, I took measurements from a cell tower. I happened to be hiking and got some readings of a 4G Verizon tower. Dr. Swanson told us that the amount of power was hard to pin down. The manufacturer said it was only about ten or twenty watts. I am not sure what we should believe. Since there is so much variation on it, we need to be able to put a large error safety bar on these values. I am most concerned about the layout of these small cell antennas which resemble a phased array.

A phased array is the way that modern radar picks its direction. Remember that old ones had oscillating antennas. A phased array nothing moves but you change the characteristics of the antenna in order to steer the beam. The hardware layout for small cell 5g antenna areas meets the requirements for a phased array about a hundred meters apart over an entire city. Once this antenna is built, a maligned operator using software could upload to the array to alter its function from the benign communications function to a high powered steerable array either to disrupt communications or to actually be used like this military device. Foster et al say in IEEE 95.1 “The use of multiple steerable beams from 5G base stations will introduce new issues for compliance assessment for future RF exposure risk” which I think is quite an understatement.

I don’t think that we or the FCC, can effectively regulate either operating frequencies or power levels of such an array because today’s equipment hardware characteristics are completely transformed by software. You need only to consider the VW “Dieselgate” cheat to see how software can be used to hide or reveal deeply embedded nefarious capabilities of hardware. Since regulation of wave parameters can’t be done with this array, the phased array deployment has to be blocked by controlling what kind of physical antenna can be built.

We could continue on our current path of allowing maligned foreign entities to sell us 5G equipment or even components that go inside these things. How hard would it be for a remote operator over the internet, to toggle the equipment from its benign communications into another role? This role may operate on another frequency for espionage and surveillance, or to increase the power as a weapon and deny us our Constitutional right for assembly. It would be easy if that maligned capability was built into the hardware that we purchase as a Trojan horse. There is once piece of good news in this. The atmosphere attenuates the signal fairly strongly.

There is a spectrum on the last page. In the mm band, there are really only a few windows. The military application picks the biggest of the three peaks between 1-10 mm at 3.75mm and those are also the same bands you want to use for communications. The Air Force began development of” Active Denial System” in 2000. It used 3.25mm (95Ghz) RF as a crowd-control device whose range was “greater than conventional small arms” (3km). In testing, it could cause “an instantaneous burning sensation” in .1 sec exposure, along with first and second degree blistering burns on human subjects for exposures of less than 10 secs. One case required a two day hospitalization. It was tested as a 30MW mobile truck-mounted “area denial” system in Afghanistan in 2007. Could a malign player (foreign or domestic cyber-attacker) pursue a nefarious use of RFR against our civilian population? All of this suggests a couple of avenues we could consider.

Prevent the rollout of antenna array that can be used as a phased array. Transmitters should be built using MIL-SPEC US component suppliers, with the same degree of security and oversight used in other weapons systems. Do any citizens in the US ever worry about their constitutional rights, or oppression at the hands of their own government?

Abrami: We need to end here. We are going to have to follow up on your major points.

IV: Tim Schoechle PhD: National Institute for Science, Law and Public Policy presentation:

Schoechle: Computer and communications engineer for 45 years and on the faculty of the University of Colorado for a number of years prior. I’m speaking now for the National Institute of Science, Law and Public Policy think tank in Washington that writes on health and safety issues as well as telecommunications and energy issues.

The purpose of this paper is to give an overview of current technology and both the technology and the policy issues in telecommunication including internet, wired and wireless.

1934 the Telecom Act established the FCC which regulated broadcast radio and telephone service.

1986 The Bell Monopoly (AT&T) was broken up.

1996 Telecom Act revised the 1934 Act. Wired Communications were covered under Title II (common carrier), leaving the wireless and cable essentially unregulated.

1990-2010 Wireless rolled out 2nd and 3rd generation wireless.

What developed out of that was the reincarnation of the Bell Monopoly that began around 2000 which resulted in today’s duopoly of Verizon and AT&T. This is not the Bell AT&T.

A major point here is: the massive cost subsidization of wireless by diversion of fiber to serving cellular network. One notable point is Verizon’s abandonment of FIOS that it was marketing in 2000.

Abrami: You say there are two major players but what about T-Mobile?

Schoechle: Cable is the third player. It makes it more complicated because it’s a wired service and wireless. It’s really a trio-poly. The rest is much smaller.

Abrami: Talk about the flow of money and the diversion of subsidization. Are you talking about the charge on landlines that were supposed to be used for optical fiber infrastructure?

Schoechle: The “Book of Broken Promises” is a 600 page book that describes in detail how this diversion took place. The obligation was to upgrade wired infrastructure from the charges that ratepayer money for on the telephone bill. That money was charged against the wired and used for the wireless. It amounts to about 500 billion dollars. Basically, it made wireless look a lot more profitable than it would be otherwise.

The drivers: the need to cell more phones and now its 5G. It’s about selling equipment. There has been a slowing on the sale of cellphones. The industry philosophy is planned obsolescence.

The new subsidy is YOUR public rights of way. It’s a preemption of local property rights and rights of way that give telecom a grant by right to public property. Over twenty states have adopted legislation to take away the rights of localities which was inspired by if not written by the American Legislative Exchange Council (ALEC). It was written to take away control of states and localities of deciding on this equipment.

The FCC is a captured agency and presently chaired by a Verizon attorney, Chairman Agit Pai. It’s not surprising that it serves their purpose.

Surveillance Capitalism: There has been a transformation in the past twenty years that began in 2000 to a surveillance business model. This is really important if you want to understand the telecommunications industry and particularly the IT industry.

It has gone from selling products and services to the new model of trading in personal data. The tail is wagging the dog. The data is more important than what the equipment does. This was developed by Google and refined in 2010. It has been adopted by Facebook, Microsoft, Amazon and now Verizon, AT&T and the entire IT industry. There is a book called “The Age of Surveillance Capitalism” by Shoshanna Zuboff of Harvard University. She has written a monumental piece that details how this occurred and the social implications. You have to understand this to understand why information technology is going where it is today. It is selling data, selling behavior and advertising primarily. It is also selling behavior modification, which has political implications as we know. Selling control of people is where this is headed.

Wireless devices and networks are complex and proprietary. I am going to compare wired and wireless. The wireless is unregulated. It has progressed rapidly. It is extremely complex and changes all the time. Wired networks that are copper or fiber are simple stable technologies and are open. What you have is essentially a generation of wireless technology which is designed primarily to gather data about you. Wired networks particularly optical fiber, are much more secure than wireless.

Some of the risks of the wireless industry:

- Loss of community rights, property rights and rights of way for private corporate gain.

-A loss of revenues that come out of that is essentially a forced subsidization of your community to wireless by giving them stuff they would have to pay for.

-If 5G was not subsidized through this form, it would not be feasible.

-The loss of community environmental regulation is a critical factor. There are a lot of environmental implications to this technology.

-Risk to personal privacy and corporate and government surveillance.

-Risk to public health and safety. Vast literature on this suppressed by industry or ignored by federal regulators.

-Damage to the environment birds, bees, insects, plants, animals, tree, etc. particularly mm waves.

-The FCC limits are obsolete and they have no health expertise and have swept this under the rug.

What can states do?

- Let's get fiber to everybody. Fiber should be the first priority. Fiber is a basic utility like sewer, water, roads, etc. Wireless is an "adjunct service". The fiber should be owned and controlled by the municipality. This should not be privatized. Fiber access is superior to wireless in every respect except mobility. The fed has no policy on this and local power companies and rural electric companies are stringing fiber optic. It offers speed, stability and better privacy, safety in weather events, reliability and it's cheaper.
- Internet access is a necessity to modern life. You can't operate government today without the people having access to the internet.
- Cellular wireless is an energy hog as well.
- Community fiber would reduce the need for cellular wireless.
- Enable community fiber.
- Integration of distributed energy. Fiber will be needed for solar/storage and the future of the electric grid.
- Enable local control of cellular wireless facilities: Initiative in Colorado is repealing ALEX laws passed in 2017 which preempts local legislation.
- California just enacted CCPA (California Consumer Privacy Act). Take a look at this.
- Health and safety studies of EMF need to be supported.
- Enforcement of Environmental Protection laws. The appellate court just overturned part of the FCC order on the basis of its failure to enforce NEPA, the Environmental Protection Act.
- Antitrust enforcement and divestiture. The last thing we should do is allow merger between T-Mobile and Sprint. Fifteen AG's from states have filed a separate lawsuit challenging this merger.

- Read ,"The Book of Broken Promises" and do something about it. There is a case proceeding in the 10th district in Washington, DC in January on this investigation.
- Support the Green New Deal: 1/ a distributive solar micro grid and 2/fiber smart grid and optical fiber nationwide.

FCC has abdicated its responsibility to public health and safety as have other regulatory agencies.

FAA has failed to regulate creating a debacle which could sink Boeing.

California PUC has failed to regulate PG&E, one of the country's largest utilities and is in bankruptcy largely due to the failure of regulators.

Another example of regulatory capture and the revolving door is now we have the FCC's failure to investigate cellphone radiation, safety and their obsolete radiation limits which flies in the face of the NIH Toxicology Program study that shows cellphones can cause cancer.

Abrami: You have reinforced many of the things we have been talking about in this commission. What do you know about what is going on in China and their 5G rollout?

Schoechle: I submitted a paper ," What is 5g and why do we care?" In it, it refers to China. It's a financial driver in China and part of a surveillance state. It takes surveillance capitalism and the capitalists are the government.

Abrami: So we should be concerned about the chips and things coming from China?

Schoechle: It's not just China. Korea is also a major manufacturer. They have become famous for LG, the television that are watches you. Those televisions are sending information to Google and Facebook and who knows where else on the internet. You don't even know that is happening.

Sherman: Is there somebody in the legislature in Colorado that you have been working with who has been translating some of the work you have been doing into legislation or bills?

Schoechle: The majority leader is on board with this. I wrote a 20 page report named "Reclaiming local control over cellular wireless facilities". I just sat down with a member of the House and went over that in great detail. We are looking for a sponsor for that bill. We are in recess right now. I can give you more detail on that if you want to follow up with me.

Sherman: That would be great. I am chair of Senate Health and Human Services. We try to not reinvent the wheel. If there is legislation enacted or in process that seems to be working through the system in Colorado that may be appropriate here in New Hampshire, we would like to take a look at that.

Schoechle: If you send me your contact information, I will try to facilitate that. The big focus in Colorado last session was major changes in energy policy. Electricity, oil and gas have been a major political debate in Colorado and we have made progress on that. Telecommunications will be in our next session.

Heroux: In your report in section 3.3.3 pg. 34, you say most of these sources never turn off and cannot be turned off. I believe you say this in context of IOT. Would you agree that the hardware switch on these devices would allow a person to eliminate radiation and eliminate transmission of information if the user wants to? Do you think it's feasible to implement or to legislate for such a device that would restore an individual's right to privacy and manage his radiation exposure?

Schoechle: That is a good question. The trend in the consumer electronics industry is to develop products that don't turn off. They look like they turn off and you think you turned it off but they are still on. This is a problem from an energy standpoint and from a data standpoint. I think what you are suggesting would be a good idea and we would have to look at how policy would influence the consumer electronics industry.

Heroux: You could design it that the switch is only disabling the transmission. You make it unable to send out data and you eliminate the radiation. You could also say that the fact that it is off, you do not disable the other functions of the device. It is a matter of engineering. We all depend on engineering. This type of switch could go a long way toward protecting privacy and making it possible for Electro-sensitive people to survive. How can this be imposed? Do we need IEEE to promote this? Do we need the Chinese government to promote this? How can this be achieved? You know industry well. If the goal is to restore that kind of power to the individual, what is the path to achieving this?

Schoechle: That is a wonderful question. I will have to think about that. It's not so simple. Particularly, with cloud data, the whole business model on these products is capturing that data. You are asking to change the business model for a whole industry. I agree with you completely. We will have to think that through very carefully but I think there is a path. Maybe the IEEE, but an organization called Consumer Technology Association (CTA) is more likely. I am on the cyber security committee and that would be a good focus for that. We are writing a new standard for consumer products. CTA2088. We also have an international committee that works on this. There is a concept of residential gateway for this as well. We could address it through standards and at least make that an option that people could buy.

Heroux: Since realizing that you are the best person probably anywhere to do this, I assume that we can count on your cooperation to further this idea perhaps in cooperation with the Committee in some form or other.

Schoechle: Absolutely yes!

Miller: I would like to explore your statement on enabling community fiber. You also said community fiber would reduce the need for cellular wireless. I am not sure I agree with that statement since we like to be mobile and fiber is not mobile. The other thing is why do you say community fiber owned and operated by municipalities?

Schoechle: Well, because for the municipality, there is a political process for governing it. If it is provided by a Century Link or Verizon, even if it's fiber, you don't have any control or assurances of net neutrality or if it will be equitably distributed in the community. You don't have that control. It's not something that should be privately controlled.

Miller: You go on to state that cooperative electric utility is a better model in some ways for smart grid which would be enabling fiber to the premise. That is not community controlled either. That's controlled by members through charter but not a community controlled network. So I am not sure what you mean, totally controlled by municipality? Or partnered with an electric coop to disperse fiber? Can you elaborate on that?

Schoechle: My first choice is municipal electricity and municipal fiber together. I consider the perfect model as Longmont, Colorado. They have done both of those. They have the most advanced fiber system in the country. That is preferred. But America is very diverse country. The rural electric associations are called coops. It is possible to go through the coops in a democratic way unlike a private corporation. They are like a Frankenstein monster, out of control and basically ungovernable.

We are looking at a new technology standard Ethernet cable Cat5 or Cat6 copper wire. This can carry data over short distances at the same speed as fiber. This can also deliver DC power. You can plug phones, computers to a USB connector throughout your home so you don't even have wireless in your home. That is coming… a USB connector standard USB3 type C something like that. This will be the new standard because this is the new internal wiring in cars will be gigabit ethernet.

Miller: This doesn't address mobile access. People want to be mobile.

Schoechle: I am saying it will lessen the dependence on mobile. Right now, if Verizon had their way, you would only have mobile access whether you want to be mobile or not. If you have fiber, you will have faster better service and when you are mobile, you have a mobile phone. I have a mobile phone and it's an old flip phone. If I want to do data, I use my laptop plugged in at home. I am not going to do that in a car driving around. People need the choice.

Sherman: I am not sure people would be quite so wedded to their phones if they were aware of the health impacts to themselves and the environment. If you were to take that new USB technology, would you be able to go to airplane mode on your phone and still have complete access to your phone? Would an on/off switch shut down antenna? Like an airplane mode for television or CPAP machine which is now wireless, as well? Would the concept of being able to shut down on all devices be what we are talking about?

Schoechle: Yes. It's analogous to airplane mode. Airplane mode is to prevent radiation for interference with aircraft systems. Right now many cell phones have a feature called wifi calling so you are not using cellular calling but using fiber access or whatever so you are not using cellular wireless network. Of course the cellular operators don't like that but all the phones now work that way. You could plug in your phone when you get in the house and turn off your cellular antenna and still have phone access.

Ricciardi: The town that I live in is entertaining fiber optics. We would have to put it on our ballot for the people to vote. I have two questions: I have heard different things. If we put fiber optic in, would that make it easier for 5G to come to our area? Would that give them a segway to attaching themselves?

Schoechle: That is a very good question. Many of my colleagues and I have arguments about this. Some say you are just going to enable 5G sites by putting in fiber. Well, that's why it needs to be democratically controlled by the people in the community.

Ricciardi: But my understanding is that the FCC can just allow them to come and put the 5G in. You won't have a say as a municipality. If that is the case, we would just be making it easier for them.

Schoechle: They can't make you use their fiber. The FCC ruling is just about siting, not the use of fiber.

Ricciardi: Oh, so it could help you keep 5G away.

Schoechle: The issue is not whether there will be fiber or not. The issue is who is going to own it and control it. That's the issue. If you put it in, you control it. If Verizon puts it in, they decide how it's used. That doesn't stop them from putting in 5G but they have to put in their own. They don't get their subsidy off of us.

Ricciardi: In the state of New Hampshire, our utilities are in the public right of way. There is a NH law that I have looked into. I have been looking into an ordinance for this. That is a factor in our state. It is a little difficult to overcome.

Schoechle: Yes. A lot of these laws were written that way and need to be revised. That's unfortunate. The goal should be Local Control.

Heroux: I have a comment about mobility. We need mobility. The cellphone industry has paid little attention to reducing exposure of users. There are some people who occupationally need to use the cellphone. They don't even have a choice. In other words, I recognize the right of people to accept EMR exposure if they want. However, there are people who do not have a choice to use the devices that are on the market. It is possible to reduce the exposure of a person by a factor of about a hundred if you make the proper engineering efforts to do so. You can have the exactly the same services you have now but your risk would be reduced a hundred fold by design of the antenna and software adjustments to the phone. There will be no loss of functionality however, an enormous loss of biological impact. Industry in the past has not done it. It needs to be told.

Schoechle: I agree completely. That is a very good point.

Abrami: Here's the issue. 5G is a concept that means something different to every one of the phone companies. They are all developing their own version of 5G which makes it hard to track. One thing for this commission will be a Health issue potentially and definitely a political issue is the deployment of these small cells at telephone pole heights in front of people's homes. That becomes a real intrusion. Regardless of what the science says, many people will say, I don't want that. We already know the battles in our communities to put in a regular cellphone tower somewhere in the town, let alone a small cell in front of a home.

What is your view on that? We have engineers, doctors and toxicologists on this panel so we are having interesting conversations that really should be happening at the Federal level. What is going on in Colorado? Are there deployments of these small cell towers?

Schoechle: Well, yes. Verizon is rolling out in Denver. The issue has not come to Boulder yet. But the issue is what they have done with these ALEC laws and the FCC. They have lawyers that go around and tell city councils and county commissioners… oh…. you need to change your codes now to be in compliance with state and federal regulations. Our response is, let's change those. Of course that is a bigger hill to climb. People are getting up in arms because they are seeing the permitting of these small cells. Just the permitting has raised concern and communities are mobilizing around here. There are over a hundred cities around the country that have bonded together to sue the FCC. They have had some success. In November, there was a ruling in the 10th district. Industry wants to do this because 5G will need a shorter range. People don't realize that 4G and 5G will be bonded together. You cannot separate them. You will have both 4G and 5G. The new small cell sites being put in are 4G which will become 5G as well when they figure out what that's going to be. The technical standards aren't finished, the spectrum isn't allocated. 5G is an add- on to 4G which allows faster data transfer. It does not support voice communication. It doesn't support a lot of the things that your present cellular supports.

They talk about 5G for autonomous vehicles. I think that is a bunch of hype. There are safety issues that have not been addressed at all. It's marketing hype. The term 5G is a marketing term. It is not a technical term.

Sherman: My nephew is an engineer on the autonomous car, Waymo .They have no dependence on the internet. It is completely autonomous. So it's not just hype. It's a lie.

Schoechle: Right.

Abrami: Thank you for your time.

Schoechle: I would like to connect with the commenters. Thank you. I like the idea of technical standard approach to devices.

V. Next meeting: January 10 8:30-10:30 Devra Davis and Theodora Scarato

We are now going into Legislative Session. We need to do meetings on Monday or Friday. What about professors? Friday seems to work best.

VI. Meeting Adjourned at 10:35 am.

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS OF EVOLVING 5G TECHNOLOGY

Meeting held:
1/10/2020
8:30-11:00am:
LOB 308

Meeting called to order by Rep Abrami at 8:30 am.

In attendance: (12)
Rep. Patrick Abrami-speaker of the house appointee
Rep. Ken Wells- speaker of the house appointee
Kent Chamberlin-UNH-appointed by the chancellor
Denise Ricciardi-public-appointed by the governor
Michele Roberge-DHHS- Commissioner of DHHS appointee
Dr. Paul Heroux- Professor of Toxicology, McGill University- speaker of the house appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee
Carol Miller-NH Business & Economic Affairs Dept.
Senator Tom Sherman-president of the senate appointee
Bethanne Cooley-CTIA , trade association for wireless industry and manufacturers
Brandon Garod-AG designee, Asst. AG Consumer Protection

Not present: (2)
Frank MacMillan, Jr. MD-NH Medical Society Environmental Medicine
David Juvet-Business and Industry Association

Agenda:

I. Approval of minutes from 12-13-19:
Minutes were approved. Unfortunately, the minutes were posted on our website prior to approval. We will make sure that does not happen again.

Abrami: Discussion about subcommittees and members meeting outside of the regular meetings. Small groups are allowed under the rule is 50%+1. If groups are larger, we will have to develop subcommittees.

II: Theodora Scarato, Executive Director Environmental Health Trust:

Environmental Health Trust is a scientific think tank. We coordinate with scientists all over the world on issues such as wireless, climate change and environmental health issues. Dr. Davis has long worked on climate change, toxic chemicals, environmental possible causes of breast cancer and toxins in the environment. I have a lot in a power point. I hope it will be useful for you. I will not get to everything in here as my focus will be on policy.

At EHT, we publish research and brief policy makers as well as develop educational campaigns for people and for parents on how do you reduce exposure. I have a lot of materials. The most recent paper I published was with Frank Clegg, former Microsoft Canada President. There are links to all of this and more in the power point and it's all hyperlinked.

The Babysafe Project: There is a campaign that we have co developed with Grassroots Environmental Education is called the Baby Safe Project. This campaign has been signed on to by over 240 doctors and scientists and educators, to reduce exposure to pregnant women and developing babies because of research showing brain impacts. Dr. Hugh Taylor, who presented at the press conference for this campaign talked about his research showing damaged memory and increased hyperactivity after cellphone radiation exposure to pregnant mice. There is other research that Dr. Davis will go into as well showing impact on brain cells to what would be legal exposure limits of radiation.

Many pregnant women take the phone and rest it on the abdomen because they don't know. People don't know to keep the device away from the abdomen or use safer technology and you won't get that exposure. I have a quote from Dr. Taylor, chief of Obstetrics at Yale. That might be someone that you would be interested in having to talk about his research. He has a quote:" I am deeply concerned about growing exposure to cellphones." There is a video online at the BabySafe Project where you can watch him talking about this with recommendations on how to reduce exposure.

Wireless and energy consumption: Health and environmental effects of 5G are not just about the radiation, it's also the energy consumption from all of these devices and all of the additional small cells. There is a French climate think tank report (The Shift Project) which talks about the explosion of energy use. Even though there are energy efficiency gains, they are not keeping up with the amount of devices and these new installations, which create an increase in energy use. They document that as well as the environmental effects and every part of the life cycle of devices. For example: You have conflict minerals, e-waste from disposing devices and energy use of the manufacturers. All of these are polluting our environment. This report has a short two pager which is useful for the highlights.

Insurance coverage: I know that one of the questions of the commission is: why don't insurance companies cover damages from electro- magnetic field exposure? As you probably know, in the annual reports of almost all of telecom companies are statements to the shareholders such as " If radio frequency emissions from wireless handsets or equipment on our communications infrastructure are demonstrated to cause negative health effects, potential future claims could adversely affect our operations, costs or revenues". "We currently do not maintain any significant insurance with respect to these matters."

We have a page on our website linking to all the annual reports with these statements. Why are shareholders being warned of potential risks in the future and not people? I got involved almost a decade ago because I am a parent. I did not believe this at all. I knew enough that I had to take some time to dig in and here I am.

We have list on our website that we try to have a repository with compendiums of information that has all the white papers of industry where the insurance companies rate EMF as a high emerging risk. The SwissRE report just came out rated 5G mobile networks: the impact is high. The quote in this report with regard to health effects is: "As the biological effects of EMF in general and 5G in particular are still being debated, potential claims for health impairments my come with a long latency." I think that's most people's concerns here.

<u>The Harvard Center for Ethics Report</u>: What's going on here? If there are all these studies showing adverse effects, why isn't there the follow up that we would all expect from an exposure this great? In this report, the investigative journalist talks about money that has gone to Congress and the way that the FCC has former telecom executives as commissioners and also when you retire from the FCC, many commissioners end up working for the industry. This is all documented and he also talks about the correlation to Big Tobacco. "It is these hardball tactics that recall 20th century Big Tobacco tactics." This report is from 2015 and I really want them to update it because so much has happened since in terms of this issue with the revolving door. The title of the report is: How the Federal Communications Commission Is Dominated by the Industries It Presumably Regulates by Norm Alster. There is also published research that has found industry involvement affecting the quality of the results, the design of the studies, sponsorship and publication bias just like there would be in most industries. The consulting firms of Big Tobacco are now working with Big Tech. There is a report out that we are looking at a 12.3 trillion dollar market.

<u>Revolving Door:</u> This is a slide that I made showing the Former FCC Chair, Tom Wheeler was the former head of CTIA, Ajit Pai, the current FCC Chair was formerly a Verizon counsel, Brendan Carr, FCC Commissioner who was a former lawyer for Wiley Rein LLPP who represented the Wireless Industry in suing San Francisco for their Cell Phone Right to Know Ordinance. Bruce Romano, Asst. Legal Chief in the FCC's Office of Engineering and Tech went to the law firm of Wiley Rein representing the CTIA.

<u>Short Timeline of US Regulatory Action on RF and Human Health</u>: This is probably one of the most important slides that I have. You don't have it in your packet.

Abrami: please give us your non PDF versions of your files that we can click hyperlinks.

Scarato: I will do that. This is just a short timeline. It does not have everything in it.

In the 1970s-1990s, the EPA had a robust research program tasked with developing RF safety limits.

1996: the EPA was defunded and told that they could not work on EMF as they were set to release their phase one of safety limits which was on heating effects. The second phase was supposed to be on non-thermal.

1996 FCC adopted RFR exposure limits based largely on limits developed by industry and military connected groups (ANSI/IEEE C95.1-1992 and NCRP's 1986 Report).

We adopted those limits without our experts setting what is a safe limit? What is a safe limit for long term? What is a safe limit for children and pregnant women? Later in 2008, the National Academy of Sciences did a report documenting gaps in our understanding of the issue. What is going to be the impact of children exposed for a lifetime? That is my number one question. My background is as a social worker and I directed programs in schools. I worked with a lot of kids who were born of crack addicted parents. I know the differences between the kids. You have trauma, brain impacts from prenatal exposure. Kids who have been adopted and we know their history. That's what really brought me into this too. Knowing the challenges of my clients and knowing the impact that brain damage can have.

2001: GAO report and letters from experts in government saying there were problems with these limits. Those were not responded to. In 2008/2009, there were Congressional hearings on cell phone radiation.

2012: GAO Report: " FCC cannot ensure it is using a limit that reflects the latest research on RF energy exposure." Reassess RF limits and update phone compliance testing requirements.

2012: H.R. 6358 The Cell Phone Right to Know Act was proposed at the federal level and not passed. When I found out cell phones emitted non ionizing radiation, I thought what?? Why didn't I know that? My kids spent time on the phone because long distance was free and I spent hours on the phone talking to my girlfriends. I just wish I had known and I could have made that decision.

2013: FCC open inquiry proceedings (in response to GAO 2012 report) We have links to the docket and the submissions, doctors, scientists, industry, cities, lawyers.

2018: GAO listed status of the 2012 report as "closed/not implemented". But just recently, the FCC issued an item closing the inquiry, saying there is not science that says we need to update our limits. They based that on the FDA's opinion. There is a three page letter in the docket. You can see all of these.

Abrami: Just so you know Theodora, one of our goals is to try to get someone from the FCC to actually talk to us. We are a state. We are not the federal government. But I am not going to give up trying to get someone from FCC to answer our questions.

Scarato: I would hope the FCC as well as the FDA would answer your questions. We have questions. Scientists have been writing letters. I have a slide on letters that have not been responded to. I believe the American people need to have answers to these questions. What the FCC did on Dec 4, 2019 was to say there is no need to update the limits, "that we decline to revisit our RF exposure policy as it pertains to children". "Similarly, the FDA maintains that the scientific evidence does not show a danger to any users of cell phones from RF exposure, including children and teenagers" even though there was a submission in the docket on damaged brain cells.

There were submissions that said the testing of the phones should require zero spacing. They don't think that they need to. They think the information in devices is adequate to inform people of these issues. I think I am pretty smart and I did not know that information was there. I have a Samsung Android and I cannot find my SAR testing easily at all. It is not in my phone. It is not listed online. The only way is to go to the FCC and type in your model and make to figure it out. That is not adequate. I would expect more of our government.

Gray: Mr. Chairman. I do object to some of this testimony. Let me explain why. A lot of the testimony that we are getting right now is: somebody wrote a letter and we didn't get an answer. Somebody else wrote a letter and we didn't get an answer. I have sat through many hearings on vaccines and listened to this electromagnetic radiation all the way from when I was a teenager and we were worried about the power lines. I would love to hear the data that you have got. The experts from the FCC have said there is no scientific data out there. That's what I am interested in, the scientific data that deals with 5G, because that is the crux of this committee. If there is data about the scientific problems with 5g then I want to hear that but I don't want to hear that I wrote a letter and I didn't get an answer.

Abrami: Well, I don't disagree with you. We are trying to get at the essence of this. I want to talk to the FCC directly and the IEEE. We are still trying to get at the facts. We have talked a lot about the science on the commission probably more than any other state legislature. I am hearing conflicting things about the FCC. Did they look at biological effects or not? I want to know. It would help us as a commission to understand. As the Chair, I am not releasing a report if the FCC says X and we say Y without data to base that on. People will ask, just like you did. What did you base that on? The FCC says its fine. That's why we have to keep digging.

Sherman: I want to remind the commission that this is our guest. We don't usually shut down a guest because we don't like what they are saying. I would ask that we let her speak as invited and you can be your own filter for what she has to say rather than objecting to her testimony.

Woods: I understand the Senator's concern. But by the same token, even if we have scientific data, we need to know what context or social context this has been interpreted and conveyed. That is just as important to me. If we find that the FCC got a letter and didn't respond and we know there is a study about that, then that non response is important. I understand that data is important but the context and how it is conveyed is also important.

Abrami: The other thing Theodora, you are doing a great job laying this out. This commission is deep into the weeds on this. We don't know all of what you are saying here. We are filling in gaps so continue along your presentation. The other thing we will be talking about with Devra is we need to see that some of these studies are replicated. We can't look at a study and say that's bad if it's not replicated. For me to feel more comfortable, science has to be replicated.

Scarato: She is going to be talking about that. I had read the questions that your commission is tasked with. I was basing my presentation from the policy side based on those questions. I am trying to explain why and give you links to it. For example, the American Academy of Pediatrics sent a letter with concerns to the FCC. I felt it was important to talk about this.

Abrami: I agree. Public policy wise, like you said earlier, most people don't know you shouldn't keep it on your body. I did not know that myself until about a year ago. As a commission, we would really like to see what other states and municipalities are doing if you have that.

Scarato: I can fast forward to that.

Abrami: You may want to do that because we may run out of time.

Scarato: <u>The Systematic Review</u>: This is important. It is a gold standard and I want to point out that is hasn't been done. When scientists are writing letters, one of the questions asked is where is the systematic review? Where is the full report on all the studies and what they found and how to weigh them by independent experts? What does the science say as to what is a safe level? I know that is a question that you are looking at.

<u>What do US Health Agencies say about NTP study?</u> I am pointing this out because I think it's important for the commission to see what different federal agencies are saying on their websites about this issue. For example, on the National Cancer Institute, unless you know what you are doing, you would be hard pressed to even know what this study found. All they say is, "primary outcomes observed…". This is not what most of the American public would even know what that means. The FDA disagrees with findings of NTP yet no systematic review, no report, no citations, no FDA peer review. The CDC says nothing about NTP. EPA says nothing on NTP and sends you to the FCC. The EPA used to actually have statements on their site. We watch all the sites and you can see what they previously said. They had a statement about an open question of safety, but that's been changed.

2014 The Department of Interior letter states "however, the electromagnetic radiation standards used by the FCC continue to be based on thermal heating, a criterion now nearly 30 years out of date and inapplicable to today".

2002 EPA letter to the EMR network of VT: "federal health and safety agencies have not yet developed policies concerning possible risk from long-term, non-thermal exposures"- Robert Hankin, EPA,2002.

FDA: Scientists 2019 letters to the FDA that have not been answered.

NTP: Ron Melnick is a 28 year NIH senior scientist, who lead the design of the NTP study. He has published how there are unfounded criticisms of the NTP and addresses that.

The FCC said testing phones are zero mm is unnecessary. Women put their cellphones in their bra. I can probably find three or four women on the street in DC who carry their phones in their bra because they don't know. Phones are always radiating even when you are not on them. They say that operating instructions are adequate. Kids don't know.

Abrami: Theodora, please for the sake of time, it would be great if you get to what states or municipalities are doing.

Scarato: Montgomery County, MD has a federal court challenge to the FCC. This was filed before the FCC did its filing stating they don't need to update the limits. This case is still proceeding. How can the FCC be streamlining 5G when they haven't completed their inquiry? The FCC should complete the 2013 review before issuing 5G streamlining order. See the links to Putting the cart before the horse-"FCC's 5G first, safety second" policy by Albert Catalan, Eric Gotting and Timothy Doughty, the Journal of Local Government Law. That's one of the lawsuits to know about. I have a link to the filing.

Cooley: Mr. Chairman and Ms. Scarato, I don't mean to interrupt but I think there needs to be some clarification to that slide. The way that you characterize it is that Montgomery County is suing on RF grounds. Montgomery County raised the RF issue in light of the FCC's state and local item with respect to streamlining 5G facilities. I think that's an important clarification for the minutes. I hope I wasn't disrespectful by interrupting you but I wanted to make that point.

Scarato: I hope I was clear on that. What they are saying is, how can you streamline 5G without having finalized the inquiry preceding it or pushing something forward without having done the review?... not that there is a health problem. That is what I meant if I wasn't clear on that.

Cooley: I believe that Montgomery filed again though after the FCC item on Dec 4th. I would like that to be clarified.

Scarato: Oh. I know they are continuing their case.

Cooley: They are continuing their case. I am not disputing that.

Abrami: Theodora, you may want to check that out and get back to us.

Scarato: Yes. I will

Letters from Senators: We have links on our site of senators who have written letters to FCC and FDA, asking for their review on 5G and their letters.

Lawsuits: I wanted to point out two lawsuits: 1/ Irregulators vs FCC and the Fegan Scott lawsuit. Irregulators lawsuit alleges that there was money for maintenance of wired lines that was switched to wireless. I am summarizing. The Fegan Scott lawsuit is about separation distance in phones.

NEPA decision: The FCC's action to streamline 5G, has stripped local authority with regard to infrastructure. There was an appeal by the National Resources Defense Council and Native American Tribes that was won. There needs to be compliance with NEPA (National Environmental Policy Act) for small cell and wireless facilities. Cities and states have argued about amount of caps and leasing spots. There are two separate cases. The FCC has vacated a part of their order saying they do not have to be in compliance with NEPA. So now, small cells need to be certified it meets NEPA requirements. The NRDC did a Q&A about what this means in terms of municipalities. I will provide a link to that.

Federal level: Three Bi Partisan bills on 5G passed the House at the federal level. (H. Res. 575, H.R. 2881, H.R 4500)

Local ordinances: Cities and towns have been coming up with in order to address this because many people say ,I don't want these in my front yard and what do we do? Then they realize they don't have an ordinance in place to handle it. They don't have a permitting process. They don't have any kind of authority. Cities and towns are trying to find out what authority they have and make the most of it. Examples: (City of Los Altos: installation of small cells on public utility easements in residential neighborhoods is prohibited; 500 ft. set back from schools; 500 ft setback for multi-family residences in commercial districts; 1500 ft separation between installations)(Petaluma: 1500 foot minimum separation; No small cell shall be within 250 ft of any residence)(Bedford, NH: 750 foot setback in residential) (Burlington, MA: annual recertification fees; applicant must pay for legal notices of public hearing) (Fairfax, CA: small cells prohibited in residential zones; 1500 ft separation; city to study citywide fiber optic cable network)

Example of issues that come up from lack of infrastructure and permitting/compliance: I will tell you what happened in our town. On this slide, that small cell on private property is illegal even when it was placed on private property six years ago. It was placed there even though the permit was for down the road. The owner repeatedly testifies asking, can you please remove this from my property? Everyone says they can't because no one has authority. It is still there. What is happening is that there isn't the infrastructure that there needs to be to oversee the permitting process that needs to be done. Community members started looking in to this and found several permits that were incomplete and over a dozen that were placed where they shouldn't be placed. Then there is the whole issue on, why can't this woman get that removed from her home? You could have a whole meeting on permitting, review and compliance.

Sherman: I don't understand. We already have utility poles and rights of ways. If this is in violation, why doesn't it fall into the utility right our way or violation thereof and why can't it be removed on existing statute? For example, in Rye there are double telephone poles going in and they are failing to remove the old poles. That's a violation of the right of way and now will be removed. I don't understand why this would take five years if they are in violation of the right of way.

Scarato: I am not going to profess to know all of the details of it. You can watch her present just a few months ago. Every jurisdiction has different policies.

Abrami: I know this isn't the science part of our discussion. 5G means something different to everyone. Different companies are rolling out differently. We are concerned what's in those antennas, how much power is coming from them, how far away should they be from each other, a home or business. Eventually, we will get to that. From a policy stand point, we have to understand the science to be able to make intelligent recommendations Just from an aesthetic standpoint, as a homeowner, I would be upset too. We need to separate the aesthetics from a science too. Some people just don't want it for aesthetic reasons. We are concerned about both because there will be push back. We are trying to get ahead of the curve and understand the science.

Scarato: We all had that question but it's quite complex because every antenna or small cell facility will have different antenna depending on the network using a variety of frequencies. 4G is a backbone of 5G, as I understand it. There is a study that came out that I don't' know if Dr. Davis will talk about. There is a study that looked at small cells in communities and communities without them and found there will be an overall increase in environmental level. Industry will say it's negligible. Scientists looking at biological effects will say it's important to consider, I believe. I don't want to speak for anyone but I know that is what is being put forward. That's a good question. We aren't getting 5G but are getting 4G and they put cells 2-10 homes.

Abrami: Usually, we hear of 5G in mm waves, further up the spectrum.

Scarato: But they aren't going to be using only mm waves. They are also using low, mid and high band frequencies, at least from the CTIA report. All of those frequencies will be utilized in 5G depending on the carrier and location. So, to say it's only mm waves is…

Abrami: Every company is different is my guess.

Scarato: <u>What can cities do to retain their authority</u>? Many cities want to retain as much authority as possible related to 5G. There are now 120 cities in Italy passing resolutions on 5G. In Cyprus, they removed wireless from pediatric units and provide safety information for parents. Internationally, is all online on our website EHTrust.org.

Cooley: Thank you for your presentation. We can talk about what is happening internationally but the US has a unique set of laws. In terms of what cities can do, we have to remember the FCC state and local order is the law of the land. It went into effect in January 2019. Yes, it is being litigated. Oral arguments are February 10th in the Ninth Circuit in Pasadena, CA. As we are looking at policy recommendations, we have to remember there is federal law. There is also the Communications Act section 332, specifically which we should delve into because other states are looking at what they can and cannot do in this space. I want to frame that properly. Yes, there are ordinances around historic preservation, aesthetics that cities can look at. But in terms of legal framework, I don't think New Hampshire would want to be inviting litigation by recommending something that would perhaps run afoul of federal law. On that slide, I wanted to make that point.

Scarato: I would expect that lawyers would assure that local, state and federal law was being evaluated depending upon where you are. There is a lot that you can do and a lot that you can't do. There is a lot that cities can do actually.

Cooley: Yes. Absolutely, I am not disagreeing with that. The only other point I wanted to make. You mentioned a Federal Right to Know law that was introduced in Congress in the early 2000s and you mentioned the San Francisco Right to Know Ordinance which you seem to allude could be something the commission could look at.

Scarato: As I understand, San Francisco continued their arguments and decided to pull out because whoever won would have to pay the court fees and it was not implemented.

Cooley: That's correct. It was never implemented.

Scarato: Also, the Berkley cell phone law did pass which I did not talk about. It basically says that people have the right to know when they buy a phone from a retailer that if it touches the body, it could exceed FCC limits. The Supreme Court let it stand.

Cooley: It was not implemented.

Scarato: Right.

Roberge: On your slide that had cities with protective ordinances, you use the term facilities in terms of setbacks for facilities. Are you referring to antennas?

Scarato: When I said facilities it refers to the installation of equipment and antenna.

Roberge: I just wanted to make sure we were talking about antenna and equipment not a facility as in a building.

Sherman: I have a quick question. With multiple different networks and multiple different carriers in any one municipality are there multiple different 5G networks being proposed? Does each one emit a certain amount of radiation? If for example,you have TMobile and Verizon in same setting,what does that mean for total exposure for the public? Is it double? How does that work?

Abrami: To add to that question. Currently, there are towers with multiple antenna, will there be sharing?

Cooley: Yes, there will be sharing and Theodora made a great point. Carriers will be using different frequencies. TMobile for example, their 5G will mostly be on their existing macro towers. So they are going to be 200 feet in the air vs Verizon or AT&T who might be using the millimeter wave on that light pole. It's not kind of a yes or no answer.

Sherman: If we are in Concord and we have TMobile, Verizon, AT&T all providing service, are we going to have three different networks to which we are exposed all at the same time? Or is it one shared network? The ultimate question is does it mean are we going to have 3X the 5G exposure? And what does that mean?

Cooley: I am not an engineer but the answer is no. Depending on the facility being used, they are going to have different power levels which will change the amount of non- ionizing being emitted. So, it's not really apples to apples to say…. you've got one Verizon, one AT&T , one Sprint and one TMobile because they are probably not all going to be on the same facility because they are using different spectrum frequencies. So, it's not just to say, Yes…. You will increase by four. This is really an engineering question.

Scarato: While that's true, it's also true they don't want to share installations. It came up in Washington, DC. They don't want to share a hotel but that means that different carriers don't want to share an installation. Each will have its network rolled out. You will get the increases.

Cooley: But that's specific to DC. There are locations where hoteling does occur and carriers share one pole. It's completely specific on the network needs and the spectrum being used.

Abrami: We have an engineer right here with a question.

Gray: I wanted to go back and defend my comments in the middle of the presentation. When a guest is asked to come given the criteria, I expect certain things from that guest. I don't expect to get bombarded with health things that are trying to tug on my heart strings, other information that doesn't go back and say yes. We have this but here is the data that I can look at that says this is happening. I've got a lot of people from Health and Human Services coming to talk to me about vaccines that say here is anecdotal information that this person ended up with because of that vaccine. We go through this whole presentation and we say, so what real data did they present at all that says here is this radiation, this frequency of radiation, this level of radiation that caused these things and that is why we are protecting you. So, when we go further than that and you say there are a bunch of cities out there who have regulated placement of antennas. What information did they use to regulate that? If it's clearly identified information then everybody across the country would have done it. Or is it because they were scared? I am on the planning board and City Council in Rochester. There are people there who would like to regulate all kinds of things. It's just like the environmental thing, global warming. Give me data. Don't give me, I asked a question and I didn't get an answer.

Scarato: Dr. Davis will be talking about that data and all that data is on our website. Dr. Davis is presenting the science. I am presenting the policy.

Abrami: Yes, Theodora. You did exactly what I asked you to do. I was trying to get a sense what's going on around the country related to this in terms of ordinances and states taking action and all of that. We, as a commission are doing a pretty good job of not taking things on face value. We are trying to understand the science. This may have not met your needs today on this but we are trying to get as much information on this as we can. I understand your position, Senator Gray. When I talked to Devra the other day, I told her what I want to know is what studies have been replicated multiple times.

We will be meeting through October on this and we will continue to try to bring in the right people. We have the outlines and the picture and we have a lot of filling in to do as a commission. Thank you for your comments but our guests are our guests. As a commission, we do appreciate you coming here.

Wells: I just want to make a quick point from a moment ago, just to clarify the science of electric fields and magnetic fields. When we talk about electromagnetic radiation, they are additive. It does not depend on the frequency you are talking about. It does not depend upon what brand name it is or the locality. It's called the superposition principle. If you have multiple carriers in an area, they will overlap and add.

Sherman: I think that answered my question.

Chamberlin: The 1996 Telecommunications Act says that health effects from exposure to radiation cannot be used for objecting siting. How does that come into play or does it come into play in the legislation you are familiar with?

Scarato: Well, it says that concerns about environmental effects cannot be used in the siting of facilities. This was then interpreted by case law and lawsuits to be health concerns. If there is a community and people only talk about health concerns and the city says because of these health concerns our citizens have, we are not going to site the tower, then they can be sued. People say don't we have a right? How can this be? (Section 704 of the 1996 Telecom Act) I didn't mention this, but at that time, this was the most heavily lobbied bill in the United States. The lobbying only increased after. The amount of money that went into that bill was pretty impressive. I would say that everyone should be able to have their time in court to argue if they have been harmed.

Cooley: I would add that there is litigation just filed yesterday actually in Camden County, Georgia with Verizon. They are suing on the merits of that very issue. The FCC has exclusive jurisdiction over regulating anything that emits RF. So, if a locality does violate that, they may see litigation as we saw yesterday.

Scarato: Several times companies or CTIA have sued and they haven't always won. They haven't always talked about health issues but aesthetics and other things.

Sherman: For my part, I found this very helpful. So, thank you for coming. We are trying to make our decisions on whether or not to move forward or how to move forward based on as much science as we can. You have given us a nice framework on what others are doing in terms of implementing policy. With your help, there has been for me a nice framework on what are the limits of our capacity to do so.

One of the most troubling parts to all of this and you are not the only one who has shared this with us, so you are not alone is that it sounds like the FCC has sole jurisdiction over what happens with the rollout of these networks, yet they are completely in bed with industry.

In the medical world, which I represent, we have a similar problem with pharma and their regulation and the FDA. This is not something this commission can take on but you provided a framework in a nice way to help us understand what are the limits of policy that we could actually consider and roll out if we wanted to provide regulation. Thank you for coming and providing some of that perspective. I think we need both policy and science. So this has been helpful.

Heroux: I would like to address you as representative of CTIA. I just want to drag you out of your comfort zone. As a specialist, I have heard hundreds of reports of deleterious effects of electromagnetic radiation, and you have sat very patiently as we outlined these things in sessions.

What about the positive effects of cellphone use? What I mean by that is, if because of wireless and a cellphone, I can avoid a car trip and then perhaps a car accident. Then surely there are benefits to this, right? There are benefits to the use of wireless. Has the CTIA supported and documented the benefits to using wireless? After all, we have to balance the negative with the positive.

Cooley: Thank you so much for that question. This is a policy question, right in my wheelhouse. Absolutely, I will do a plug for CTIA.org. Accenture and Deloitte have done host of studies on the benefits of what 5G will bring to this country. Nationally, 3 million new jobs, 500 billion contributed to the US GDP.

Heroux: I am sorry. I don't mean about economic activity because that is dollars that can go one place or another. I am talking about avoiding deaths and diseases. Surely, wireless has substantial capability. I perceive that your industry has not documented these things in great detail but have been driven by an alternative variable, which is commercial success. In other words, if things are bought, people want them. So this is an index on how useful they are. My point is…we love potato chips but we can have trans-fat potato chips. You see where I am going?

Cooley: Yes. The benefits of 5G for remote health care. If you live in a rural area and you don't want to have to drive into the city or remote surgery. AT&T is doing some really exciting stuff. There is the first 5G hospital at Rush hospital in Chicago. There are absolutely benefits to consumers and society and agriculture. Drones survey networks so we can see where people are without service. We need to save them if their houses are on fire so we can communicate with first responders, so yes. There is a ton of research on that and independent agencies as well. I would be happy to provide this commission with those studies.

Heroux: Most of those things like remote surgery doesn't need 5G. It can use fiber optics. What I am talking about is specifics. So you could come up with a report that would document the advantages of wireless specifically independent of data transmission. We have not seen that much documentation on this aspect of it. Ultimately, we will have to balance these things right?

Cooley: I am happy to share those use cases with the commission because I disagree.

Abrami: yes. I would agree.

Cooley: I am happy to share those reports we have right now and there are a host of reports coming out, I think second quarter of this year that are not CTIA. We don't do the research. Other entities do the research. I am happy to share those.

III.Devra Davis PhD, MPH, President, Environmental Health Trust (via speakerphone):

I have been working in science at some of the highest levels for many years. We started Environmental Health Trust when I was at the University of Pittsburgh Cancer Institute, where I had set up the Center for Environmental Pharmacology. I worked as a member of the President's Cancer Panel. I was confirmed by the Senate. So, I have been around for a while. I have written two books. The most relevant and recent book is “Disconnect: The Truth About Cell Phone Radiation”.

I am going to first explain that when it comes to getting information about any toxic agent whether it is chemical or in this case, RF, we look at experimental studies including *modeling* of exposure. Please understand that that is all we have for exposure. We can’t go inside the brain and actually pick up exposure when it comes to humans. What we can do is use computer simulations that are anatomically based on models of the human brain including specific parts of it that are relevant. I will talk about today, particularly the hippocampus. We can fairly accurately model those. Those models have been validated and are used right now. Some of the models I am going to show you are used to set the standards for surgery or approval of equipment by the FDA.

Then there is *invivo* testing which means whole animals. We take animals and expose them usually over a period of several weeks or some time for two years. Rarely, are animals exposed from before birth to their death.

Next we have i*nvitro* studies which look at cell cultures either animal or human cells to measure DNA damage or other things that happen in cells. Those studies, I want to stress are done in order to predict human effects and prevent them. That is why every drug that you take is subject to animal testing. The same standards being applied to testing drugs have been applied to testing RF. Please keep in mind that everything we know for certain causes cancer in people because we have data for example from asbestos or arsenic will produce it in animals.

In terms of *ecological* studies, we can look at trees and grasses. There are experimental studies as well on bees and other smaller animals.

Finally, we have *epidemiology,* the study of people and I am a fellow at the American College of Epidemiology. I was also a member of the American College of Toxicology. So, I am familiar with both of these overall approaches both, toxicology and epidemiology.

For epidemiology, *cohort* studies are the weakest form of analysis that we have. In the case of what we are looking at for brain cancer, we cannot follow people through their entire lifetime with detailed information. We therefore rely on case control studies of those with the disease and compare those to others who do not have this disease but are otherwise similar.

The next slide shows you a child. It explains that because of the modelling studies that have been done, we can conclude without question, that children will absorb more RF into the brain soft tissue inside the skull and 10x more into the bone marrow of the skull, compared to adults.

<u>Virtual reality simulations:</u> I just showed that to you because virtual reality is a very cool and exciting thing but the way it is often used is with wireless transmissions and when you have a microwave radio right in front of the eyes and frontal lobe, you are getting greater exposure if you look carefully through the top of the skull of the six year old on the right side. You can see much greater penetration into both eyes and we are very concerned about the eyes of children right now from a number of exposures.

Summary of the EU REFLEX Project: The European Union in about 2000, funded about ten million dollars for twelve different research labs in seven countries. They were asked to look at the question of whether or not the same radiation that would be received from cell phones could break DNA in a variety of human cells and by the way including brain cells and human lymphocytes and fibroblasts. The conclusion of that study, much to the surprise of the people doing it, was that they found clear evidence of DNA damage. At the beginning, when they first found positive results, they assumed they had faulty equipment. They had so much money that they went out and bought new equipment to test things. Those of you with a medical backgrounds, which I am pleased to know are on your commission and also part of your legal body there, understand that being able to buy new equipment means you have a lot of money. The results shocked the researchers. They clearly showed changes in gene and protein expression in several different cell lines. Interestingly, they did not show damage in the mature human cell line. Damage was much greater in human fibroblasts and human cell lines that are less mature, stem cells.

Abrami: Can you go back to that slide please? So, they replicated a study that was done in 1994 but it was a 2004 study they replicated again?

Davis: Yes. In 1994, Lai and Singh produced a study showing damage to the brain of the rat from cell phone radiation, DNA damage. They were shocked by the results. They did the study all over again. When they were about to publish the results, the industry engaged in what was called "War Games". That was the strategy and what it was called in 1994. Remember, in 1994, very few people used cell phones (about 10%). People in industry understood the importance of this, went to the journal that accepted the article for publication and tried to get it unaccepted. They went to the NIH and accused the researchers of fraud and went to great lengths to conduct what they called War Games. That was 1994. In 2004, when another group was asked to see if there was anything to this, they were confident they would find nothing. In 2004, they replicated it.

Abrami: This is the EU REFLEX group.

Davis: The Comet Assay: Right but there's more. I'd like to show you more about the replication of the DNA on deregulation of cell proliferation and exaggerated programmed cell death otherwise called apoptosis and genotoxic effects all show from very little exposure. The next slide is a summary from there (The Comet Assay). You can see the sham or the perfect cell on the left is a cell with no DNA damage. When you have damage, you get a common tail. See the tail on the top right and the bottom. In 1994, those tails were only measured by somebody looking at them and giving you an estimate of what percent tail there was. Now we have much more sophisticated ways of automating the measure and extent of that tail. The top right is damage from gamma radiation like you would get from massive exposure from a CT scan which could happen in a pediatric CT scan where the scanner is not properly set. The top left slide is your control. The far right on the top is the impact of gamma radiation from xray like pediatric CT scan gives you that much exposure. The bottom right was what they achieved after 24 hours of exposure to mobile phone like radiation at 1.3 watts/kg.

Abrami: Is that continuous exposure for 24 hours?

Davis: Yes. It was exposure like a cellphone. A cellphone is not continuous. Within four seconds, you get huge changes in power density over time.

Abrami: I am trying to understand how far away that cellphone was from the eyes. This is eyes right?

Davis: No. These are not eyes. These are cells taken from the brain.

Heroux: It is slightly lower than the FCC SAR limit.

Davis: It was below the US current standard of 1.6 watts/kg.

<u>Subsequent work confirms the REFLEX project</u>. They showed clear evidence non- thermal microwaves from mobile phones affected repair of DNA in human cells. They showed the same effects at the GSM frequency of 915Mhz. These studies referenced at the bottom of the slide, were all produced subsequent to the REFLEX Project from 2004, 2005 and 2009.

Abrami: so there are four other studies listed there?

Davis: That's correct.

Sherman: All of those corroborate the findings of DNA damage?

Davis: That is correct. Further, the next slide is from Lerchl.

<u>Lerchl</u>: Lerchl was widely known as a skeptic of any of this. In 2015, Lerhcl started with exposure at conception. The rodent reproduces in three weeks. In a very short time, you can follow these animals through their lifetime. Then the equivalent of early childhood, the animal was injected with a known carcinogen, something that we know causes cancer (ENU). Then, those animals were subsequently exposed to RF exposure. The levels of exposure were .04 watt/kg, .4 watts/kg and 2 watts/kg. What you can see is that the control animal developed very few liver cancers. The ones exposed to the carcinogens developed more. But the ones exposed to cellphone radiation developed far more. Much to the surprise of the investigator, they were able to show that the mice exposed in the womb to a known cancer agent, then exposed to cellphone, had significantly higher rates of cancer, tumors to the lung and liver. The study was designed to replicate an earlier study by Tillman, also of Germany. When he first presented his results, said they were remarkable. His study was ignored. Lerhcl found higher rates of cancer in all of these mice. Also survival times of the animals were much lower of those who were exposed. This was a very powerful replication as well and further replication because you had asked me, Mr. Abrami about focusing on replications.

<u>The NTP study</u>: You already heard about this so I won't go into that. But, I want to remind you that what is on the website of the National Toxicology Program right now summarizes this information. It states clear evidence of tumors in the *heart* of male rats. I want to stress these are very rare cancers. I suppose in a way, that's the good news. There was also some evidence of tumors in the brain of male rats, again rare. There were multiple cancers in other organs, some of which did not achieve statistical significance

but were still elevated. In the NTP study, they said, not only do we have evidence of cancer but precancerous conditions of the heart, meaning damage to the heart. This is quite worrisome.

The publication that came out from NTP shows DNA damage to the *frontal cortex* of both rats and mice. I want to stress that although the cancer showed up only in the rats, the DNA damage showed up in both the rats and mice. There is clear evidence of replication of results of DNA damage. The cancer results are also replications. This is not a one off study.

I want to stress something about the frontal cortex. It's really hard to get mice to make phone calls. That is why the exposure has been carefully calculated not to increase the temperature of the animal but to allow whole body exposure that simulates the kinds of exposures that can occur today.

Slide 14 and 15 give you a much more detailed analysis of NTP. Slide 14 looks at the tail of DNA using computers now. In 1994, they had people who could just look at the tail. Now we have computers to do it. They can score the number of cells in terms of the evidence of fragmentation of the DNA. Zero is your control. You will have some fragmentation of DNA just because that's life. We are breathing. We have sunlight. We get DNA damage all the time. If we are healthy, we eat our broccoli and sleep in the dark, we will have repair of our DNA. This is showing that exposure to CDMA which is a type of cellphone radiation. You get statistically significant damage indicated in the male rat *hippocampus*. The hippocampus is what allows us balance, memory and impulse control. It has been well studied in many different systems and shown to be damaged by exposure to cell phone radiation. Slide 14 is showing you the rat and slide 15 is showing you the mice.

Slide 15 shows the effects to mice are in the *frontal cortex*. In the rat, it was the *hippocampus*. Slide 16 discusses the implication of the NTP result. Dr. Melnick was involved in setting up the study originally in 2008. The study was designed to test whether or not heat was the only effect. They set up a study that did not heat up the animals. That design was carefully calculated by Swiss engineers using methods that are validated, they were able to show results that I just showed you, increases in brain tumors, increases in heart as well as DNA damage in multiple organs in both rats and mice.

Abrami: Is that the replicated study that was done?

Davis: Yes. Smith-Roe is the first author of that study that was just finally published in 2019. Dr. Melnick and I and many others believe that the FCC by issuing its latest order saying we are going to be keeping our 23 year old standard for RF is ignoring this body of evidence I just showed you and more. I would like to show you a little bit more.

Gray: Before you leave that. The radiation that you applied is less than what it would take to heat. What is that in relationship to normal radiation from a cellphone an inch away from the head?

Davis: Thank you for that question. It is the same radiation you would get from a phone and they did it with ten minutes off and ten minutes on simulating the way we are exposed. As you may be aware, even when a phone is in your pocket as long as it's turned on, it's constantly checking for signals from a tower.

Gray: I understood that it was the same radiation. What is the level of radiation? I want to know if the radiation that I would get from a cellphone an inch away from head is a higher level than what these rats and mice would have experienced just below the level that would cause heating.

Davis: Well as a matter of fact. I am really glad you asked that because the answer is we get more exposure from our phones than these rats got. The reason we know that is because I assume you have seen the results of the Chicago Tribune test. Have you?

Abrami: No.

Davis: Theodora, I think you should show them the 60 second video of the test from Chicago. Do you have that? The Canadian Broadcasting Corporation, the French government and most recently the Chicago Tribune have actually taken real phones and tested them. They have found that the phones when in your pocket emit actually more radiation than the NTP study. The NTP test, tested the amount that they are supposed to emit. The Chicago Tribune paid for independent testing at an FCC approved lab. They took phones off the shelf and what you may not be aware of is that the way phones are tested today. They are provided by the manufacturer to a test facility and they select the phone to be tested. There is a whole scandal about that because as it turns out when you do that, of course the phones pass the test. When you take phones that you can buy and test them next to the body, they all fail the current test. (Nine out of ten of them to be precise) They fail it by as much as five fold in the United States.

Sherman: That is significant, what she just said.

Scarato: I wanted to say that when you put a phone near your body, you are getting an intense localized exposure near where the phone is. NTP did that at localized exposure, not the full body number. They wanted to see what the intensity would do to the tissues. This is not a whole body number but a localized number that we are talking about when we are comparing. The FCC occupational limit is 8.

Abrami: So, when they did the test and took the phones off the shelf what did they do?

Scarato: They measured the SAR levels at body contact and at 2mm and the French government measured hundreds of phones and body contact and found excesses of the limit.

Abrami: Most of the public is putting it next to the body because they don’t read the fine print.

Sherman: I am trying to get at what is the significance of exceeding by five fold in the Tribune test? What does that mean to us?

Davis: The significance of the Chicago Tribune test should be that it would call for re-examining the whole test approach.

Sherman: So we are basing the emissions coming from phones based upon the tests done by the manufacturers under FCC guidelines but these independent tests in Europe and by the Chicago Tribune and Canada are showing no, that's not necessarily the case. We may be getting five times that exposure of RF. Is that correct?

Davis: That is perfectly said. Thank you.

Scarato: in high exposure conditions.

Cooley: I just want to add to the record from that Chicago Tribune story which came out in August. The FCC immediately opened an investigation to look into that. On December 19th, after doing their own independent investigation, the FCC published a report saying they tested the same models and found all of them compliant with the FCC exposure limits.

Sherman: This is the FCC that currently has every member as a member of industry, former, future or current. Is that correct?

Cooley: The commissioners. If we are talking about the "Captured Agency" slide that Theodora had. The commissioners don't do the testing.

Sherman: No. But they are the ones who approve what comes out. It's like an Editorial Board. Is that correct?

Cooley: I don't know how or if they approve of a report. I don't know that process.

Davis: The protocol for the FCC was developed based on the assumptions that the only effects that needed to be avoided were heating. The tests were developed 23 years ago when phones were solely used by medical and business people. How many of you used a phone 23 years ago?

Sherman: I did.

Davis: Well, you are probably the physician in the room.

Sherman: yes.

Davis: My dad was a brigadier general and he also had one but very few people with normal jobs had phones. It was only about 10%. That's when phone protocols were set up and they were set up to be tested up to an inch away from the body because they would be in a holster which is the way people had pagers and phones in those days. They didn't carry them. They had them in a holster.

Scarato: Can I clarify what Beth is saying here? When the FCC did their test after Chicago Tribune, they tested at 5mm from the body. They didn't test at zero mm which was the whole point. They said they are compliant but if you look at the test report, it says 5mm. Then the news headlines read," they are compliant". But it says right on the report… 5mm. The issue is people have close contact.

Gray: The 5mm problem bothers me alright? The reason it bothers me is there are 2.54 mm per inch so if I take 5mm, I am at a quarter of an inch or so and when I look at where the antenna is in the phone because there is a spacing there, I would think that 5mm is probably a pretty good distance when I have the phone right up to my ear.

Davis: It turns out that the antenna in the old days were towards the head. The newer antennae are toward the thyroid and lower. Your smart phone can have four or five antenna: One for data, one for video, one for voice, one for satellite GPS which is not RF. You have multiple antennae now that are located lower in the phone. We are now concerned that one of the explanations, not the only one but one of the explanations for the increase in thyroid cancer could be cellphone radiation.

Ramazzini: (slide 18) I do very much appreciate the opportunity to speak to all of you. I am delighted and honored to be able to speak to you and the fact that you exist really means a lot to all of us that have been working on this issue for quite a while. I never imagined I would be spending a decade or more of my life on this. I previously worked on lead and asbestos and I thought this would be a pretty simple issue but it's not simple. Ramazzini did a study like Lehrcl but they took thousands of animals and exposed them at different levels before and at conception and followed them until they died.

Their results on slide 19 was to show damage, the same type of damage that the NTP found at levels of exposure to their animals that were far less than NTP. In particular, they showed a *synergy* between RF and xrays (gamma radiation). *This is really important because it shows there is an additive effect between RF and gamma radiation (xrays).*

Abrami: the Ramazzini study was an independent study basically in parallel?

Davis: yes. It is the equivalent of the NTP for Italy.

<u>Uptake of glucose in the brain</u>: Slide 20 is a summary of a paper that was published in JAMA by some of the top researchers of the US government, the Director of the National Institute of Drug Abuse on the effects of cellphone exposure to the uptake of glucose in the brain.

Slide 21 shows the study design. A person with two cellphones strapped to their head. The study was done more than a decade ago. They had a PET scan which can measure the uptake of glucose in the brain. The person with a phone strapped to their head did not know whether the phone had been turned on or not.

Slide 22 is the results. If you look at the slide to the right, it shows the increase in glucose in the parts the brain that got the most exposure. Look at the slides comparing glucose uptake when the phones were turned off compared to the slide with the phones on. Look at the increased amount of glucose in the exact part of the brain there was the exposure. Why is that important? *Alzheimers* has been called *diabetes of the brain* because people with Alzheimers have too much glucose in the brain. Nobody knows the consequence of having too much glucose in the brain from holding a phone next to your head. It remains unknown. This study was subject to "War Games" as well.

Slide 23 explains part of what might be going on. You will see the control on the left without exposure. The slide on the right shows little tiny dark spots of damage, *indicating that the blood brain barrier has been breached.* At the bottom of the slide you will see references.

Abrami: is this a human brain? Or no?

Davis: oh no. We can't do that. These are Sprague Dawley rats.

Davis: at the bottom of the slide you will see references to subsequent studies. The first study showing this was in 1975. Alan Frey did that work. Cold War was still on and radar is a vital part of it and he was basically told to stop doing research. All of that is documented in my book.

<u>What happens when you have a cellphone in your pocket</u>: I have done a Ted X talk that I think you will find interesting. I make the point that sperm have to swim the equivalent of the distance from Los Angeles to Hawaii in order to succeed in fertilizing an egg. Do you know why it takes at least a quarter of a million sperm to make a healthy baby?

Abrami: why?

Davis: It's because they don't know how to ask for directions.

Abrami: I fell for that one.

Davis: When you get these slides on your own computers, you can simulate the exposure. Look at the white in the control slide. That indicates either the nucleus or the border. On the exposed slide, you can see that on some of the cells, the nucleus has been degraded and in many cases, the border is gone. Again, indicating damage to the membrane. So, cellphone radiation damages the membrane of the *brain* as well as the *testes*. I believe the *eye,* as well.

Abrami: I see the Cleveland Clinic quote there. Was this research done there?

Davis: Yes. Some of this research has been done there. Some of it has been done in Australia at their equivalent of the Cleveland Clinic and other work has been done at other clinics. What's interesting is that people doing this research started to do it two decades ago because they were concerned with the number of doctors showing up having fertility problems. What they concluded in a cross sectional analysis was that those who had the most beepers and things on their pelvis had the lowest sperm count.

<u>Recent study glioma on Slide 28</u>: Summary of the most recent work I have done with Prof. Anthony Miller who has himself authored more than 600 publications. It basically shows every study that has looked at people who have regularly used phones for ten years or more, for an hour a day or more we found an increase in *glioma*. More studies have been done now. The most recent study was released this week.

<u>Thyroid Cancer</u>: The American Cancer Society supported a study of thyroid cancer. It was done at Yale University that shows a double risk of thyroid cancer from those using phones that had specific SNPs which are quite common. These SNPs have to do with repair like p53 and other things that have been identified. The newer phones have antenna located closer to the thyroid. The study concludes that they have found a link to an increase in cancer from regular cell phone use. *It was just published this week*.

Effects on children's brains: Slide 31 tells you of the effects on the brains of children are substantial. Here is a study that looked at the brain matter of preschool aged children, using MRI. I don't know how they got approval for this study but they did. They concluded that there was degradation in the brain white matter looking at microstructures with heavier regular screen use, which is further reason why the American Academy of Pediatrics has said we must reduce exposure in young children.

Abrami: They based it on one study or the preponderance of evidence thus far?

Davis: Well, this is one study but it's a replication of many other findings on effects of attention, behavior and learning in children.

Effects on memory in teenagers: Slide 32 looks at teenagers and again they find a deficit in memory of kids. I will let Theodora talk to you about synergies on slide 33 they found in Korea. Mr. Abrami, you had stressed you wanted replication. I am showing you these are all replications of results on adverse effects on learning, behavior and attention from cell phone use in children.

Why so many conflicting studies? Slide 37: The answer is, follow the money. The majority of the studies in this field have been funded by industry or the military. That's just a fact. Analyses of the studies show that 75% of all the negative studies have been funded by industry or the military. Microwave News 2006 assessed *funding bias*. You don't need to be a statistician to know which way the wind blows.

Insurance Industry Slide 39 shows secondary insurance Swiss Re and Lloyds of London and others will not cover damages from wireless devices or EMFs. They rank it in the same category they once ranked asbestos.

Abrami: We were well aware of this fact. Have you spoken to anyone from the insurance industry about this? Why don't they insure?

Davis: Several years ago I did. They run the numbers. They think there is sufficient scientific concern and the 10K reports of wireless industry say they may face liabilities from lawsuits. There are lawsuits right now on behalf of people with brain cancer that are still going through the courts. They have not been thrown out and frankly I think they are going to win.

The last slide is the one of the cartoon. I just want to remind you. It had been very difficult to get people to stop smoking in the environment of children because the science had been deliberately manipulated. Unfortunately, that is what we are dealing with here as well. Why did the FDA reject the NTP? They have not even given a reason.

Sherman: We kept hearing about the need expressed by federal agencies for a comprehensive review of all the studies that have been done and yet that hasn't been done is my understanding. Is there any plan for comprehensive review? If there is, would that review take into account funding sources? We know from several other medical studies that the impact of funding is huge on conclusions and editorial control of final conclusions on the studies.

Davis: Environmental Health Trust, I can say is that we are the mouse that roared. We have managed in the paper that I shared with you, Miller et al. That is the closest thing to a comprehensive analysis. That was done in 2018 two years ago.

Abrami: We have to pause. Beth has to leave. I am thinking about the 14th of Feb for our next meeting.

Cooley: I am not available but I can see if someone internally is.

Davis: What is your schedule for completing your work?

Abrami: We have until October to have our report finalized.

Davis: Your work will be vitally important because there is a huge gap. The federal government has abdicated it's authority for years. We have been really shocked at the appalling situation with the FDA. It just flies in the face of science I have shown you just briefly here. I could have shown you even more on male and female reproduction in animals. I could have shown you more effects on humans. This simply indicates that there is a robust body of scientific evidence, including the study I just showed you that just came out on the thyroid (Luo 2020). That study is putting another nail in this coffin. We know industry knows how to make safer phones. The real question is for 5G, what does all this mean?

Sherman: Can we get a link to that?

Scarato: Yes, and also the bees because they look at MM waves specifically.

Abrami: Yes. We are interested in bees. That is an area we want to pursue.

Davis: I have a video in my slides of the bees. This study was done by bee experts with three hives. What it showed was the hive with phone off and the control hive had no effect. The hive with the phone turned on, those worker bees did not return and they stopped producing honey. Obviously, you are not going to have a phone in a bee hive. But it's clearly indicating a susceptibility to this exposure.

Abrami: This has been very helpful. We are trying to get the facts and understand. Unfortunately, as a commission, we don't have the resources of the federal government here in New Hampshire. We don't get any funding to do anything other than us being here as volunteers. We are going to work as hard as we can to get at the facts. We would like to hear from the FCC somehow or at least a member that was in the room. You suggested that there may be someone that may be willing to chat with us.

Davis: I think he may be willing to do it without being identified by name. It is a tough business.

Abrami: Well, we will take him anonymous.

Davis: I will ask.

Sherman: I can talk to our federal delegation and see if they can twist some arms to get somebody here. This is something Jeanne Shaheen should be able to compel.

Davis: I fully agree by the way .The appalling thing is there isn't any staff member at the FCC now with any training in this field of bio-electromagnetics.

Abrami: I would like to know in their last ruling, what they based their decision on?

Davis: Montgomery County if preparing to file suit against the FCC because in their statement, they confirm the 23 year old standard. They do not show any recognition of the 1900 pages of scientific evidence they received in response to their proposed rules. They asked the question: in advanced notice of proposed rule-making, should we change our standards? They received hundreds of scientific statements including from us stating that they should. In failing to review the 1900 pages, they are violating the Administrative Procedure Act. I don't know if any members of your commission are a lawyer.

Abrami: We have someone from the AG's office on our commission.

Davis: That's wonderful! I would like to talk to the AG and see if the state wants to join this lawsuit as an Amicus. It doesn't cost any money. Montgomery County probably has a budget equal to your state.

Garod: have any other states joined?

Davis: We think California is going to. What I have been told by a reliable source who was at the meeting, was that Ajit Pai said, I don't care about science. This is what we are doing. That is so arrogant.

Sherman: Are the FCC meetings public?

Davis: This one was certainly not.

Abrami: Devra, I will connect you two by email and you guys can have a chat.

Davis: and I will connect the AG person with the AG person in California.

Abrami: well, we will start with you talking to him. We are out of time now. We would appreciate maybe down the road having another conversation with you.

Davis: I am happy to do that. The fact is that the federal government is failing in its duty to protect public health. That's very unfortunate and therefore you guys are in a very important role. You really are. I have been accused of being a closet Republican. The fact is it may take Republicans to do this because the Democrats have been in bed with these guys for a long time. I hope I don't offend anybody.

Abrami: Let me see, about half anyway.

Davis: The fact is both Republicans and Democrats are both well supported by this industry.

Abrami: At the state level we do this on the cheap. We don't get any money.

Davis: I know you are a citizen legislature with real lives and real jobs and you are doing this as well and I am truly grateful to each of you.

Abrami: We are trying to do what we can do and to get the facts. We appreciate your time and Theodora as well. I will connect you with Brandon our Asst. AG. Another other questions:

Woods: how do you know the level of scrutiny the FCC gave to the scientific information provided? You say they didn't' look at it. How do you know that and what level of scrutiny did they give it?

Davis: I know that because of a person who was at the table when this happened.

Woods: Ok

Sherman: Is there any reference to the science?

Davis: No. it's as if all of it doesn't exist. Let me be clear, five years ago I brought a number of different scientists who had done this research from Turkey and England to the FCC and met their so called interagency group on RF radiation and briefed them. There is such a group. They have no power. They have no authority. They have no statutory standing to do anything at all except to advise. I don't go into the FCC to brief anyone any more. There is no one to brief. In fairness to the agency, they have huge responsibilities to a lot of different things. This issue is one where yes, you want faster connections to your services. You don't want you fire and police to rely on wireless. It's not reliable. Snow and rain can interfere with it. When you have too many people trying to call, its slow. We cannot afford to have emergency services, public health and the hospitals relying on wireless. It's not safe. We need wired connections and we need to have a major push for fiber optic cable and broadband access to and through the premises.

Abrami: We saw that on 911 in NYC.

Davis: From the point of view of the Dept of Defense, they have issued a report on this warning about the vulnerabilities we face. Demanding wired connections for those that need them is the way to go. I think those in public safety have to reset the conversation. If you are really going to protect public health and safety, you've got to have it wired. It's the only secure connection you can have.

Scarato: I want to add to what Devra was saying about to the two questions about the FCC. How do we know what the FCC did or did not review? There is actually an item the FCC released where they talk about the decisions they made and based on what. As an example, Environmental Health Trust put in countless submissions. We were one of the high submission groups and they didn't address our submissions at all. They addressed some but the large majority of research on biological effects was not addressed in any deep way that one would expect. On the NTP, they just said we are going with what the FDA said. There is a three page paper on what the FDA says and there is only one paragraph on the biological effects. Scientists would expect a more robust document that goes over you gave this study but this scientist thinks this. That wasn't there.

My second question of who is doing a systematic review? The WHO EMF Project which is different than the WHO International Agency for Research on Cancer, there have been a lot of criticisms of transparency on the WHO EMF Project for many reasons of which I have a link to. They have been trying to do a review and it's been mired in questions of transparency. Who are the experts? Who is picking the experts? Whereas, the International Agency for Research on Cancer, when they did their 211 determination that you are familiar with Class 2B possible, they vet the researchers for ties with industry and I should add that they are now calling for a reevaluation for the carcinogenicity of RF and that should be completed before 2024. That is model systematic review on everything.

Miller: I would argue that the solution that Devra is proposing does not solve the problem at all. Our public safety entities all have fiber to the premises. They don't have access to fiber when they are on the road. So mobility and interoperability are key.

Davis: Let me be clear. There is no 5G for voice. There is probably not going to be 5G for voice for perhaps a decade or more because 5G as you all know is fast and short. It doesn't go very far. In order for you to have 5g on the road, you need to bury it in the highway and people are proposing that by the way. The 3G and 4G that you use now travel miles.

Miller: Are you saying that 5G is the only product or technology that causes radiation?

Davis: No.no.no.

Miller: So, it doesn't matter which generation, 3, 4 or 5. They all cause radiation. I think the mobility factor is very important. So the solution needs to come elsewhere within the design of the devices and not to be taken lightly.

Davis: I completely agree. That's why California issued safety advice about how to use cellphones more safely which your commission should consider. The French government issued a guidance that will take effect in July that said, the abdomen of teenagers and pregnant women should not be exposed to cell phone radiation. That's the French government conclusion. We need to educate the public about how to use cellphones more safely and we need to encourage cellphone designers to do frankly what many of them are already doing to redo the software and the hardware so exposures are much less. There are things that they are doing to do that. Within the industry, there are people I have talked to who say the only problem is the lawyers, no offense again.

If they come out and say now we have got a safer phone and people will say, why didn't you make one before? What about all these people who have tumors in their ears and tumors in their brain and other problems that came from their phone? It's a huge liability problem for them. You are absolutely right. We need safer phones. By the way, our twitter handle is @saferphones.

Abrami: We have had conversations about that in this commission recently as well. This shouldn't be adversarial with industry. We should be shooting for the same goal. Let's make it safer.

Sherman: Devra, two of my close friends were Marianne Donovan and Ron Herberman.

Davis: oh my goodness. Two of my dearest friends.

Sherman: I served on a board with them. But back when Ron was testifying and taking an awful lot of heat for that in Congress, one technology that was available was a very lightweight shielding along the skin side of cellphones to shield from RF from the antennas. Do you know what happened to that? It was low cost and light weight and could have been incorporated into the phone without much difficulty.

Davis: That was a company called Pong but has been renamed. There are cases that have been devised that do reduce the radiation somewhat.

Gee, then you know then what Ron went through. You know what happened to Ron who was such a distinguished scientist. He told me had never experienced anything like that in his professional life.

Sherman: yes, I was there when that happened.

Abrami: Out of respect for everyone’s time, we need to go.

IV. Next meeting: February 14th. 8:30-10:30   Agenda to be determined.

V. Meeting Adjourned at 11:00am.

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS OF EVOLVING 5G TECHNOLOGY

<u>Meeting held:</u>
2/14/2020
8:30-10:40 am:
LOB 202

Meeting called to order by Rep Abrami at 8:30 am.

<u>In attendance: (10)</u>
Rep. Patrick Abrami-speaker of the house appointee
Rep. Ken Wells- speaker of the house appointee
Kent Chamberlin-UNH-appointed by the chancellor
Denise Ricciardi-public-appointed by the governor
Michele Roberge-DHHS- Commissioner of DHHS appointee (*Augustinus Ong attending for Michelle)*
Dr. Paul Heroux- Professor of Toxicology, McGill University- speaker of the house appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee
Senator Tom Sherman-president of the senate appointee
Brandon Garod-AG designee, Asst. AG Consumer Protection

<u>Not present: (4)</u>
Frank MacMillan, Jr. MD-NH Medical Society Environmental Medicine
David Juvet-Business and Industry Association
Bethanne Cooley-CTIA , trade association for wireless industry and manufacturers
Carol Miller-NH Business & Economic Affairs Dept.

Agenda:

I. <u>Approval of minutes from 1-10-20:</u>

Abrami: Michelle is not here but we are allowing *Augustinus Ong from the Radiological Health Section of DHHS t*o sit in for her.

For us legislators, it's been an interesting past couple of weeks with most of us running non stop. Bethanne Cooley could not be here and we knew about that. I am not sure about Carol Miller. We are allowing Augustinus Ong to sit in for Michelle Roberge from DHHS. With regard to the minutes, Bethanne Cooley sent me a note saying, she was incorrect to say that the San Francisco Right to Know Ordinance was struck down. So I am going to adjust the minutes on page 9/10 and take out those comments. I give her credit, she went back and checked and found she was incorrect. With those corrections, minutes were approved.

II: Denise Ricciardi- Outside call concern:

Ricciardi: I debated about this but I think in the interest of transparency, it is important to mention. I received an email in my personal email which is not the email that I use for this commission, from Dr. George Carlo in Washington. He said that he wanted to speak to me and thought he could be of help to this commission. I called and I was uncomfortable and uneasy with the conversation and I asked him to speak to our commission. He said that he could not do that, that he has to work under the radar. He kept using the word "we" when talking with me and I asked him who is "we"? I asked him how did you get my personal email? Oh, somebody gave it to me.

This went back and forth on the phone and we followed up via email and I used the right email that I use for the commission. He asked, why can't you and some of the delegation come to Washington and talk to me? I said because of Right to Know laws and transparency and I was very uncomfortable. I am not implying anything… for the record. I did research him and do you mind if I just read this?

Public Health Scientist and Epidemiologist, is one of the world's leading experts on Electromagnetic Radiation. But from 1993-1999 Dr. Carlo headed a 28.5 million dollar project funded by the telecommunications industry. It went on to say that he studied cellphone health effects and discovered that the risk of acoustic neuroma, a form of brain tumor was 50% higher in long term use of cell phones and it goes on. I am just putting it into the record for the interest of transparency. I am not implying anything. I just want it to be known.

Abrami: thank you. Are there any questions on that?

Heroux: Most of you are aware of Dr. George Carlo's past involvement?

Abrami: not really.

Heroux: He is an epidemiologist and a lawyer and at one time he was retained by the cellphone industry in wireless technology research to devise a research program that would shed light on the effects of cellphones. After he was recruited by the cellphone industry, it seems that things became very complicated and nebulous so people have various takes on that but he is a very important central character in this whole issue. But, I would say that his motives are a little bit uncertain for many people. So, that is his history but he is a very central character in this issue.

Abrami: Did you ever ask him if he would be willing to speak with us here?

Ricciardi: Oh yes and I have it in email. He says he can't. He has to work under the radar that what he says could be taken out of context. I just felt uncomfortable. I debated if I should address it or not but I think it was the right thing to do in bringing it up. I hope you all agree.

Gray: I just want to remind the commission here that your task is 5G. It isn't 3G. It isn't 4G. Your task as defined in legislation is 5G. If you are going to say other technologies you should relate it to that there could be difference because of mm waves and get it back to the topic. Your task is not 4G or 3G. It's how 5G affects and whether we should do something about 5G.

Abrami: We discovered early on and I didn't realize this when I wrote the bill for this commission, that you can't talk about 5G without talking about 3G and 4G. We broadened it early on in our meetings. It turns out that 5G is this nebulous thing. It depends upon what company you are talking about with 5th generation. Will they use mm waves or not? I understand what you are saying Senator but it seems we cannot talk about 5G without talking about the others.

Gray: Representative, there was the opportunity to put a bill in this term that would have expanded the scope of this but we didn't. I am just trying to do what the law tells me. The law tells me this commission is supposed to look at 5G. What is the health effect of 5G vs 4G? We talk about the size of the wave. We talk about how that can affect and again, a lot of the things we have had as testimonies don't deal with 5G at all. They deal with 4G technology, things that were studied and not using the same size waves that we are talking about in 5G. Again, that is what our task is.

Abrami: If you go back to one of the earliest meetings and review those minutes, I said I believe if there is no objection, I think we have to broaden this a bit. I have been on plenty of commissions that things get broadened as they come up.

Today we are going to get at the towers that are 5G with Paul. We have conversation among us that the technology is hidden in the antenna. So it's very hard for us to understand even that if this is proprietary how much power, the configuration of the antennas and all that so ….

Ricciardi: It is my understanding that if 5G were to hang in front of everyone's home, that it can't solely work on its own. It would be piggybacked with 4G. If I am correct in that, that's where they come together.

Woods: Two aspects. Number one, looking at 5G is relatively new and research is not as robust but looking at using 2, 3, 4G it's like any other research protocol. You look and say what does that tell us? Then you look at mechanisms and then you say, let's look at 5G. It gives us a basis in which to look at 5G and educates us for parameters that we need to verify. Secondly, we also need to understand what 4G does because we haven't really gotten into synergies yet. Physical systems and biological systems for sure become more complex with synergies. We really haven't but I am sure we will as we go along, talk about synergies. I think those two things are important for us to look at both. I understand the concern and we have to focus more as we go along in terms of decision making.

Gray: The things the good doctor has said is consistent with my statement. If you are going to talk about other technologies, you need to say why 5G is going to be harmful, how it compares to it. Again, don't' just throw out a study and say its cellphone technology, so it's bad.

Abrami: I agree. A lot of the testimony we have had is on cellphones themselves. Again, a cellphone is communicating with whatever.

Wells: Just to reiterate something we talked about before. When we talk about electromagnetic radiation, you talk about characterizing it by frequency, energy intensity and polarization. That's really what we need to talk about whether its brand name is 5G or 4G is immaterial. The characteristics of the waves that we talk about are given by the physical parameters.

Abrami: To me, what we are discussing is all things RF radiation. Our goal is to try to understand this. Where is the line drawn and where or if, are the health effects? We are in contest with FCC and FDA. We are just a little state here but what keeps me going is there is enough compelling research out there saying something that it seems we should pay attention to. Where we end up late summer or early fall, I am not quite sure. We haven't started bringing this together. What can we do as a state? Where are we heading with this? First of all there are a bunch of lawsuits out there right now against the FCC and those things will play out. The other reason for the bill was to get ahead of the curve as a state on all the push back that is going on around the country. I don't know whether that pushback is based on hysteria or not. I don't know. But, there is pushback. Every day I get stuff sent to me like yesterday from Huntington, NY. My brother lives there. I said to him, do you know anything about this? He said not really. Are we straying off the theoretical parameters a little bit? Probably but I think we need to. Is someone going to slap my wrist for doing that? I think you have to, in order to be able to discuss this topic.

Chamberlin: Because 5G is an add-on to 4G, the more we understand about the preceding technologies, the more we are going to understand about the impact of 5G technology. It is really important that we look at the body of information that is out there on previous generations.

Heroux: With 5G, we have no epidemiology and relatively few studies. The other aspect is that there are low, middle and high frequencies for 5G. As Mr. Wheeler of the FCC said, the technology is ill defined. So we don't have a very precise target. They are going to be on common structures. To be well instructed about health impacts, you have to know about EMR as a whole and experience we have is from earlier generations, if we are going to epidemiology information as a goal at all.

Abrami: the studies of 3G and 4G impacts do impact what we are looking at. I appreciate the comments but we have to plow forward. Obviously, in our report we are going to be addressing 5G but if we find out that there are things we should mention in our report related to RF radiation, we should do that. We are going to vote and I mentioned this once before. A House commission is different than a Senate commission. You sign off on a report on a Senate Commission. We don't sign off. Your way of not agreeing with the majority is to write a minority report. That's the way our commissions work.

III. Pat Abrami: Smart Meter Bill:

The next thing on the agenda, is this on topic or not on topic? We have heard some discussion about smart meters. I was minding my own business one day when I overheard the prime sponsor of the smart meter bill. I said we are doing 5G, sign me up. Senator Sherman signed up too. I think the Representatives can understand, sometimes you look at a title and think I could contribute to this bill. Unfortunately, I had not read the bill until just before the hearing a few weeks ago. It turns out that the prime sponsor knew nothing about the topic. He was submitting it for a constituent. NH has a statute on the books about smart meter gateway devices. That was passed eight years ago. It's a pretty strict provision. My understanding of a gateway device is that it gets readings from your refrigerator and different appliances and that connects to your electric meter. My sense and I am guessing now, is that this was more about security than RF radiation when they passed this bill. We are big on security in legislature. If electric company wants to put one in your home, you have to “opt in” not “opt out”. That’s a tougher climb. You have to sign a piece of paper that says, yes, I want this device in my house. This was almost like a preemptive strike on something that someone was anticipating.

Sherman: I remember the discussion on this. I think one of the problems was if you have a meter that can be read by anybody because it’s transmitted then this was mostly a privacy issue. If your use goes up significantly, that’s your business. I think the big concern was law enforcement being able to tap into this.

Abrami: So it was a totally different angle.

Ricciardi: Do we have a law here in NH about privacy protection because that segways right into the lack of privacy with 5G. I just wonder. Do we have anything in place?

Abrami: I don’t know.

Sherman: I don’t think we have a single law about privacy protection. Even the technology of license plate readers being used by police was blocked in the Legislature. So we don’t allow them to hold onto the license plates after you go through the toll booths. We don’t allow police to go into a parking lot and do license plate scans. I don’t think there is a single bill on privacy but I do know that as bills come through there is a high level of scrutiny on how much personal freedom this might impede.

Ricciardi: That should coincide with 5G then because that is surely a lack of privacy.

Abrami: When I read the literature on preparing because I testified on this bill. There were four issues: One was privacy with the smart meter relaying to electric companies.

Chamberlin: I don’t know if we are talking about the same bill but there is a current bill that came before the House Science, Tech and Energy Committee about 5G smart meters and one of the concerns was health, so they deferred to our commission.

Abrami: Yes. That’s the one. I testified that day. You missed the hearing that day. The bill was filed and what it did was mark up the existing statute basically taking away what we have. I testified in the hearing and said this bill needs to be worked big time. It turns out that there are different degrees of smart meters. There are like three layers of smart meters. Eversource came in and said, wait a minute. We have a truck that drives around and it activates when we want to take a measure that is very low level. It only pulses when it is signaled to pulse. Eversource saying wait a minute, what are you doing to me and you would have to agree with that. Then there’s is the electric coop, which is bigger than you think. They have it and they say that theirs only pulses 14 times per day. You can’t really say there are any health affects because it pulses 14 times in a day. The continuous pulse is the third. I think that’s the one related when you read the list about health effects. So clearly, in your committee there wasn't enough evidence for them to consider so what they did was they asked if our commission could take a look at this. So, if we have time, we will take a look at it. Does it have to do with 5G? I don't know. But its continuous pulsing and people are concerned about continuous pulsing.

Sherman: We actually have a new lawsuit in Rye. A resident is having to leave she said because of the smart meter pulsing from a town building which is actually the school. She is suing the town for cost of having to move to a new location. The concerns are already out there and are affecting municipalities.

Abrami: The big thing especially apartment buildings where all the meters are in one spot, that's the ones that I read are problematic. Supposedly there are ways of shielding that.

Wells: I think we should hear some testimony on that. I am very skeptical that a metal plate is going to do anything except radiate on the other side. A faraday cage will keep the field out but it won't keep it in.

Abrami: We have to bring in the right witness who knows this topic cold with the different types of smart meters. They did the right thing. The bill was not ready to be passed and Science and Tech did not have the time to fix it. They have 50-60 bills I think in their committee. They have a lot. That was the smart meter update.

IV. Dr. Paul Heroux-Cell Tower Placement

Heroux: Essentially, this is about 5G. 5G will have as a primary consequence installation of a lot more towers in our environment. The question is, what do we know about the impact of EMR coming out of towers from the past? I did a short study trying to gather the written literature on this. I have a number of articles that I will leave with you and I have as well an Italian film on the Vatican. What this film does is help us gain historical perspective on how long conflicts relating to the radiation can drag on throughout the years. The situation with the Vatican is still ongoing. They are going on trial for manslaughter. This is something that is very old but persists today.

Essentially, we don't have epidemiological evidence obviously, on the impact of 5G towers because they are very new and sometimes they are not even activated yet. Some of these units can function in one mode or another. The experience we have is from towers of the past. I have assembled some publications. There is a publication here by Michelozzi, 2002 that describes childhood leukemia up to a distance of up to 6km from the powerful Vatican radio transmitter. The Vatican needs to broadcast throughout the world. They have very interesting antenna. They are huge structures that rotate. Of course the intensity of this radiation is very large which is why it seems that the epidemiologists have detected health effects as far as 6km away. This is an extreme area of antenna not representative of cell phone towers that we have in our immediate environment.

Abrami: That's an important point. They are their own little country. Do they have standards?

Heroux: They have standards of radiation that are different than those of Italy. Of course the radiation is coming across the border which is a problem we all have. Radiation from one in multi-family dwellings impacts the neighboring family. This is not an uncommon problem. In the Vatican, you have a very powerful transmitter with a very small population of people affected because it's mostly small cities and countryside around these huge transmitters. But epidemiologists observed very high relative risk.

Abrami: Can you give us a sense though of how intense?

Heroux: It was at the legal limit for Italy.

Chamberlin: These are under 30Mhz aren't they?

Heroux: Yes. There are a number of antenna there and the relative risk was 7 for lymphomas and for non- Hodgkin's lymphoma and leukemia 5 times. So there is very high intensity and very high relative risk of these diseases.

Then Santini in 2002, this is a study that is remarkable in that it documents a number of health effects, not only cancer but other neurological effects. But, it is weak because it was based on questions asked of people, which is always much less reliable in terms of epidemiology. Of course the investigators tried to do the best they can. This is not like the documentation of say a tumor but they said up to 300 meters, they could observe neurological effects from cell towers.

In 2010, Khurana provides a review of 10 base station proximity and neurobehavioral effects and three investigations of cancers. He reports that 8 of the 10 studies report increased prevalence of adverse neuro-behavioral symptoms or cancer in populations living a distance of less than 500 meters from base stations.

Probably the most convincing evidence, I would say is from Dode in Brazil 2011. This is a study that if you read it through, is performed in a way that is very open handed. They used tumor classifications and sub-classifications from the international committees. They used public health records. They had the cooperation of utilities as well as many universities and their documentation is very detailed. So, if one is to be given weight, it should be that one. Essentially, they came to the conclusion that yes, they can document these effects.

What is most striking, is they can also detect that if they install a cell tower near your home, within two years, is when you will get the maximum incidence of cancer. They documented cancer because, unlike neurological symptoms, cancer is not subjective especially when they are quantified by histology and by international classification. This report of a large city in Brazil with a large population which is known to have a public health system that documents. Within 500 meters of a base station and there are many base stations that are documented, you will have increased incidences of cancer. These exposures are much smaller than the FCC limit of course. They have a range of exposures that they measured within the study. I think this, needs to be read.

In 2020, Pearce essentially provides the most recent assessment. Each of these studies of course goes through a bibliography of its own. It promotes, again the 500 meter setback to limit future liabilities of the cellphone industry. He is talking mostly to the cell phone industry and saying if you want to limit your liability in the future, you should respect the 500 meter distance.

In 2018, I have an article by Affuso which examines the economic impact on home values. If you are within .72 kilometers or 720 meters of the base station, your home value goes down by up to 9.78%. As the NTP studies are more widely known in the population, this is probably going to increase.

We do have studies of high intensity that have documented cancer at long ranges. We have studies over large populations that also confirm the 500 meter danger zone. In other words, your health will not be the same in terms of cancer and neurological impacts if you are within that zone. So when we are considering 5G, we will be considering antennas that apparently will have more powerful output because of this radiation goes less well through oxygen and water. It has focused beams to go through structures to attain people who are hidden. So as a result, exposures will be more transient, more focused and more intense. But we don't have epidemiology on that. We would have to wait 10 or 20 years before we have the information. Sadly, the only information we can rely on is information from the past. I think that anyone should read the study on Belo Horizonte, the third largest city in Brazil will see that this study was done very carefully and in my opinion is very convincing.

Ong: Dr. Heroux, in the Brazil study, was there any comparison between the pediatric incidents and the types of pediatric cancers before installation of these towers and comparison of those rates and incidents after these installations?

Heroux: I believe that all the cancers were classified according to international standards so some of these classifications are specific to pediatric but the control were regions that had no cell towers that were investigated at the same time.

Ong: But you mentioned earlier that the Belo Horizonte have very good cancer registry. So for the same region, you will have the same data prior to the installation of towers vs. the rates after installation.

Heroux: I believe their data covers approximately ten years. I believe that they used the reports within those ten years and discriminated between those near cell towers and those that were not.

Abrami: Well, what I think he is trying to say is, are there other reasons for this higher rate of cancer and filter out the other effects that may cause it. I understand what you are trying to say.

Heroux: I guess you would have to read the study to satisfy yourself about these details.

Sherman: Getting at one of Senator Gray's concern, to fully understand. This study was done with presumably 3G and 4G towers. Is that right?

Heroux: Yes. Those are similar to ones that you would see here.

Sherman: One of the things that you mentioned was that the peak cancer effect was within two years. So we wouldn't have to wait twenty years to know. If we used this as a springboard for what is happening with 5G, it would be interesting to do a study in a city that has already implemented 5G then you might be able to do the before and after registry.

Heroux: Yes, ideally but the wheels of government and science turn rather slowly in a sense. This was done in 2010 but this technology is about 10-15 years old already…before you get the agreements between the number of universities and public health systems and so on and so forth. But they have a record of when the antenna was installed and when the cancer occurred which allows them to come up with this statistic.

Abrami: This is the thing that has been nagging me about the small cell tower. We just don't know. That is the whole premise of this. We just don't know and how do we get at that? Clearly, there is not money supporting research.

Gray: Part of what we are hearing is that if there is a 500 meter limit then the amount of radiation is very important in to the rates of cancer. I am accepting your data at face value okay? Now, we look at 5g technology. We have smaller towers. We have less power. So that 500 meters may be 275 feet. You talk about being able to submit a minority report. If I was to try to do the peer reviews about all the different things that people have presented to this, I would be talking about billions of dollars. I go back to 1960's when I was watching 60 Minutes talking about the EMR coming off high power lines going through the Midwest affecting the cattle that we eat and we are all going to die because of it, okay? Again, I am just trying to get you to stay on topic and the 500 meters… yes. There may be a component in there that the amount of radiation nearness to it, you said 30 Mhz and below and 5G starts at 30Ghz and above…all of these things affect what we are supposed to be looking at and the results we are going to get. The one study that we were given that they talked about it wasn't fair to do whole body radiation on a particular animal because that would have a much more devastating effect and all you have to do is find one cell within that whole body that would react.

Abrami: we are not there yet. We are still working on this.

Sherman: We have had a lot of scientists around this table. I think nobody is pretending to come to any conclusions at this point. But in science and in healthcare, we try to look at all available data which is what we are doing. Some is going to be historical data that comes from other RF sources. I think it's perfectly reasonable to look at other RF sources especially since those aren't going away. 5G isn't coming in and replacing all of this as far as I understand it. 5G is coming in on top of 3G and 4G. So, I think it would be a little bizarre for us to look at 5G in a vacuum without the understanding of the current environment and the data on the current environment. I think with a cautionary tale that I hear coming from Senator Gray is that doesn't necessarily mean that we can extrapolate data from 3 and 4G and say that this is going to be the impact of 5G. Study commissions go where the data takes them and I think we are doing that. I haven't heard of anybody coming to any conclusions yet. I think we are still looking at data.

Ricciardi: I just wanted to mention that I believe I forwarded Rep. Abrami information on a town in the Netherlands that put in the 5G, the town became rapidly ill. I can go back and find that. That is 5G and that is evidence on human beings. And that is on topic.

Chamberlin: That was a small study as I recall.

Ricciardi: Yes. They put it in and very shortly after the whole area became very ill.

Chamberlin: True. But somebody could claim that maybe it was a water problem as well. I am interested in following up on that…. particularly, in places like South Korea where they have installed on a larger scale. We need to keep our finger on the pulse there. If you find any more of those, forward them to the rest of us.

Heroux: Can I have one last remark? Essentially, the tower question of course takes care of the general environment but in relation to the new phones which will also have this and possibly more radiation from these phones. The phones could be altered in a very simple way to simplify things for users in terms of health impacts and even perhaps for industry. These cellphones are immensely useful. But one of the problems is that when we hold them close to our body, they tend to over expose us to radiation. There is all this controversy around the proper SAR. They can put 5 cameras and 10 antennas in the most recent phones.

What you can do is put a proximity detector in a phone so that when it comes near to your body, it doesn't work and doesn't radiate any more. This would mean that you could use your phone exactly as before but the risk of overexposure of the phone would be severely reduced, in my opinion. You would cut out all the extreme radiation putting it in your bra, your pants near your genitals or near your head. This is something that is not done right now but technically it is far from impossible. It's relatively easy to put in a distance detector and you would be instructed by your phone to expose yourself less. I think from the point of view of industry that if it is told by government to do that, they don't incur any more liability. If they do this on their own, their lawyers will tell them…hmmm.. you are admitting to something that may not exist. This is a problem. But if it's imposed on them, you are solving a problem for them as well.

V. General Discussion:

Abrami: Thank you. So I have amassed a list of potential speakers. I have reached out to most, but not all of them yet. If there is no comment on the paper, it means I have not talked to them yet either by phone or by email. Dr. Carpenter we will hear from in a minute. Dr. Martha Herbert can do something in April or May. Dr. Sharon Goldberg has been in conversation with Michelle. You can read through the list. I wanted to talk to Hardell because he is the former WHO fellow who is retired that was involved in this whole thing. Kelting is retired and will be our speaker next month. Dr. James Lin, I am really interested in. He is an electrical engineer but his appointment is in a medical school. He has published a lot in IEEE. I talked to him the other day and told him he could do it by phone. He doesn't like to do it that way and wanted to know if we could pay for his travel. I said, well, you don't understand. This is New Hampshire. We don't have a budget! So he is thinking about it. I have not contacted everyone yet.

Dr. Chamberlin, I was going to talk to you if you have any need to have a fellow electrical engineer come in for any kind of seminar series, maybe we could tie it to that.

Chamberlin: I will check into that.

Abrami: I think this guy is worthwhile having. I have checked some of his papers. They are very technical papers that he presents. I know that there are some others names that aren't on this list that people are suggesting to me. I am going to warn you Senator, that Carpenter may be a little broad so bear with us. He is aware of some legal actions in NY State. I know it would be great and I am trying to get more focused on the technical. With this group, I think we know what the issues are. We understand the science here.

We can start the discussion about the next meeting. March 6th won't work because Dr. Sherman, Sen. Gray, and I are on the Seacoast Cancer Cluster Commission together that day. Beth told me that she cannot make the 13th. On the 20th, Senator Sherman will be out of town.

Gray: On the 6th, you could do an afternoon meeting because the Cancer Cluster meeting will be over.

Sherman: I have a Seabrook working group on the opioid crisis so I can't be here.

Abrami: We could do the 20th. Out of fairness, I want to make sure we have Beth at the table.

Garod: I have a jury trial the week before that. There is a possibility it may not be over.

Abrami: Brandon, did you ever connect with Theo or whoever?

Garod: After you sent the email, I responded to her but have not heard back. I encouraged her to reach out to me.

Ricciardi: So, you did reach out to Theodora? Ok.

VI. Dr. David Carpenter-University of Albany "What is 5G and what do we know about the health effects of 5G?"

Abrami: David, welcome. You are in our meeting. We have someone who will move the slides for you. Please introduce yourself.

Carpenter: I am David Carpenter. I have two titles here at the University of Albany part of the SUNY system. I direct the Institute for Health and the Environment which is an interdisciplinary research institute that is a collaborating center for the World Health Organization. I am also the Professor of Environmental Health Sciences and the former Dean of the School of Public Health. I have been involved in issues related to electromagnetic fields for a long time. I first came to NY as the director for the state health Wadsworth laboratories. Two weeks before I arrived in New York, there was a settlement between the state Public Service Commission and the State Power Authority asking the question was there an elevation in cancer risk by high voltage power lines? As a new guy on the block, I was given the responsibility of administering that program. We had 15 research projects funded by state utilities. At the end of that project, we did find elevations in childhood leukemia in children living exposed to high magnetic fields. I became the spokesperson for New York State on that issue. Once you touch a controversial issue like this, you never escape. It's never been my personal research but I have been involved in this and published extensively on it. I have been on national and international committees.

Abrami: What did NY State do about that?

Carpenter: Effectively nothing. They did establish a standard for the magnetic field for the edge of Right of Ways. But they determined that standard by measuring the magnetic field at the edge of Right of Ways and the standard was the highest one there so there wouldn't be any new magnetic fields greater than those that were existing. This is really one of the problems with RF fields. We are all so dependent on things like electricity and communication frequencies and nobody wants to restrict use of it and hopefully not make it worse than it presently is. It's very difficult to restrict use.

Electromagnetic Spectrum:

Let's go to the second slide, the electromagnetic spectrum. The form of EMR that most people know is visible light. At higher levels than that, we have the ionizing portion of the spectrum that includes x-rays and gamma rays and these have enough energy to directly damage DNA, cause cancer and birth defects and that sort of thing. Below the visible light, we have infrared radiation which is heat from the sun. Without that, life on Earth would not be possible. Below the infrared, we have the communications frequencies. It is important to note that the 5G that is being proposed is just below the infrared. It's Gigahertz frequency. The electromagnetic spectrum is all packets of energy with different frequencies. The higher the frequency, the more energy it contains. But the frequency is important. At the left of the slide, the extremely low frequency that's the magnetic fields associated with electricity that I was originally involved in.

Radiofrequency (RF) EMFs:

The point is that these radio frequency EMFs are communication frequencies, everything from radio to television to cell phones to radar. This exposure has increased enormously in the last number of years. Now we have Wi-Fi everywhere. We have smart meters put on many of our homes. These are meters that use RF waves to transmit your use to the utility. In the future, there are going to be ZigBee drives in your refrigerator, dishwasher and every appliance and it's going to communicate your electricity use to your smart meter. That's' going to make the kitchen and laundry room particularly hotbeds of exposure. Driverless automobiles will use RF fields to see the car ahead and will enormously increase exposure to these things. The microwave oven uses RF fields and most of these frequencies are in the microwave range. Clearly, if you can cook your potato with a microwave, there is potential harm from exposure. But most government agencies, certainly the Federal Communications Commission (FCC) has the position (which I think is wrong) that there is no hazard from microwave exposure if it is at an intensity that is not sufficient to cause tissue heating.

RF in the Ambient Environment:

It used to be that RF environment was really radio and television. In the past few years we have increased the RF in the ambient environment enormously and with the imminent rollout of 5G there is going to be a great increase in human exposure. One punchline is that 5G has not been studied. It has not been around long enough and we don't have any population of humans that have been exposed so that we can determine whether it's really dangerous or not. We do know a lot about our existing 3G and 4G. As these generations develop, they go to higher and higher frequencies. Our cellphones, Wi-Fi, smart meter are all 3G and 4G frequencies. What does this sudden increase in RF exposure suggest regarding human health?

Health Risks to Humans from Existing RF:

We know very well that extensive use of a cellphone held to your head increases the risk of cancer. Gliomas particularly, less so other forms of brain cancer, and particularly glioblastoma which is a very malignant form of cancer. This is the cancer that killed Ted Kennedy, Beau Biden, John McCain, the lawyer in the OJ Simpson case. I am not saying that it was definitely cell phone use that caused all their cancer but these are people who undoubtedly used cell phones a lot. The cancers only occur on the side of the head that people use the cellphones most of the time. In addition to the glio cancers, there is a Schwannoma tumor of the auditory nerve that we see commonly called acoustic neuroma. It's not a cancer but a tumor that grows in the bony cavity in the ear and causes problems. There are some elevations in cancer of the parotid gland on the cheek and the thyroid gland. It seems likely that excessive exposure to RFR at non thermal intensities increases the risk of a variety of cancers and what is really critical is which part of the body is exposed.

National Toxicology Report/Ramazzini Intitute Study/Other:

Now the International Agency for Research on Cancer (IARC) which is part of the World Health Organization (WHO) has rated communication frequencies as possible human carcinogens. This was a number of years ago and one of the reasons why it wasn't a stronger reading in that there hadn't been clear evidence that cellphone frequencies cause cancer in animals.

National Toxicology Program (NTP) which is part of the National Institute of Health (NIH), just last year came out with the results of a two year study. It demonstrated that rats exposed to cellphone frequencies develop schwannomas of the heart.

Abrami: Just so you know, we have talked to those folks.

Carpenter: Ok. Let's go on. The Ramazzini Institute did a similar study but at much lower intensities. They found exactly the same thing. We now have good animal evidence in addition to human evidence. There are other health effects that are well documented, particularly reduction in sperm counts and infertility in men from abnormal sperm and some evidence of spontaneous abortion and premature birth in women with excessive exposures. There is some evidence for cognitive alteration in children, if they are on their cellphone too long. It's difficult to understand if it's a direct effect of the radiation or because kids aren't sleeping because they are talking all night.

Then there is the very controversial but pretty clearly real problem with Electro-hypersensitivity. Some people, by no means all become the best way to say it is "allergic" to the RF fields. They develop headaches, nausea, vomiting, and a sense that the brain isn't working properly. Sometimes they have heart palpitations and a general feeling of ill health. This has been seen in adults and now fairly frequently in children in school environments where there is intense Wi-Fi, much more controversial than brain cancer.

Emerging wireless technologies:

5G (5th generation cellular technology) as I have said, is RF but at a higher frequency that we have at 3G or 4G. It's being promoted widely just about everywhere. This is the whole concern of the Trump administration with Huawei the Chinese company. The idea is that 5G when fully developed is going to just change the way that life on Earth is done. It's going to be the Internet of Things, Smart Appliances, Smart Cities, certainly self- driving vehicles and wearable devices. A lot of hype about this and a lot of sense that somebody is going to make a pile of money and that this is going to be good for communication at the much faster rate than we have currently with 3G/4G. The 5G frequencies will be in the Ghz range which is higher than current 3G/4G which are lower than 1Ghz, in the MHz range. Ultimately, the 5G can be up to 70 Ghz which is almost at the frequency of infrared radiation. It will be 100x faster than 4G, potentially add new jobs and a lot of economic growth. It's a higher speed greater capacity.

Limitations of 5G:

The problems with 5G are several. Because it's at much higher frequency, the waves do not penetrate as far as the 3G/4G waves do. They are easily blocked, even by weather. The radiation will not penetrate a building. It will not go through glass and won't travel so far. This is a real problem so as 5G is being implemented around the country and world, instead of the cell towers that have ranges of over 2,000km, the 5G will require mini cell towers to be placed in front of every 6-8 houses in urban areas. The 5G will only have a range of 20—150 meters not kilometers. That means that as these are placed everywhere, you are not going to be able to walk down a side walk anywhere without being continuously exposed. Now if you are in your house, since the beam won't penetrate the house, that's probably a good thing. Now one of the real problems however, as we are rolling out 5G, our current infrastructure is 3G and 4G. These mini cell towers places all along the street are not just going to be exclusively 5G, they are going to be 3G and 4G as well. While we haven't really studied health effects of 5G, I have already told you of health effects of 3G and 4G. This is going increase the exposure to 3G/4G dramatically. These mini cell towers are going to be everywhere. That is a real problem totally independent of the question what are the hazards of 5G.

Abrami: We have talked about these things in our commission. We are trying to get at what is in those towers. It's really about the power. Let me ask you though, the issue with the small towers is you get every company with different strategies of 5G. Can you discuss that a little bit?

Carpenter: Well, I am not an expert on that. I know that each company has their own power also they don't share their information very much. It is very difficult to get that information. They really don't want the other companies to know what they are doing. I can't really answer that question. But I do know that all of the ones being implemented right now are not exclusively 5G. I think the expectation is probably pretty good that 5G is not as dangerous as 4G. That's because 5G is not likely to penetrate the brain. It's not likely to cause brain cancer because it's going to be blocked by the skin. Now that raises a whole series of other questions. What is going to be the effect on the skin? Is there going to be an increase in skin cancer? Is there going to be alteration of sweat glands? We don't' really know that answer. Again, my big concern is the greater exposure to the 4G frequencies which we know to be hazardous in extreme exposure.

Abrami: This is the discussion that we are having. The towers are lower to the ground. They are right in front of your house. There are science issues and all that but there are emotional and aesthetic issues that people are pushing back on. Our understanding is that it is less power and we are trying to grapple with how much damage compared to a large cell tower.

Carpenter: In the large cell tower, there have been studies showing increase in leukemia in people who live close to the large cell towers. But the large cell towers direct the beam at the horizon. That's for the purpose of having a reception over a very long distance. These small cell towers close to the ground are going to have beams directed right at everybody. It's going to dramatically increase exposure relative to that you would get from a large cell tower.

Abrami: It's the $1/R^2$ rule right? The closer you are to the tower….

Carpenter: that's right. The question is …whether the beam is directed or if it's like a radio transmission tower which is 360 degrees. Our current cell towers have a focus beam at the horizon. For some reason, people living very close to a cell tower probably get less exposure than people living some distance away where the beam then sort of spreads down. These mini cell towers on a lamp post or wherever they are on the street are going to be very close to the ground level and it's going to be impossible not to have elevated exposure.

Abrami: Usually with cell towers, there is a radius around and there is nothing there. There are plenty of studies showing the fire station concerns but these small cell towers are going to be right on the street and low to the ground.

Carpenter: yes. I was actually in California for the Fire people opposed to towers on every fire station just for that reason and they did block that plan.

Sherman: On these small cell towers that will have 5G and 4G, is it a lower power 4G since there are going to be more and they are going to be closer and there is not going to be the same need to shoot at the horizon? Or is it the same power as the big towers?

Carpenter: I don't actually know the answer to that question. I suspect it's going to be a lower power. But, I don't actually have good knowledge of that.

Abrami: Let's keep going.

Carpenter: The issue is there is no real research on 5G. There are a few animal studies now. Again like any new technology, there are people making outrageous claims for hazard and others that make outrageous claims for safety. So, I think we just don't know. But the issue of cancer from RFR, that is very strong. The issue of effects especially on male fertility is very strong. The Electro-sensitivities are certainly going to increase as people are exposed more.

Carpenter: Is there anything uniquely bad about 5G? I think the answer is no, other than the fact that the way it's being implemented is going to increase exposure.

<u>Who is protecting us?</u>

The FCC has no health expertise. I visited them several years ago trying to push them to at least have some cautions in their recommendations. They basically said, we don't have any health expertise, we depend on other agencies for that. Then they don't have any other government agencies that are pushing them. I am actually a plaintiff in a legal case against the FCC for their standard, which says that there are no adverse health effects except those caused by tissue heating. That simply is not true.

Abrami: Can we pause on that for a second? Which suit is that? There are several out there now.

Carpenter: Well this is all fairly recent. Bobby Kennedy is the lead attorney on this suit. But there are several out there. It's really sort of outrageous that the Federal Communications Act of 1996 specifically prohibits placement of any cell tower based on concerns of health. This is a real problem for many localities and states because this is federal law. You can object for other reasons but not for health concerns.

<u>How Strong is the Evidence of Harm?</u>

The evidence is very strong for 3G and 4G, especially for cancer and effects on male fertility. It is less strong on some of the other things but certainly enough evidence to merit concern.

There are so many sources of RF and the average rate of exposure to RF has increased over time. Since 2003, there has been an enormous increase as we have gone to just about wireless everything. The latency for many of these health effects, especially cancer is going to be long. We know from ionizing radiation that the latency is 20-30 years. One big concern is we roll out all these new sources of exposure, what is going to the long term impact? We are seeing an increase in glioblastoma risk in the US and around the world. Not so much in other brain cancers. Actually, some of the other brain cancer rates are going down. But, there is reason to be concerned.

The conclusion is with 5G, you can download your movies faster. There may be other benefits. It is not obvious to me what the other benefits may be to the individual, maybe to business, maybe to government but it's just that we are rolling out 5G very rapidly without any good information as to whether the risk might exceed the benefit.

Abrami: Well, thank you on this. Let's talk about NYS. That is where you are based. Are you aware of anything going on legislatively in New York? I thought I read that they may be thinking about forming a commission like ours.

Carepenter: They haven't gotten past that. It's being rolled out across the state and there are a number of legal actions. There have been a couple of meetings in the state assembly on the issue, but no significant legislation has passed. There is a growing concern. It's interesting, one of the Vice President's here at the University of Albany, asked me to give a talk for a public group and he knew nothing about the issue until they put a mini tower in front of his house. That seems to be happening around the state. Little information, if any and then the mini towers are placed and implemented and that gets people pretty concerned. There is a fair bit of angst among the population but only the population where it's being put out otherwise there is very little information.

Abrami: I just received something about Huntington, Long Island. I had seen this before, a public hearing in their town council. For five years they have been complaining to the town officials and they are very concerned because these small cell towers are going up in their community and a lot of people are pushing back. We are seeing this across the country.

Carpenter: Sure. It's really across the world. I am being taken to Australia to talk about 5G this summer.

Abrami: We just heard that Switzerland put a hold on 5G until they understand the science a little better.

Carpenter: Yes. I think one of the concerns is that there seems to be absolutely no benefit to the ordinary individual maybe to business and industry. Other than the fact that you might be able to download a movie more rapidly, what's the benefit?

Abrami: one of the things that I saw was autonomous vehicles but it turns out that the industry is not going in that direction with the little towers along the road. It's going to built into the cars.

Carpenter: It's going to be built into the cars and likely to be lower frequency.

Ricciardi: I just wanted to clear up a question I have or make sure I understand it correctly. Although our commission is tasked with the health effects of 5G, what I understand and correct me if I am wrong, because it will actually be placed approximately every few homes and because it cannot work independently and has to work with 3 and 4G, what's going to happen is whether we know much about 5G or not, the fact of the matter is everyone is going to be living under a cell phone tower and being exposed to radiation continuously which can heat tissues over time. Is that correct, Dr. Carpenter?

Carpenter: Well, the last part I think probably is not correct. If you have low intensity to these, there may be a level of heating that can't be measured but you would be constantly exposed but there would not be any measurable increase in temperature. That's the debate with the FCC because there is this enormous amount of information showing health effects at non thermal levels. But, I don't think because you are continuously exposed at a low intensity that there would be a measurable increase in temperature.

Ricciardi: Okay, but you would be exposed continuously which would potentially precipitate other health effects.

Carpenter: That's correct. I am sorry I probably should have prepared a more technical presentation. I didn't realize that you were so well informed on this. We have a pretty good idea what the mechanism of these damages is. The primary mechanism is that non thermal levels of RFR generate Reactive Oxygen Species (ROS), commonly known as free radicals. If you remember in the NTP study, they demonstrated direct DNA damage in those rats and these were clearly non thermal intensities.

There are many nasty things that generate ROS. In fact, our body generates them just as part of the normal metabolism. We also have a whole series of enzymes in our body that are there to protect us against them. Very clear evidence that non thermal levels of RFR cause the generation of these ROS. If you are exposed continuously, then you have a continuous generation of those ROS. You don't need the temperature rise, to cause harm. The ROS can damage proteins, lipids, carbohydrates and DNA. The evidence is quite strong that this a common mechanism that then leads to a whole variety of other changes. For example, changes in brain metabolism and blood flow to the brain and whole variety of things. There is a good body of evidence that allows us understand how you might get damaged from continuous exposure to RFR at levels that don't raise body temperature.

Sherman: Just a quick question. What you are describing is the epigenetic impact of non-thermal RF levels. You are actually changing the DNA. Do you know of any evidence of people who are more predisposed like family history like genetic makeup? In other words, is there anything in your genetic makeup that would predispose you to increased risk of being within an RF field?

Carpenter: I don't know of any real study on RF fields. There is a very interesting study on the magnetic fields from power lines. There is a study on electricity from China I believe that did look for different genetic traits in children that developed leukemia from being near power lines and children exposed who didn't develop leukemia. They did find there is a genetic susceptibility factor there. I would be quite surprised if that weren't also the case with RF but I am not aware of anyone that has really studied it.

Wells: On one of your slides, you talked about current 3G/4G cell towers having a range of 2,000 km. I just wanted to check on that because my interest is not just on the transmitter power but the power over the area and what that means in terms of the intensity in watts per square meter to which people will be exposed. So, 2,000 km is the correct figure for 4G?

Carpenter: Well, yes. That's the correct figure. Of course not every cell tower has intensity that goes that far. For example, in most urban areas you don't have that intensity. But in rural areas and so forth, you have a higher intensity. That's also true when you use your cellphone. If you are a long way from the tower, your cellphone automatically increases the intensity of the signal it sends back to the cell tower. That 2,000 km is sort of the upper limit of a cell tower.

Wells: If I can just follow up on that. You talk about 5G only penetrating skin. I was wondering if you would comment on current SARs on Watts/kg versus intensities of watts/square meter. Which do you think is the more appropriate way of looking at exposure?

Carpenter: well, certainly with 5G watts/square meter is more appropriate metric because we have no reason to believe 5G is going to penetrate beyond the skin. The 5G is actually being used a little for crowd control. If you have sufficient intensity with 5G, of course you have tissue heating. You can direct a beam at someone who is trying to escape the police.

Abrami: Rep. Wells is all over that one!

Chamberlin: So, I have a question about the strength of the evidence that exists. Since getting on this commission I have been reading a lot of papers and I find that there are lots and lots of papers out there. You can't deny that there is a risk of harm. It's also somewhat overwhelming, the number of papers that exist. Have there been attempts to bring that all together to these meta studies that you mention? Where can I get access to them with high statistical confidence that a problem does exist?

Carpenter: That's a good question and it's a complicated one. The place where most of the evidence is put together is in the BioInitiative Report. I was the co-editor of that. But that report was criticized by just about every national and international body, as being selective. In fact, it was not selective but we have not had effectively any government agency with real credibility and that's true around the world acknowledge the strength of the evidence that I think see and I think that you see. The problem is, first of all you have a powerful industry that doesn't want their product tarred as being dangerous. Secondly, we are all so happy with the benefits that come from modern technology that we don't want to hear that it's potentially harmful. I am frankly baffled by the antagonism that the Bioinitiative Report has received. It was criticized as not being peer reviewed. Well, the original report wasn't peer reviewed but almost everything in it was published separately in peer reviewed scientific journals and passed review. But it remains a very controversial subject.

Abrami: Can you send us that report? The chair has been corrected. We already have it.

Carpenter: It was originally published in 2007 and updated in 2012. There have been some additional updates in 2014. It's huge and much more than anybody ever wanted to know and I think the individual chapters on specific subjects. I think there is something like 3 or 4 thousand references in the report.

Abrami: Are you the prime author on this?

Carpenter: No. I was a co- editor. I had the major role in writing the public health chapter. But each of the chapters was written by other people and actually Cindy Sage was my co- editor and was the power behind it but I had a major role in identifying who would write chapters and so forth.

Chamberlin: As a follow up question, can you give us the sense of relative risk? Is the relative risk something like 1.2 or something like 10? And do these have associated low e values?

Carpenter: Well, I am involved in all kinds of hazard investigations. My major research actually is PCBs and dioxin and pesticides. Some of my colleagues wouldn't agree with me but I don't think the relative risk here is anywhere near as it comes from things like smoking and chemicals that are toxic but one has to be careful about this because again, our exposure has increased so dramatically so recently. We have evidence in links to cancer but in latency being long, what's going to happen twenty years from now? You can look back at smoking and you can look back at PCBs and DDT and these things in the 60's and 70's were thought to be quite harmless. Now we know they increase the risk of all kinds of diseases. That's why that last slide I mentioned the Precautionary Principle. At the moment I don't see that the relative risk comes anywhere near the risk we have of other kinds of exposures but I am not sure that it's not going to be viewed as much greater in the future. If you put a mini cell tower in front of every 8th house, in every street in the US, who knows what the outcome is going to be in 20-30 years? The cancers that we see are relatively rare. But they are also fatal when you get them.

Sherman: Dr. Carpenter, I am also a physician. I am a state senator here in NH. I sense some frustration in your voice. One of the issues that we have been grappling with which is what Rep Abrami talked about is PFAS how it's in our drinking water. But the similarities between both of these is that we have very powerful and well- funded industry that is basically dismissing all science that is raising alarms in both of these areas and one of the big concerns that I have is that well- funded would not be a good description of the NH legislature and certainly not the people who are pushing back against industry. You are in an academic setting and you are doing some really good work on this. Do you have any suggestions on how we can lift up the Precautionary Principle before everything is installed and in place and we have to wait 10-20 years to know that we have just done in an entire generation? Do you have any models or any communities that you worked with that have been able to mitigate the influence that some of these companies so we are not regretting down the road that we did not provide at least some precautions as we move into this new era of RF exposure?

Carpenter: well, I certainly work with a number of communities that are trying to do that but I can't say that it's been very successful. The big barrier here is the 1996 Federal Telecommunications Act. There have been some communities where industry has sort of backed off hoping that the angst will go away but in others, the telecommunications companies has basically taken legal action on the basis of the Federal Communications act saying we have the right to put these in and you have no right to object to it.

I think what I would really like to see is that provision in the Telecommunication act being invalidated. It is outrageous that communities and states are prohibited by that regulation from opposing this kind of development. We don't have that similar kind of thing with chemicals like PFAS and PFOA. This is a very strange situation where we are prohibited from protecting the health of the public. You can debate how hazardous this is but it should not be up to industry just doing anything it wants to and public and other forms of government having no ability to block it.

Abrami: Let's go back to the Kennedy case. What are the two sides on this? Is it the FCC?

Carpenter: The case is that the FCC by virtue of having this philosophy that there are no harmful effects other than those caused from tissue heating is causing severe harm to the US population. The plaintiffs are a public health person and a mother of a child that died of a brain tumor. There are a couple of people that have Electro-hypersensitivity. The goal of the suit is to get the FCC to tighten the standard of exposure for RFR.

Abrami: we are probably the most lax of most countries, right?

Carpenter: Oh yes, by far. There are other countries that are equally as lax but we are way more tolerant of exposures than others. The Russians have had the lowest standards for the last fifty years. Now, I don't know that they reinforce it that much. Our standards are just ridiculously high.

Abrami: What court is this going to?

Carpenter: I don't know. It's directed to a federal court but I am not clear where it's going to go yet. This has all happened in the past couple of weeks. There are other suits pending too.

Abrami: The Environmental Health Trust that we head from a month ago. They have a suit as well against the FCC. As a commission, we want to talk to the FCC and also where they get their guidance. If the FCC says well, we listen to the FDA and FDA is saying there is no problem, I think that's part of the suit the EHT is involved in. But IEEE is setting standards, right?

Carpenter: Engineers and electricians setting standards for health is pretty ludicrous.

Abrami: We would love to talk to someone from the FCC but that is proving to be a bit of a problem and the FDA. EHT said what we should do is write a letter to the FCC with questions and the same thing to the FDA with questions. They have been known to respond. I think we need to do that. If we can't bring in a human being to testify, we can at least say we tried to elicit comments from the FCC. What I am suggesting to everyone here, send me your questions. I will sort through them and we can talk about it for the next meeting.

Carpenter: I think that is a very good plan.

Abrami: If you have any questions, send them to me, too. Someone in the back of the room would like to talk.

Public speaker: I have one quick question. For all the doctors in the room, I recently saw a video with Dr. Lena Pu who had done a blood test on a teacher who was in a classroom with Wi-Fi and the blood test indicated after a day of exposure that the viscosity and quality of her blood had basically coagulated like it was cooked. Would it be simple to do a study on people who say for a week have not been exposed to any cellphone, Wi-Fi, television and do the blood test and then test again after exposure? I am wondering if there are any other parameters besides cancer that should be looked at. I think blood quality is pretty important and leads to all kinds of other stuff.

Abrami: I thank you for your comment. We have been trying to explore the different research that is out there. Does anybody recall anything on blood?

Heroux: Yes. The rouleaux formation is very well known. Even short term tests can show if you expose blood to EMR and you have some but even if you show that to the FCC, they will say…so what?? This will dissipate after some amount of time and the mechanism for that is probably that you have free mitochondria in the blood actually. It's very new data. You have a lot of mitochondria floating freely in the blood and they help the red blood cells to coagulate together. There is plenty of that kind of evidence. What does it mean for the people in that class? If no one is willing to take that step, we are wasting our time.

Abrami: In the classroom situation, we are talking about routers everywhere. One of the people who testified for us when we got the bill passed was Cece Doucette who years ago was involved in getting wireless technology into the school until she realized, what have I done? Now she is working to try to undo some of it and have safer technology. There is no reason schools need these routers. They can be hardwired for instance.

Carpenter: With hard wire, there is no exposure whatsoever.

Abrami: And actually speeds are better.

Sherman: Speeds and reliability.

Sherman: Do you know any blood impacts Dr. Carpenter?

Carpenter: There are colleagues in Paris that have done some very good work on measuring some things in the blood that are markers of people that are electro-sensitive. They focus mostly on this electro-sensitivity. Again, all the markers they are finding are related to these Reactive Oxygen Species (ROS). Dominic Belpomme in Paris is the one who has done that. We have published with him and I can send you the article with that information and I would be happy to do that.

Woods: We already know that blood can be temperature sensitive. There's cryoglobulin anemia in people where if you put an ice cube on their skin, they get hives. This is a known entity and it's not everybody. Again, it's a genetic variation. But it bespeaks a broader picture in fact that a lot of the studies at least to my eye have been bulk tissue or bulk material investigations. What we are wrestling with now is getting down to the molecular level instead of bulk tissue, we need to look at cellular and molecular levels and that's what we are hearing here and what we have been surmising where we need to go. We don't have a lot of these good molecular studies although we know mechanisms clearly can take place already , like you mentioned the mitochondria and we have talked about other issues before that get away from what the IEEE looked at and getting down to the molecular level. We are trying to make that transition.

Sherman: I have one question. We are mainly interested in human health impacts but we have heard some rather frightening studies on environmental impacts. Can you comment on those Dr. Carpenter if you have any expertise or knowledge about environmental impacts, specifically of 5G but since this is going to be ubiquitous, the concern is this is also going to be 3G/4G… bees, insects, plants. Any thoughts?

Carpenter: Well, there is some evidence for effects on bees for example, some concern that the demise of the honey bee may be related to the RFR distorting their ability to find their way back to the hive. Again, that evidence is somewhat weak. There is a tendency whenever there is a health problem, whether its bees or humans, everybody has got their favorite villain to blame. I don't think that the effect on honey bees is very strong. On the other hand, the suggestion that hives that are placed near cell towers lose their population of bees relatively quickly. I had a high school student do a project with me last summer. She was looking at the effects of cellphone radiation on the growth of plants. She used wheat seed and had an active cellphone by one plot and an inactive by another. The active cellphone resulted in poor growth of the wheat. So, there is some evidence but again it's not 100%. Again, I agree the concern should be human health. Unlike many of the toxins that we have studied, I think we have stronger evidence for human hazard than we do for plants, bees and animals. It should be humans we care about. That's why I emphasize human research.

Abrami: There aren't research dollars coming this way.

Carpenter: They are not coming this way. They are not there at all. Again, that is the influence of the industry.

Ricciardi: I just want to comment. Knowing whether we know all we need to know about 5G or not, it disturbs me that we know it is going to work with 4G. We already know what that can do and living near a tower can do. They roll out 5G in the state of New Hampshire and it is going to be in front of our homes. Essentially, they are forcing our residents to live under a cell phone tower. I don't understand that. We know 4G is not safe and they are going to hang together in front of people's homes.

Carpenter: That is exactly right.

Sherman: And there is nothing you can do about it.

Ricciardi: This is the "Live Free or Die" state here. Now that you are putting something in front of my home that may make me ill, I am sorry, I just had to put that out there.

Abrami: Well, we can do what we can do as a state but there are laws that trump others. The 1996 law, that's the real issue.

Ricciardi: Well we are certain that 4G will do harm. Whether 5G does or doesn't they will be hanging together in front of my house. That's my point.

Abrami: There is evidence. Yes. There is frustration with the current state of affairs. As a commission, I think we are all more educated on it than three or four months ago. Dr. Carpenter, I really appreciate, the dialogue was great. Thank you. If you send us that one article, that would be good.

Carpenter: Alright. I will do that right away.

Sherman: thank you so much.

Carpenter: My pleasure and I really appreciate the fact that your commission is looking into this.

Abrami: Ok. Thank you. That was a good summary and it sounds like we keep coming back to the same thing. We know what the issues are and I would really appreciate any comments or questions please send to me via email on the FCC and the FDA.

Sherman: For my part and this is not a part of the commission but I will reach out to our federal delegation on the clauses in the FCC law. I don't see any reason why health effects should not be part of, it doesn't matter what political party you are from. If there is a health impact or potential health impact, it should be part of the decision of whether you can roll out new technology.

Abrami: Well, politically they figured it out if there were health effects, it would slow the whole thing down. That is the political reality of what happened and here we are. I have been in meetings on just regular cell towers in my town and know how hard it is to get just a regular cell tower up. People are up in arms about that, let alone be in front of their house. Verizon was getting very upset with our town as it took three or four locations before they said okay since they were concerned we would be sued by Verizon. So, the last location, they said okay. This is where it is going to go, despite upset residents in nearby areas. I was in these meetings and the neighbors were arguing health effects even with 4G towers. They said no, can't talk about that. That's just the reality.

Sherman: One of the things that he said that struck me was essentially the further you are from the source, the higher the energy that is going to be generated by your phone so while we worry about Rye has the same issue. We can't seem to get a cell tower. We have spotty cell service all along the seacoast. Does that mean that our cellphones are maxing out with our local exposure? Could the fact that you don't have a cell tower nearby and have to have a more powerful transmission from your phone increase your risk more than having a cell tower closer?

Gray: I can comment on that part. There is a decrease risk from radiation that comes from here. There is an increased risk of the radiation that comes from the cell tower antenna. You are closer to the antenna, you are getting more radiation. But with this, the power level of the phone goes down.

Sherman: That is what I am saying.

Abrami: I think we have concluded that from our meetings is that's the reality, the your cellphone works harder, the further away the tower is, it's really working hard to make a connection and is continuously trying to make that connection and will wear your battery out quicker too.

Wells: I was wondering if we could take a look at that FCC act of 1996, The Federal Telecommunications Act. If it's about cell tower placement with respect to health effects, there may be another way of addressing this.

Abrami: Section 704. We will have it for the next meeting.

Heroux: It was interpreted in the courts as meaning "health" but the wording is "environmental" that they use in the act itself.

Abrami: so the court interpreted the words.

Heroux: Yes. It's an interpretation.

Ricciardi: There was an incident in Bayville Elementary School in New York. You can research it. They put the tower near the school and after five years, 30% of the students and teachers got different cancers and three of the children died. They had a lawyer, I can't think of his name but you can google it. They went to court over it and they definitely conclusively showed that it came from that tower but because of that Telecommunications Act of 1996, nothing could be done about it.

Heroux: So the mechanism by which this occurred is very simple. In Washington, industry lobbied the government elected officials for a uniform law that would implement prosperity, essentially. But they confused communication with wireless and the deregulation of the industry when the breakup of AT&T happened, made it very profitable to promote wireless vs. optical fiber. Essentially, those are all unintended consequences that happened historically.

Abrami: there have been arguments from other speakers we have had here that on your phone bill, they have been deducting money for wired communications (landlines) but that money has been diverted to wireless.

Abrami: I will see everyone on the 20th. We won't see Senator Sherman.

Sherman: I will be here in spirit.

Ricciardi: Dr. Sherman so you will be getting someone to move forward with the FDA or FCC?

Sherman: yes, that gives me two things to talk about with our delegation. I will do both.

Ricciardi: Ok. Thank you.

VII. Next meeting: March 20,2020 8:30-10:30

Meeting Adjourned at 10:40 am.

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS OF EVOLVING 5G TECHNOLOGY

Meeting held:
7/1/20
1:00-3:00 pm EST
Via Zoom (https://unh.zoom.us/j/98794338097)
Via telephone-US (+1 646 876 9923) ID: 987 9433 8097

In attendance: (11)
Rep. Patrick Abrami-speaker of the house appointee
Rep. Ken Wells- speaker of the house appointee
Kent Chamberlin-UNH-appointed by the chancellor
Denise Ricciardi-public-appointed by the governor
Michele Roberge-DHHS- Commissioner of DHHS appointee
Dr. Paul Heroux- Professor of Toxicology, McGill University- speaker of the house appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee
Senator Tom Sherman-president of the senate appointee
Brandon Garod-AG designee, Asst. AG Consumer Protection
Bethanne Cooley-CTIA , trade association for wireless industry and manufacturers

Not present: (3)
Frank MacMillan, Jr. MD-NH Medical Society Environmental Medicine
David Juvet-Business and Industry Association
Carol Miller-NH Business & Economic Affairs Dept.

Meeting called to order by Rep Abrami at 1:01 pm

Abrami: To respect everybody's time, I am going to start the meeting. This is the Commission to Study the Environmental and Health effects of evolving 5G technology. This is the first time we are meeting via Zoom. We have had a hiatus of about 4.5 months. The last meeting was February 14th. The State House has been closed for many months and we finally got the green light to proceed via Zoom. We are using Zoom, courtesy of University of New Hampshire through Kent Chamberlin who is the Chair of Electrical and Computer Engineering Dept. Kent will go over some technical things then I will read a paragraph about why we are doing it via zoom and not in person. Kent, I will turn it over to you.

Chamberlin: This is very brief. I am assuming most of you are pretty familiar with using Zoom. In your upper right corner, you have speaker view or gallery view. You can play around with that if you want to only see the speaker or the whole gallery. You may want to play with that. You won't hurt anything. Also, if you are not speaking, please mute yourself. You will see the mute indicator on the lower left. If you wish to speak, you can unmute yourself or push the space bar, say what you are going to say and when you let up on the space bar, you will be muted again. It's a good idea if we all mute ourselves so we have no background noise. Also, if you are dropped or have any problem, you can always rejoin the session. That's really all I wanted to say on how to use Zoom. Anybody have any other comments on how we might best use zoom?

Abrami: Kent, we wanted to save the gallery squares for our members, our guest, Joel and Deb. How do we do that?

Chamberlin: If you go to a block that only has a name on it and you right click, it should give you an option to only show those who have their video turned on. This will reduce the clutter on your screen. Is that working for people?

Anderson: I think there are several members who have their video turned off, Senator Gray and Senator Sherman and Brandon Garod. So they may disappear off the screen as well. You won't see their names. Just be aware of that.

Abrami: Ok. We will go with that. I have to read a public statement now:
As chair of the Commission studying Environmental and Health Effects of evolving 5G technology, I find that due to the state of emergency called by the Governor as a result of the Covid 19 pandemic in accordance with the Governor's emergency order number 12 pursuant to executive order 2020-04, this public body is authorized to meet electronically. Please note that there is no physical location to observe and listen contemporaneously to this meeting which was authorized pursuant to the Governor's emergency order. However, in accordance with the order, I am confirming that we are providing public access to the meeting via telephone and other public access via video means. We previously gave notice to the public of the necessary information for accessing the meeting, including how do I access the meeting via Zoom and via telephone. This information was printed in the House Calendar and Senate Calendars.

Welcome everybody to the meeting. Most of our meeting is going to be hearing the presentation from Dr. Herman Kelting, who has been so gracious to be flexible in his calendar. I reached out to him about four months ago. He was going to be our next guest when we stopped doing our meetings because of the virus. We will be following along his syllabus he sent to us. Before we hear from him, we have to review the minutes of the last meeting which was February 14th.

<u>I.Approval of minutes from 2-14-20:</u>

Dr. Chamberlin gave me two corrections this morning. One on Page 5- one quote Dr. Chamberlin feels was from Dr. Sherman. "I don't know if we are talking about the same bill"….

Sherman: As long as it's not inflammatory, I am happy to take credit.

Abrami: Also, on page 19, the last line Dr. Chamberlin said " low e values should be low p values". Without objection, we will make those changes. Are there any other changes that people noticed from those minutes? If not, instead of taking a vote, I will say without objection, we will approve the minutes as changed. Ok with everybody? We are all set. The minutes are approved with those changes.

II: Direction during the final months: We lost four and a half months and we need to discuss where we go moving forward. I think this is going to be the last presentation on the science. In reviewing Dr. Kelting's syllabus, it is a good refresher. There's a lot of good stuff in there that will get us going again from the science standpoint. Most of us are in agreement, not all of us, that the FCC needs to look at the biological effects. We have been trying to reach out to the FCC and FDA with no luck on this. With that said, it's hard for us as a state government to change the FCC's mind on anything. But that does not mean that we shouldn't focus on certain guidance for our cities and towns on the actions that they can legally take to help mitigate any potential harm. I think that's where we need to spend the next four months on looking at what is reasonable guidance that we can give. What really highlights this for me is that about a month ago: Deb Hodgdon, who takes our minutes and me, who are both from the same town were asked by our Planner to attend a zoom kind of meeting with our Planning Board. All the meeting was really was to give the Planning Board an update on what's coming down the pike on 5G. The two takeaways I got from that meeting are that most planning boards have no idea what 5G is and they have no idea of any of the issues surrounding it. I thought we were just going to be observers in the meeting but they asked me to give an update on 5G. They were very interested in what we had to say. The other takeaway is that they are very interested in what we come up with as a Commission for guidance. They are looking for some guidance as a town. We know that there is pushback in other towns and other towns are doing things. I think we need to formulate what is reasonable and what can help with this issue.

Denise Ricciardi who is on our Commission, is on the Board Leadership in the town of Bedford. They have recently adopted ordinances that Denise was instrumental in drafting. We don't have time today to talk about those. I have done research on what other towns around the country have done and there are a variety of actions being taken. Whether they hold up to a legal standard is another discussion. But towns and communities are trying to at least put some parameters around 5G. We should be looking at those examples and working our way through to what we think is reasonable.

Now, understand as I have said over and over again, as a Commission in New Hampshire, we are going to have differences of opinion among us as Commissioners. The way this is handled from the House is that there can be a Majority Report and there can be a Minority Report. That's the way we handle these things. We only have four months. Denise and I chatted earlier about, is there any way we can get an extension? There really aren't many commissions that have reactivated since the shutdown. I will ask leadership in the House whether we can get an extension. The problem we have is that it crosses over into a whole new Legislature and we may be able to do something next year to continue our work. But I think we have to assume our goal is still to have a report out by November 1st. If we think we still need more time, we could see if we could get legislation passed but that will have to be the beginning of next year.

Because there are a lot of us, what I would like to do is to form a subcommittee to start putting some meat around the bone of ideas. Then present that to the full Commission for discussion. I think that is probably the more efficient way of proceeding. I will be looking for volunteers of those willing to work on that subcommittee. If you volunteer to be on the subcommittee, we will probably have to meet once a week for an hour or two and I don't want to wait any longer than a month for the next Commission meeting. Because we lost 4.5 months, I can't see any other way to do this efficiently with the time we have left. If everybody wants to be on it and is willing to work every week on it, that's one thing but I don't want to have to ask everyone to do that. Tom?

Sherman: I think it's a great idea, Pat. I unfortunately, cannot be on it because I am chairing a subcommittee for the drinking water/groundwater Commission. It's a great way to get this done as long as it's representative and as long as all of us have ample time for feedback and input. Getting something down as a framework for a report and allowing feedback and discussion as a full group is a great way to do this.

Abrami: Well, the way I have done it in the past is there will be a lot of introductory stuff and all that but there will be sections of the report. I am really looking at the recommendations section that we really need to focus on. I don't want to put people on the spot here. I will just ask you to drop me a note if you want to be on the subcommittee. Denise already volunteered and I think Kent may want to be involved. Any others that want to help, that would be great. If I don't think we have enough, I may be reaching out to you and asking again if that's ok.

<u>III. Next Commission Meeting:</u>

Everybody pull out your calendars. Let's talk about the Next Commission meeting now. How about the 27th?

Sherman: Patrick, I work on Mondays. We usually meet on Fridays.

Abrami: Can everybody do Friday, the 24th? I think we are good for our next Commission meeting to be on Friday July 24th at 9 am via Zoom.

Ricciardi: Mr. Chairman, could I just bring something up for the record? All things being fair and equal, our information is important. As you know, I wrote explicit questions with your permission to the FDA and the FCC and still waiting for a response. At some point if we don't hear back, those are invaluable to making these very important decisions that I think those questions should be put in the record.

Abrami: Ok. Without objection, does everyone agree we should put those questions asked of the FCC and the FDA into the minutes of this meeting? Does anybody object to that? Ok so with that, we will put the record of those questions asked of the FCC and FDA into this meetings minutes.

Ricciardi: thank you.

Abrami: I will share with you those questions after this meeting. By the way, we have been having a problem getting things out the way we should. Because of the virus, the staff has not been as accessible as they should to distribute things or post on our webpage. I am trying to be in catchup mode on the things I thought were sent out but haven't been. So I am working on that. I apologize for that.

With that said, most of our meetings we have had, we have tried to get our arms around the science. We have a group that understands the science to a good degree. Dr. Kelting has put together a presentation with 13 objections. When I looked at it, objections 7-11 are really at the heart of what we want to talk about more. He can start a little earlier and go a little longer if need be because there is a lot of material here. Dr. Kelting has been looking at this issue for many years and has published on this issue and we welcome him. After his sections, we will pause for questions.

IV. Herman Kelting, PhD presentation *(For more details, please refer to presentation materials)*

"I am grateful that you have invited me to testify on the safety of 5G/4G Small Cell Antennas placed in residential and commercial areas which I. I object to 5G/4G SCAs based upon adverse health results. In my testimony I will discuss the attributes of 5G/4G SCAs and 13 objections related there to; time will permit me to discuss only a few research citations. Since 5G is new and has only limited historical application even in 5G/4G SCAs, and 4G and prior generations well established, my research evidence will emphasize the link between 4G and prior generations RFFR with injury to living organisms. I will also discuss 4G emissions in the context of cell phone, Wi-Fi, macro cell phone base stations, etc. because 5G/4G SCAs add to already high levels of 4G emissions from many other sources. As a general rule, I oppose air-borne, wireless emissions."

Attributes of 5G/4G that I will use in my objections to 5G/4G.

A. Two sets of antennas in a "5G/4G SCA": One beam forming on-demand 5G antenna and three 4G antennas, the latter pulsating 24/7 RFFR sited at about every 100 meters in residential neighborhoods. Movement of 5G source (e.g., cell phone) transfers signal to 4G antenna. Hence, I have concluded that the purpose of 5G is not to get 5G into residential neighborhoods but to bring 4G into neighborhoods to satisfy increased demand and revenue. *SCA wireless emissions may be avoided by* ***hard wiring from street to homes.***

B. 4G signals are being increasingly modulated, thereby more biologically active, and potentially more harmful to living organisms. [Oram Miller]
   1. Marginal harms to fetuses and young children are very severe from 4G/5G and all other wireless communications with thin skulls, over adults who are also harmed.
   2. All RFFR is a stimulant causing anxiety, depression, stress, and many other illnesses. Its radiation places a forced on charged particle on our bodies, namely electrons.
   3. **Remember this: All manufacturing processes fail in the sense they operate outside the engineering design:** 5G/4G antennas may mal-function to create very high-power densities and frequencies injuring those nearby, who will not know the extent of the damage because they do not have meters. Even if one can prove harm with a meter, damages are limited to the company's equity because insurance companies do not insure injury from RFFR.

C. Power densities of SCAs have not been publicly disclosed.
   Oram Miller indicates power densities from 5G/4G SCAs may be up to several hundred thousand $\mu W/m^2$.

Objection #1: 28 llnesses/ 20 Symptoms known to be caused by or inferentially linked to RFFR. [Letter from Herman Kelting to the secretaries of Health and Human Services and Homeland Security; original letter dated October 3, 2019; Revision 1 dated January 8, 2019; Exhibit C Herman Kelting. "United States Congressional Research and Legislative Proposals to Educate the American People About the Power Density Safety of Wireless Communications (uW/m2)." *Indian Journal of Applied Research* 8(1) (January 2018): p. 263-271 (hereinafter "IJAR Jan 2018"].

A. There are twenty-eight (28) Illnesses known to be caused by RFFR. These include increased risk of brain damage to fetuses, miscarriages, cancer. children's behavioral difficulties, ADHD, cancer of the brain, salivary gland, and breasts; leukemia, anxiety, depression, stress, sleep disturbances, reduction in melatonin, cataracts, inflammation; damage to the testes, sperm, blood brain barrier, DNA (damage through strand breaks), eyes, heart, thyroid hormones, electromagnetic hypersensitivity (EMH), damage to the autoimmune system,[1] etc. [IJAR Jan 2018, p. 264-265] If a woman places her cellphone in her bra for five years, there is about a 1.0 chance of developing breast cancer.

B. There are also twenty (20) symptoms reported by those living near 4G MCPBS (three 4G antennas housed within 5G/4G SCAs) and earlier generations. These include sleep disturbances, headache, depression, fatigue, dysesthesia (pain, itchy, burning from nerve damage associated with neurological injury), concentration dysfunction, memory changes, dizziness, irritability, anxiety, nausea, EEG changes, paranoid states, adverse neurobehavioral symptoms, etc. [IJAR Jan 2018, p. 264)

C. Nine Determinants of Injury from Wireless Devices: This is a compilation that I have done on the subject.

1. *Distance from the RFFR-emitting device to a body organ.* Since emissions from a device spread out with distance, the closer a body organ is to the emitting device, the greater the percentage of emissions hitting the body—if a cell phone is placed at the ear vs. using speaker phone many inches away, a much higher percentage of total emission hit the brain, salivary gland, and other nearby organs. The brain is obviously the most vulnerable to injury. Storage of a cell phone in the bra for five years has an approximate 100% chance of resulting in breast cancer. 500 meters minimum distance from MCPBS to humans and should be 1,000 meters for a two safety multiple.
2. *Frequency modulation:* RFFR signals (e.g., cell phones) utilize a high-frequency carrier wave that is transmitted over long distanced with an attached modulated, lower frequency that carries information. The modulation may utilize frequency or amplitude modulation. Signal modulation is an extraordinarily complex technical process that may cause injury to living organisms.
3. *Peak (not average) power density of pulsed radiation transmitted to the body.* Power density is the far field (after joining of source magnetic and electric fields) measure of RFFR strength measured by $\mu W/m^2$ (micro watts per square meter). RFFR professionals have concluded that it is pulsating peak power densities that create the most harm to

living organisms; RFFR meters have options to measure instantaneous, maximum (peak), and average maximum (peak) RFFR.

Peak densities vary widely based upon the nature of the RFFR-emitting device and signal strength. I measured the far field of one cell phone at boot up of 500,000 $\mu W/m^2$, which can exceed 20,000 $\mu W/m^2$ in normal operation depending upon signal strength and other factors.

4. *Spatial RFFR density from multiple sources.* The spatial RFFR density is a measure of pulsating radiation density from multiple pulsed RFFR devices such as cell phones, Wi-Fi, cordless phones, wireless security systems, *etc.* in an enclosed space. It is distinguishable from the metered power density *per se* because it is a function of the number of RFFR emitters in an enclosure (e.g., Wi-Fi plus 25 cell phones in a classroom)
5. *Meters understate harm from multiple nearby RFFR emitters.* As the number of emitting sources in an enclosure increases, the spatial density increases, but the power density may increase little because of the random combinations of peak instantaneous power densities from individual sources. To the best of my knowledge no one else has discussed understatement of power densities from multiple nearby RFFR emitters.
6. *RFFR source enclosed in material space- vs. outdoors-sourced RFFR.* RFFR sourced within an enclosure (autos, busses, aircraft, trains, elevators, drywall enclosures; metal is the worst enclosure) reflects off the confining material surfaces making equal RFFRs more harmful indoors than outdoors.
7. *Age at first exposure to RFFR.* Fetuses have thin, incomplete skulls with six separated bones and RFFR will make direct, almost unimpeded contact with their brain through the six thinner skull bones and cranial sutures between bones, which continue to age two. Thereafter, children have thinner skulls for several years, and continue to receive more RFFR than adults. The most dangerous situation is exposing a fetus or small child to RFFR in a metal enclosure such as a car or crawling around a Wi-Fi-sourced RFFR.

"Children whose mothers used cell phones during pregnancy had 25% more emotional problems, 35% more hyperactivity, 49% more conduct problems, and 34% more peer problems." [BioInitiative 2012, Section 1 "Summary for the Public 2014 Supplement, Evidence for Fetal and Neonatal Effects," citing Divan et. al. 2008]

8. *Cumulative life-time exposure to RFFR.* It is not age linear because younger people suffer more than older people because of brain structure and skull structure.
9. *Unique cellular and organ attributes and receptivity to RFFR.* Each person has different cellular and organ compositions and, thereby, different receptivity to RFFR contamination.

Objection #2: Evidence of mental illnesses of college and high school students.

A. 25% of college students and 20% of high school students (2018) are claiming mental disabilities caused by anxiety, stress, and depression to take longer course and SAT testing times and private testing rooms because they cannot tolerate the presence of others. [IJAR Jan 2018, Exhibit G: Douglas Belkin. "Colleges Give the Disabled More Leeway." *Wall Street Journal* 05.25.2018, A3; Exhibit H: Douglas Belkin and Tawnell Hobbs. "More K-12 Students Get Special Help." *Wall Street Journal.* 07.05.2018, A4.] It is known that anxiety, stress, and depression are caused by RFFR and from this knowledge I deduced my inference that these mental disabilities are caused by cell phones and other RFFR emitting sources.

B. College student depression rates increased from 30.9% in Fall 2013 to 39.3% in Fall 2017 ("Felt so depressed that it was difficult to function.") [IJAR Jan 2018. Exhibit E: *National College Health Assessment Survey*, p. 14]. It is known that RFFR causes depression.

Objection #3: Increases in suicides of young people

A. Actual suicides for 10 to 14-year age group declined from 242 in 1999 to 180 in 2007 and increased to 517 in 2017 = **11.1%** Geometric mean (GM) increase for ten years ending in 2017. [IJAR Jan 2018, Exhibit F]
B. Actual suicides for 15-24-year age group declined from 4316 in 2004 to 4140 in 2007 and then increased to 6252 in 2017 = **4.2%** GM annual increase for ten years ending in 2017. [IJAR Jan 2018, Exhibit F]
C. College students who "Seriously considered suicide" increased from 6.0% in Fall 2010 to 12.1% in Fall 2017 [IJAR Jan 2018. Exhibit E: National College Health Assessment 2017, p.14; IJAR Jan 2018, p. 266;] "Seriously considered suicides" doubled in 7 years: **10.5% GM annual increase in** "Seriously considered suicides"**.**
D. Notice the similarity in IRR growth rates of 11.1% GM actual suicides for 10-14-year age group and 10.5% GM for college students "Seriously considered suicide."
E. In my opinion, there is a near 100% chance the increase in actual and contemplation of suicides are caused by RFFR from cell phones, Wi-Fi, MCPBS, and are additional measures of a catastrophic health crisis NOW.
F. One medical doctor told me this: "Doctors know that cell phones cause suicide."
G. **In my opinion, there is a catastrophic health crisis NOW that is being concealed**.
   1. Reported anxiety, depression, stress, and suicides to Secretaries of Health and Human Services and Homeland Security in original letter dated October 3, 2018.
   2. Secretary referred my charge to National Institute of Health immediately.
   3. NIH rejected three days later and stated "no notice to sender."
   4. HK reported NIH rejection of catastrophic health crisis to federal law enforcement agency as an improper rejection of a catastrophic health crisis.
H. On May 27, 2020, HK accessed the CDC website for precise reference for the suicide data in Exhibit F and was unable to find it after a 45-minute search. Then called CDC and telephone responder looked for 45 minutes and could not find it. The WSJ has had a number of articles on suicides and it appears to me that the historical suicide data for 1999 to 2016 has been removed from the CDC website.

I made a number of predictions in my published article. I am just going to the last one. Some of the others have already come true of course. The last one is that working lives will decline from the mid- sixties to the mid- fifties as people have more exposure to cell phones and radio frequencies. If that occurs, that is going to pretty much be a terrible situation in an economic sense for the United States because of the additional time for retirement payments plus the loss of the skills.

Objection #4: Species extinction from 5G/4G SCAs/RFFR [Letter from Herman Kelting to Mayor Katrina Foley, Costa Mesa, CA. dated January 24, 2020 opposing 5G; HK presentation to Costa Mesa City Council February 18, 2020]

A. Barry Trower: Physicist and well-known UK 5G weapons expert, who was associated with 5G weapon systems used to injure Catholics in Northern Ireland stated:
   1. Installation of 5G/4G SCAs will result in only one child in eight births being born normal three generations (60 years) from date of 5G/4G SCAs installation.
   2. He also indicated that the RFFR injures 4,500 electrical subsystems in the human body by placing a force on charged particles.

B. Evidence of species extinction in five generations or less is supported by the following scientific studies and other evidence: (ten supporting references follow but I will only refer to a few because of time.)
   1. A Greek study of the reproduction of rodent births exposed to RFFR resulted in "…mice exposed to 0.168 nW/cm^2 (1,680 µW/m^2) became sterile after **five** generations, while those exposed to 1.053 nW/cm^2 (10,530 µW/m^2) became sterile after only **three** generations." [A Balmori, 194] "A progressive decrease in the number of newborns per dam was observed, which ended in irreversible infertility" [Magras IN, Xenos, TD. "Radiation Induced Changes in the Prenatal Development of Mice." *Bioelectromagnetics* 18 (6) (1997): Abstract, 455-461 cited in A Balmori. "Electromagnetic Pollution from Phone Masts." Effects on Wildlife." *Pathophysiology* 16 (2009): 191-199, 194] (Foley 01.24.2020)
   2. Study of 361 men in fertility clinic had reduced sperm count, motility, (moving property through the female reproductive tract), viability, and normal morphology (size and shape of sperm under microscope, >14% normal) as daily cell phone usage increased from zero, < 2 hours/day, 2-4 hours daily, and to >4 hours daily usage [IJAR Jan 2018, Ref 47,Agarwal, 2008]. When you follow these decreases through multiple generations you have the end of species. That is a 55% decline with an increase in cell phone use from 0-4 hours/day.

Group	CP Usage	Sperm Count	Motility	Viability	WHO Morphology % Normal
A	No use	85.89	67.80	71.77	40.32
B	< 2 H/D	69.03	64.57	68.21	31.24
C	2-4 H/D	58.87	54.72	57.95	21.36
D	> 4 H/D	50.30	44.81	47.61	18.40

3. Experiment showed that the reproductive capacity of the insect Drosophila Melanogaster declined 36.4% (1 min), 42.5% (6 min), 49.2% (11 min), 56.1% (16 min), and 63.0% (21 minutes) exposure to a GSM 900 MHz carrier frequency and 217 Hz information frequency with exposure at a power density of 100,000 $\mu W/m^2$ (10 $\mu W/cm^2$). Again, this power density of 100,000 $\mu W/m^2$ is far less than the 6,000,000 to 10,000,000 $\mu W/m^2$ FCC MPE safe limits. This experiment showed the important relationship between time of exposure to RFFR and injury to a living organism. [Panagipoulos DJ et.al. "The Effect of Exposure Duration on the Biological Activity of Mobile Telephony Radiation." Mutation Research 699 (2010): 17:22.[2]

4. Cell phones operating at 900 MHz were placed in three colonies of honeybees and turned on for 10 minutes for ten days. After ten days the worker bees never returned to the three test hives because the cell phones were "…frying the navigational skills of honey bees and preventing them from returning back to their hives." Production of eggs by the queens was reduced from 350 to 100 eggs/day. The authors concluded that cell phone RFFR is a better explanation of Colony Collapse Disorder than any other theory. [Sainudeen Sahib S. "Impact of mobile phones on the density of honeybees." *Journal of Public Administration and Policy Research* 3(4) (Apr 2011): 131-133.] (Sisolac 08.29.2019, 13-14)

There are others listed in my presentation but I think this is adequate for proof.

C. Doctors and scientists opposing 5G/4G SCAs *(There are others, but here is one*)

<u>Baden Wurttemberg, Germany October 23, 2019</u>

Seventy (70) doctors in Baden Wurttemberg signed and 25 doctors in white coats delivered the letter, "Doctors Warn Against 5G Mobile Communications" to the prime minister on October 23, 2019 asking for a moratorium on 5G small cell antennas because of harm to living organisms. They expressed particular concern with "electro hypersensitivity (EHS)" which now affects 5-10 percent of their population. One doctor-signatory in Baden Wurttemberg stated ***"To protect the population, we need Wi-Fi free schools and a 5G moratorium!"*** *In my opinion, we also need control over macro cell base stations.*

D. Many communities have stopped 5G or will not be producing it.

<u>Haifa, Israel banned Wi-Fi in schools April 20, 2016</u>

On April 20, 2016, Haifa, Israel banned Wi-Fi in schools because of the increase in EHS/EMH and because many children were contemplating suicide. It is known that Jenny Fry, a UK teenager, committed suicide because of Wi-Fi in her school.

E. HK request for medical school research from a friend at (Stanford University) dated May 18, 2020 9:50 AM

Does RFFR make Covid-19 more virulent? Asked for Covid-19 (1) free of and (2) attached to host cells to be placed under an electron microscope with a variable frequency/variable power density RFFR to determine if the virus is more active under RFFR bombardment similar to neurons being more active in an RFFR field What gave me this idea is that we know that six CA firemen receiving brain and neurological injury from macro cell base station on the roofs of their fire stations resulting in permanent excitement of brain neurons.(hich was outputting between 10-20,000 µW/m[2)]

Abrami: Herman, can we pause right here and see if there are any questions at this point. I think what Herman is doing is adding to the list of papers and things that we have already heard about and discussed in the past. He is highlighting some of the papers that are of interest to him. Any questions or comments?

Chamberlin: I just have a question and it involves the bee study. We heard about the bee study and saw the paper on it. This is of course, very convincing. If you put a cellphone in a beehive and it's going to destroy the navigation abilities of the bees now that would be convincing. We are looking for strong evidence. It kind of surprises me that this is a fairly simple study to do. Do you know if it's been replicated?

Kelting: To the best of my knowledge, yes. In other words, there are other studies that have also shown damage to bees with the application of radio frequency. What I have done in my work is pick the best study available and I do not do exhaustive searches with additional support.

Chamberlin: Alright. Thank you.

Wells: I have a question as well. On objection 1, you list illnesses known to be caused by or linked to radio frequencies and I am wondering, could these antennas be used or hacked to cause deliberate injury in your opinion?

Kelting; yes, certainly. Remember, 5G is a beam form signal and that means when you turn on your cell phone, there is a beam that envelopes your body about ten degrees wide and if they combine that with facial recognition, they can do anything that they wish. They can change the power of the beam because that's what they did to the Catholics in Northern Ireland. It's not exactly the same because they can use higher frequencies but they can beam form and take out people with facial recognition in the antenna system.

Abrami: We know in China, they are using facial recognition with their 5G. There are plenty of reports showing that. Is that what you are hearing Herman?

Kelting: That sounds sensible but I am not totally familiar.

Abrami: Let's continue.

Objection #5: Injury specifically from 5G

A. "Preliminary observations showed that MMM [millimeter waves > 30 GHz] increase the skin temperature, alter gene expression, promote cellular proliferation and synthesis of proteins linked with oxidative stress, inflammatory and metabolic processes, could generate ocular damages, affect neuro-muscular dynamics…available findings seem sufficient to demonstrate the existence of biomedical effects…" [Di Caula A. "Towards 5G Communication Systems: Are There Health Implications?" *International Journal of Hygiene and Environmental Health* 221(3) (Apr 22, 2018): 367-375

B. 5G transmits data in a very short time period, but there are indications that "…these bursts may lead to short temperature spikes in the skin of exposed people." Research has also shown that peak to average temperature ratios "…may lead to permanent tissue damage after even short exposures highlighting the importance of revisiting existing exposure guidelines." This means that current heat standards are too high and should be lowered. [Neufeld E and N Kuster. "Systematic Derivation of Safety Limits for Timer-Varying 5G Radio frequency Exposure Based on Analytical Models and Thermal Dose." *Health Physics* Sept 21, 2018.] [Letter from Herman Kelting to Nevada Governor Steve Sisolac, Nevada Senator Nicole Cannizzaro, and Nevada Assemblywoman Shay Backus dated August 29, 2019 (Revision 02), 11-12].

C. 5G operates at the same frequencies (e.g. greater than 24 GHz) as the sweat duct, which is a helical antenna operating at a high specific absorption rate in extremely high frequency bands. This suggests 5G will heat the skin, one of the adverse consequences of 5G.

D. In an e-mail dated May 27, 2020 2:05 PM , Professor Joel Moskowitz stated "**My note:** This review summarizes research on the effects of millimeter waves (>30 GHz) on the skin. None of these studies has examined 5G millimeter waves. 5G employs specialized technology including phased arrays, beam-forming, and massive MIMO (sending multiple data signals simultaneously over the same radio channel). 5G millimeter waves may be more biologically active and result in more adverse health effects than the earlier millimeter wave studies found."

Objection #6: Injury from secondary, endogenous RFFR: Sommerfeld and Brillouin precursors

1. Sommerfeld and Brillouin precursors are induced, propagating transient RFFRs generated endogenously in the human body (or other mediums) from an exogenous source RFFR with a changed sinusoidal structure (about 6 times smaller amplitude) that displaces charged particles in human tissue, thus damaging those particles. (A117). This means that Sommerfeld and Brillouin Precursors are RFFR that propagate endogenously within the body from a source exogenous to the body without attenuation and travel faster than the source pulse. They induce movement of proteins, DNA, and ions of potassium, sodium, chloride, calcium, and magnesium. (A117) These movements damage cells and organs [Albanese,R, Blaschak, J, Medina, R, Penn, J. "Ultrashort Electromagnetic Signals: Biophysical Questions,

Safety issues, and Medical Opportunities." *Aviation, Space, and Environmental Medicine*. May 1994: A116-A120 ("Albanese May 1994".; see also OMB No. 0704-0188 94-24875 AD-A282 990 dated Jan 90-Aug 93; Jakobsen PK and Masud Mansuripur. "On the Nature of the Sommerfeld-Brillouin Forerunners (or Precursors." *Quantum Studies: Mathematics and Foundations* (November 8, 2019)] Thus, 5G beams immerse the body in a 10-degree RFFR, enter the skin and breed new, induced RFFR that travel faster than the original pulse with the radiation of the propagated RFFR damaging cells deep in the body just as 4G RFFR does.

2. Regarding the failure of FCC safety limits to consider Sommerfeld and Brillouin Precursors, Albanese stated "However, IEEE C95.1, 1991 was developed from biomedical data on pulses whose onset and offset times (or rise and fall times) were much slower than those shown in Fig 2; the standard does not embody the precursors phenomenon. Thus, in practical term, the sharp ultrafast category of pulses being discussed are not covered by IEEE C95.1-1991 or by any other formal guideline known to us…**Until the issue of tissue damage mechanisms associated to pulses that cause precursors is fully studied, the authors recommend zero human exposure to such unique precursor and gendering pulses."** [Albanese May 1994, A118]

<u>Objection #7: FCC antenna safety standards applied to MCPBS ignore radiation injury to living organisms at power densities many times lower than the FCC antenna safety standards.</u>

A. FCC antenna safety standards: 6,000,000 to 10,000,000 μW/m^2 based upon frequency.
   1. These FCC safety limits ignore actual injury from radiation at much lower limits than 6,000,000 to 10,000,000 μW/m^2. Six CA firemen received brain and neurological injury from MCPBS on the roofs of their fire stations emitting 10,000 to 20,000 μW/m^2. [Letter to two secretaries Revision 01 dated 01.08.2019, Exhibit N]

   Rep. Abrami, have you heard of this California study before?

   Abrami: yes

B. International antenna safety standards:
   Compare the safety of FCC safe limits of 6,000,000 to 10,000,000 μW/m^2 with other countries antennae safety limits. The wide range in country antenna safety limits means **no country really knows antenna safety limits and that the US, with the highest antenna safety limits is clearly in conflict with all other countries in this list.** [Remke, Amar and Mahesh Chavan. "A Review on RF Exposure from Cellular Base Stations." *International Journal of Computer Applications.* 104(12) (Oct 2014): 9-16]

	Power density	%US

Country or other geographical area	W/m²	µW/m²	
USA public exposure guidelines at 1800 MHz	10	10,000,000	100%
India	9.2	9,200,000	92%
Canada (see Attachment)	3.0	3,000,000	30%
Australia	2	2,000,000	20%
Belgium	1.2	1,200,000	12%
New Zealand	0.5	500,000	5%
Exposure limit in CSSR, Belgium, Luxemburg	0.21	210,000	2.1%
Exposure limit in Poland, China, Italy, Paris	0.1	100,000	1.0%
Exposure limit in Italy in areas with duration hour	0.095	95,000	0.95%
Exposure limit in Switzerland	0.095	95,000	0.95%
Germany: Precautionary recommendation only	0.09	90,000	0.90%
Italy: Sensitive areas only	0.025	25,000	0.25%
Exposure limit in Russia, Bulgaria, Hungary	0.02	20,000	0.20%
Austria: Precautionary limit in Salsbury only	0.001	1,000	0.01%
Germany BUND 199	0.0009	900	0.009%
New South Wales, Australia	0.00001	10	0.0001%

(1) Building Biology Institute RFFR anomaly standards for up to for sleeping: They consider 1,000) µW/m² as an extreme anomaly. They suggest for sleeping purposes that you have considerably less than 1,000) µW/m². For example, I have shielding paint on two bedroom walls of my home which brings me down to near zero.

	None	Slight	Severe	Extreme
a. Radio frequency field radiation (High freq., EM waves) µW/m²	<0.1	0.1 – 10	10-1000	>1000

C. RFFR power density meter readings from emissions of a MCPBS (MCPBS) taken 06.09.2020 by HK. MCPBS located 150 feet from about 100 two-story apartments with more apartments adjacent and to the east of the front 100 apartments. Meter readings taken about 100 feet from the MCPBS and 50 feet from apartments. Meter used: Safe Living Technology Safe and Sound Pro II. (Herman’s research)

1. Power density meter readings in μW/m²:

108,000	97,300	**224,000**	159,000
212,000	97,300	147,000	135,000
97,300	**311,000**	162,000	145,000
135,000	**580,000**	175,000	**200,000**
147,000	**208,000**	**224,000**	

2. Descriptive statistics

Average	196,663 μW/m² Rounded 197,000 μW/m²
Stdev	109,569 μW/m²
Coefficient of variation	0.56

3. How would you like to live 150 feet from a MCPBS emitting an average power density of 197,000 μW/m² when 6 CA firemen received brain and neurological injury from MCPBS on the roofs of their fire stations emitting 10,000 to 20,000 μW/m².
   If you look at these statistics with the bolded very high values and recall that the firemen were injured at between 10-20,000. These poor people in 100 apartments are living within 50 feet of this power density.

   Abrami: so Herman, this is interesting. I know a lot of people look at the readings based upon an average. What is your feeling on an average v. what the peak would be?

   Kelting: Perhaps, I was not clear on that. These are all peak readings. What I do is turn on my meter and clear it and for 15-20 secs it registers peak, hold and gets the highest peak and that's what I record on here. These are not averages. Averages are much lower. Probably less than 10%. Peaks injure.

   Sherman: Could I ask a question? So is it how long you are exposed to peak, is the duration of exposure as important as the intensity?

   Kelting: It's a combination of both. Remember now, you are talking about a macro cell phone base station pulsating RFs, the peaks of which are within a 20-30 second interval are as I recorded here. This goes on 24x7. Theoretically if you came back one hour later or two days later, you are going to get about the same distribution and the same averages..

   Chamberlin: My question involves the bandwidth. Of course, the wider the bandwidth, the greater the peak you will see because you will be looking at a superposition of a greater number of frequencies. Do you happen to know the bandwidth?

   Kelting: no. I do not. I only measure radio frequencies and that could probably be one of the inadequacies of my work. But you have alerted me to that and I have a meter that measures frequencies so perhaps in the future I can consider that.

> Abrami: But here's the thing. These are still within the FCC standards. Correct? The question on the table is, is the FCC standard set too high?
>
> Kelting: That's correct.

Kelting: On January 14, 2020 I wrote a letter to the Clark County Board of Commissioners on two sets of macro towers and cell phone base stations. One was emitting up to 218,000 micro watts per square meter about 100 yards from the two facilities which was about 100 feet from homes and the second was power densities on a building with two antenna on top which were concealed incidentally. They were emitting in the building up to 37,100 $\mu W/m^2$. That building is a Community Center.

D. Studies of harm from 4G MCPBS at power densities small fractions of FCC MPE limits,

1. In a study of 1000 individuals living for ten years within less than 400 meters from a GSM cellular transmitter site in Germany, it was found that the likelihood of getting cancer was three times greater than for those not near a cellular transmitter and that the patients fell ill an average 8 years earlier. Radiation in the inner area was 100 times the radiation in the outer area. The authors concluded it was necessary to monitor the health of individuals living near high radio frequency emissions from cellular base stations. [Eger, Horst, Klaus Uwe Hagen, et. al. "The Influence of Being Physically Near to a Cell Phone Transmission Mast on the Incidence of Cancer." Umweit-Medizin-Gesellschaft 17(4) (2004): 7 pages]. (Sisolac 08.29.2019, 12-13)
2. An apartment building with two cell phone base stations on the roof had a mean power density of 3,811 $\mu W/m^2$ with a power density range of 15.2 $\mu W/m^2$ to 112,318 $\mu W/m^2$. The mean radiation was reduced by 98% when the power density from the two cell phone base stations was disregarded. The authors concluded:

   > "Due to the current high RF radiation, the apartment is not suitable for long-term living, particularly for children who may be more sensitive than adults…the simplest and safest solution would be to turn them off and dismantle them."

   [Hardell, Lennart, Michael Carlberg, et.al. "Radio Frequency Radiation from Nearby Base Stations Gives High Levels in an Apartment in Stockholm, Sweden: A Case Report." *Oncology Letters* 15(5) (May 2018): Pages 1-29]. (Sisolac 08.29.2019, 12-13)

3. In Belo Horizonte, Brazil, it was found that deaths from neoplasia (i.e., abnormal growth of tissue; cancer) increased with close proximity to cell phono base stations. For those living within 100 meters of a CPBS, the death rate was a relative risk of 1.35, for 500 meters 1.08, and for 1000 meters 1.00. The death rate from neoplasia varied from 5.83 per 1000 individuals to 2.05 per 1000 individuals. Cell phone base stations were concentrated in the Central Southern region and varied from 8,980 uW/m^2 (0.898 $\mu W/cm^2$) to 30,660 $\mu W/m^2$ (3.066 uW/cm^2) in 2003. Brazilian power density standards were 4,513,400 $\mu W/m^2$ (451.34 $\mu W/cm^2$) at 900 MHz and 9,024,900 $\mu W/m^2$ (902.49 $\mu W/cm^2$) at 1800 MHz.

Notably, the death rate from neoplasia in Belo Horizonte occurred at power densities much lower than the US standard of between 6,000,000-10,000,000 $\mu W/m^2$. [Dode, AC, Et.al. "Mortality by neoplasia and cellular telephone base stations in the Belo Horizonte municipality, Minas Gerais state, Brazil" Science of the Total Environment 409 (2011): 3649-3665].

4. In a study of tree damage in Germany, it was discovered that cell phone base stations damaged the sides of 60 trees facing the MCPBS. The median power density from the MCPBS on the damaged side was 995 $\mu W/m^2$ and on the undamaged side was 125 $\mu W/m^2$ using peak and peak hold values. A power density of 995 $\mu W/m^2$ is obviously far less than the FCC safe threshold of 6,000,000 to 10,000,000 $\mu W/m^2$. It is also a little less than the Building Biology recommendations of less than 1,000. The authors quote from M. Repacholi, head of the International EMF Project of the WHO (p. 567), who said in part: [Waldmann-Selsam C, et.al. "Radiofrequency Radiation Injures Trees Around Mobile Phone Base Stations" Science of the Total Environment. 572 (2016): 554-569.]

   > "Given that any adverse impact on the environment will ultimately affect human life, it is difficult to understand why more work has not been done…research should focus on the long-term, low level EMF exposure for which almost no information is available"

5. In an Israel study of cancer rates near a cell phone base station, it was discovered that 3-7 years' exposure times had cancer rates 4.15 times the cancer rate in the entire population and that the cancer rate for women was 10.5 vs. 1.0 for the whole town of Netanya. The power densities were "far below" current guidelines of 5,300 uW/m^2 (0.53 uW/cm^2) for thermal effects. [Wolf, et. al. "Increased Incidence of Cancer Near a Cell Phone Transmitter Station." International Journal of Cancer Prevention. 1(2) (April 2004).]

6. In a Greek study of the reproduction of rodent births in response to a microwave power density of 1,680 $\mu W/m^2$ (0.168 µW/cm2) it was found that the rodents became sterile after five generations and those exposed to 10,530 $\mu W/m^2$ (1,053 $\mu W/cm^2$) became sterile after three generations. Note that these damaging-to-living-organisms' power densities are considerably less than the FCC safe limit of 6,000,000-10,000,000 $\mu W/m^2$. [Magras IN. "Radiation induced changes in the Prenatal Development of Mice." Bio electromagnetics 18 (1997): 455-461 cited in A Balmori. "Electromagnetic Pollution from Phone Masts. Effects on Wildlife." Pathophysiology 16 (2009): 191-199.,]

Objection #8: FCC antenna safety standards disregard power densities emitted by body proximate devices (i.e., personal property).

A. There is only a heat standard for body proximate RFFR emitting devices and it has been shown many times there is radiation injury even though the heat standard is met.
B. In a letter dated February 7, 2014, the Office of the Secretary of the Interior, stated:

   "The electromagnetic radiation standards used by the Federal Communications Commission (FCC) continue to be based on thermal heating, a criterion now nearly 30 years out of date and inapplicable today."

Objection #9: RFFR meters understate power densities from multiple nearby RFFR emitters.

This means that when you meter an area with two or more emitters, the peak power densities will not measure appropriately the addition of the second to the first and here is why.

Assume two single 4G MCPBS emitting antennas each emitting peak power densities of 10,000 µW/m^2 with a combined theoretical peak of 20,000 µW/m^2.

When you meter, you should probably get at some point a peak of 20,000 µW/m^2. You will not get that because antennas will be emitting ***unsynchronized*** peaks and lows. The probability of measuring two MAX peaks of 10,000 µW/m^2 each for a combined total power density of 20,000 µW/m^2 is zero. Thus, if we have a metered instantaneous peak of 8,000 µW/m^2 for Antenna #1 and a metered instantaneous peak of 4,000 µW/m^2 for Antennas #2 for a combined instantaneous peak of 12,000 µW/m^2, 12,000 µW/m^2 will be the peak for the two combined antennas, which is 12,000/20,000 µW/m^2 = 60% of the true combined peaks. You will likely never get the true a peak of 20,000 µW/$m^{2.}$

Abrami: Let's pause there. Does anybody have any questions? None. Ok keep going Herman.

Objection #10: Legal vs. equitable standards to measure safe human exposure limits, US statutes and case law.

A. Legal Standard is from Telecommunications Act of 1995 Section 704(a)(7)(B)(iv) Public law 104 104th Congress 110 Stat 66:

   "No state or local government…may regulate the placement, construction, and modification of personal wireless facilities on the basis of the environmental effects of radio frequency emissions to the extent that such facilities comply with the Commissions regulations concerning such emissions." [Telecommunications Act of 1995 Section 704(a)(7)(B)(iv) Public law 104 104th Congress 110 Stat 66].

In my opinion, Telecommunications Act sets a legal statutory, not equitable standard, for safety unrelated to actual known injury. **704(a)(7)(B)(iv) is unconstitutional because it violates equitable safe power densities.**

B. It is essential that equitable standards of the National Environmental Policy Act not be overridden by federal legislation. I believe there is a bill in Congress that is attempting to override the National Environmental Policy Act (NEPA).

One of the fairly good cases is.

1**.** In *United Keetoowah Band of Cherokee Indians in Oklahoma, Individually and on behalf of all other Native American Indian Tribes and Tribal Organization et al Petitioners vs Federal Communication Commission et al* No. 18-1129 decided August 9, 2019, the court was faced with the following issues and factual situations and held as indicated:

2. *Principal issue:* Was the FCC order "Acceleration Wireless Broadband Deployment by Removing Barriers to Infrastructure

(1) "<u>All 'major Federal actions significantly affecting the quality of the human environment' trigger environmental review under NEPA…42 USC §4332</u>(C). Major federal actions 'include actions …which are potentially subject to Federal; control and responsibility.'40 CFR §1508.18. Under the Commissions procedures implementing NEPA, if an action may significantly affect the environment, applicants must conduct a preliminary Environmental Assessment to help the Commission determine whether 'the proposal will have a significant environmental impact upon the quality of the human environment' and so perhaps necessitate a more detailed Environmental Impact Statement 47 CFR §1.1308; see also 40 CFR §1.1508.9. [7]

The summary of the legal issues that I have in this section is to emphasize equitable standards not legal standards, which are unconstitutional.

Abrami: Let me pause you there Herman. So you are saying that for Indian reservations, different rules can apply now?

Kelting: No. I am not saying that. First of all, I am not a legal expert on Indian Reservations and outside of them. But what I have just quoted you from was from a federal law that is not specific to Indian Reservations. It was applied to Indian Reservations but is broadly applicable in my opinion, to all other circumstances as well. In other words, the NEPA is broadly applicable to all situations where there is environmental injury. That is why we need to use equitable standards not legal standards.

Abrami: So let's take section a/ The FCC granted licenses for the telecommunication companies to install SCA on Indian lands without any historical preservation or environmental review. So what did they do? What happened in this case?

Kelting: I don't know. I think the case was the DC court of appeals.

Objection #11: RFFR-emitting devices may interfere with reception of the Schumann Resonance

A. The Schumann Resonance is a set of Extremely Low Frequencies caused by lightening in the ionosphere/atmosphere with a main frequency of 7.83 Hertz (cycles per second) and harmonics of 14, 20, 26, 33, 39, and 45 Hertz. Those resonances are very similar to the RFFR harmonics in the human brain.
B. Practical application of Schumann Resonance

   Experiments with individuals living underground indicate they became depressed until the Schumann Resonance was added to their environment. To give you an illustration here, I used a bike helmet lined with a heavy duty tin foil and got a severe headache several times. The tin foil of course should protect me from outside frequencies. When I removed the tin foil, I did not get the severe headache. My hypothesis was that maybe I had become separated from the Schumann Resonance like underground humans and that separation caused the headache.

Abrami: Before you go on Herman, does anyone recall? Didn't we talk about the Schumann Resonance somewhere along the line at one of our meetings? No? Ok. It sounded familiar.

Objection #12: 5G/4G SCA legislation does not provide a reasonable accommodation for those with Electromagnetic Hypersensitive.

A. SCAs will be universally installed throughout cities and those who are EMH will have no place to go for freedom from RFFR. Your choices will be stay in your home or suicide. There is one lady who has EMH in a place where they have installed 5G and she has to have her meals delivered to her in her house. She can't go outside.
B. Kalamata, Greece did a pilot study of 5G/4G and rejected it partially on the grounds of no protection for EMH individuals.

Objection #13: Environmental power densities should be disclosed in transfers of interests in real and personal property or in the use and occupancy of public buildings.

A. Objective: Inform the public of the quantity of power densities ($\mu W/m^2$) in their environment.
B. Regulatory issue #1: Power density disclosure to buyers and lessees of residential real estate.
   1. Power density disclosure of $\mu W/m^2$ to buyers and renters by state law. State law should require environmental assessments

a. Meter immediately outside the housing unit. "Outside" means around the outside the walls of the building including only the detached housing unit or around the outside walls of a multistory building containing several housing units all at ground level.
b. Meter inside the housing units within three feet of all interior walls during ordinary working hours or evening hours as required by the buyer or lessee. Date, day, and time must be shown on the inspection.
c. Estimate spillover RFFR from adjacent housing units if you are in an apartment or a condominium. Turn off electricity in target housing unit and turn off all RFFR devices. The remainder RFFR is from outdoors or from spillover RFFR from an adjacent housing unit. Can estimate spillover RFFR my metering near party wall. I have personally measured wifi once that was throwing off a million ($\mu W/m^2$). I believe that was in the far field three feet away. That's terrible. That means that across the party wall, those people are probably getting 900,000.
d. Measure of harm: Imagine a six-month old baby crawling on the floor with a 1,000,000 $\mu W/m^2$ Wi-Fi nearby in the same or spillover adjacent apt. Getting his or her brain fried from grossly excessive RFFR/EF. That child is going to be injured, perhaps for life.

Abrami: Herman, let's talk about this for a minute. The upper limit of the federal guideline is 10 million $\mu W/m^2$ right? Or ten W/m^2 and your example is only one tenth of that FCC limit.

Kelting: Yes and my proposal in informing the public, does not include a safety standard within the legislation. It will only say that every home and apartment will be metered and the results delivered to the renter or the buyer. There will be no notice of what is safe or not safe. The purpose of that is to avoid criticism in comparisons with the FCC. Let people start doing their own research and when they do, then you are going to get complaints. I am thinking this is the golden arrow to defeat the FCC.

Abrami: Right. I think I understand what you are saying. Publish what the readings are and let people make their own decisions.

Kelting: Exactly. It will come to a point where people will say, I am not going to buy your house because I am getting 10,000 $\mu W/m^2$ and over there at that house, I am only getting 20 or 30. I bought my house in an area by metering first. I selected my house in an area with low radio frequencies, typically less than 10.

Abrami: Ok. That's something that the Commission will be thinking about.

C. Regulatory issue #2: Need power density disclosure and prohibition of use of RFFR emitters in public buildings.
   1. "Public buildings" mean all buildings that have unrestricted public access including government buildings, retail stores selling personal property or services, restaurants, exercise facilities, *etc.*.
   2. The disclosure should be made using a time-dynamic RFFR meter showing power densities in $\mu W/m^2$ with one time dynamic meter for the lesser of 10,000 square feet of floor area or the actual space. This is so when you go in a building, you know what the power densities are. Those densities will include any cell phones and

wireless devices in the building. That's the beginning of managing radio frequencies in buildings in my opinion.

3. Prohibit use of wireless devices in public buildings (e.g., government buildings, schools, anyplace there are concentrations of people in an enclosure). I am also suggesting this after being a government agent and working in government buildings for thirty years of my life. Now that means that people won't be able to talk to their children at three o'clock while at work or talk to their buddies. That will reduce the power densities in buildings. Furthermore, there are issues of trespass. When you have a cellphone that is emitting a beam that is hitting my body, you are trespassing on me which, in my opinion is illegal under equitable standards.

D. Regulatory issue #3: Need power density disclosure to buyers of RFFR-emitting personal property (e.g., cell phones, Wi-Fi, cordless phones, automobiles) at point-of-sale.
   1. Electric field within about one inch of the item (near field), if not a moving vehicle
   2. Power densities (i.e., $\mu W/m^2$) within three feet (far field) of the device, if not a moving vehicle.
   3. For autos, meter inside vehicles in an environmentally near zero geographic area.

So in addition to the mpg on a car, there should be power densities in that car as well. The same thing for wifi, cell phones, etc even though I recognize differentials in signal and signal availability is a factor.

That pretty much closes it. I would like you to comment on what you felt about this presentation.

Abrami: you summarized a lot of work that we had gone over before the shutdown. This is all good. Some of the last comments about not having cellphones in buildings, that's a tough sell.

Kelting: yes. But if you start doing some other things like disclosure in rental and buying property, then people will become acclimated and want disclosure.

Abrami: Well let's open this up…. New Zealand, for example, their standard is 500 $\mu W/m^2$ or 5% of what our standard is. We have talked about this many times. How can we be so high of a standard and other countries take a totally different position? It's all over the board. Australia is 2,000,000 and Canada is 3,000,000. We have been discussing this a lot which is why we have been trying to get in touch with the FCC to answer our questions. It is hard getting through to them.

Kelting: It's impossible because they are controlled by the telecommunications industry. What happens with federal agencies is that eventually substantially all of them are controlled by the industries they regulate because their managers are essentially appointed by those being regulated.

Abrami: yes. We have heard all those arguments. As a state we can't set up standards. All we can do is warn and give guidance. I want to at least be able to say that we have tried to reach out to the FCC and FDA and others because someone is going to say why didn't you talk to the FCC? We just have to be able to say we tried and have gotten no response.

Chamberlin: At this point, after what I have read and after having other presenters before you and hearing what you are saying, I am totally convinced that there are deleterious effects on health due to radiofrequency exposure. I am sold. But, what I don't know is relative risk. In other words if I have a cell phone and live near a cell tower what is my risk compared to say, smoking or driving a car? Do we have some dose relationship between exposure and risk? Am I ten times more likely to die from cancer if I have a cellphone? Can you put some context behind this and give me some relative understanding of how exposure is risky?

Kelting: My answer to that question is the probability of extinguishing humanity in sixty years if we continue the rate we are going even without 5G is about 100%. We are in a process of destroying humanity right now and the evidence is being concealed. My letter of complaint incidentally on that case went to the Federal Bureau of Investigation.

Abrami: They didn't respond, I imagine.

Kelting: no.

Gray: I find objections to most of what Mr. Kelting has presented today. I can't count the number of times in his presentation he said, in my opinion. I can't count the number of times he has referenced studies that have been disproved by other things. I would admit that there probably is a radiation level that I can probably reach that would be deleterious to humans but to talk about extinguishing the human race, to talk about suicides and all these other things with studies that have not been reproduced, have not been verified and are using high levels of radiation or animals or different species that aren't humans who aren't affected the same way and taking that as gospel. I just can't get there. Thank you.

Kelting: Senator, you could if you were Electromagnetically Hypersensitive as I am because I can feel the junk.

Heroux: I think that to answer your question as to evidence that there is or isn't…. in order to assess the health effect, you have to measure it and you have to believe that there is something to measure. In relation to electromagnetic radiation, when the federal government through the FCC expresses an opinion about risk that is so clear, that there is no risk below thermal levels, there hasn't been much incentive to perform measurements. There are individuals who attempted to do this. So the only variable with relatively reliable documentation is cancer. This is a variable that has a digital quality to it. Either you have it or you don't. There are international bodies who measure this in a routine fashion. What we have on this subject as you already know, are the two reports from International Agency on Research on Cancer that says low frequency and radio frequencies are related to cancer as well as a number of studies like this Brazilian study that I think is very convincing on the impact of cell phone towers because not only do they determine from an established set of cancers but your probability of dying from it is higher if you live near a cellphone tower. The problem essentially with Dr. Kelting's presentation is that he goes to a large number of effects on which there is relatively little proof because it hasn't been investigated in a very systematic way. So, we don't have the means to investigate everything in detail but perhaps cancer is an exception. Thank you.

Abrami: Let's bring this back to 5G vs. cell phones or whatever. The real issue is our communities are going to be asking for guidance on 5G. If they roll out small cells in any community, they will be rolling them out in front of people's homes low to the ground and the great mystery to all of us is how much energy is coming out of them and is it safe to walk near one of these? Obviously, industry is probably saying yes, they are very safe. We wouldn't do it if it wasn't safe. There is enough evidence out there of ills from RF radiation on all topics. You name it, there are plenty of studies. From the beginning, we have asked, have the studies been replicated? But to me, there is enough evidence of concern. We will all have to put ourselves in the position of asking ourselves if the cell company came by and put an antenna on top of my telephone pole that is 100 feet from my house, would I think that's a good thing or a bad thing? At this point, I wouldn't be too excited about it because I am not 100% convinced that there is not some concern for safety. Maybe it's not conclusive evidence as of yet but I think the body of evidence will have to be built over time. That's the concern that we have to address for the state of New Hampshire and for the communities and citizens in the communities. That's a tough thing to get our hands around but that's what we are being asked to do.

Sherman: I was just going to second what you are saying. Whenever you are looking at studies of human health especially with potentially deleterious exposures, one other that we are grappling with is PFAS. How good are the studies on PFAS? Well, they are good enough to say everything is pointing in a bad direction. Is there something that is absolutely unequivocal? We know that with Mesothelioma and asbestos and bladder cancer and arsenic or smoking and lung cancer? No.

Is there something right now with 5G that says, boy this is really bad for us? I think it depends on who you ask. But you have got a very large, very well- funded, very powerful industry saying, trust us. We wouldn't do this if it were damaging or harmful to human health. It reminds me of some other industry issues we have had in the past saying trust us and not trying to make sure the data is robust. Therefore the data is suggesting that there is no harm. So we are left with the Precautionary Principle of public health which is, we have enough evidence to be concerned but not enough evidence to be definitive as far as I can see from sitting in on these things and what do we do?

I think the most troubling thing for me is that especially in New Hampshire but throughout the country, there is a certain amount of choice of what we expose ourselves to. With 5G, that choice is gone. Unless you want to stay in your home and wrap yourself in aluminum foil, you don't have that choice. You get into people's personal choice. We have a choice whether or not to use a cellphone but we don't have a choice if the 5G tower is going to be right outside our window because the FCC covers that. They are in charge. That is what I find to be the single most troubling aspect to this. This isn't something I can choose like what kind of drinking water I will be drinking. I can choose whether or not I smoke cigarettes. In this case, I don't have a choice. The bees don't have a choice. The environment doesn't have a choice. The trees don't have a choice. And if we get this wrong and the industry is wrong or is suppressing knowledge, which we have seen before for example in tobacco. We could be screwed, to use a medical term.

Patrick, I think you are on the right track which is saying how do we embrace what we have always embraced in New Hampshire which is our personal choice as well as our personal responsibility and recognize different people's interpretation of what is so far to me is not absolute data and what can we come out of this with in terms of recommendations? I think one recommendation is you are not going to go wrong if your community says, no 5G until we know it's safer but my concern is that we may not be able to do that.

Abrami: There are communities that have said that. It becomes how long does that last before the lawyers catch up with that and the company wins that argument. That's something that we have to consider. Whatever we do we have to be pretty confident that it will cut muster and terms of legal action or legal recommendation. I think there are things we can do to nibble around the edges on this. I think that's what we want to do as a subcommittee is to put some things together that we think might be viable.

Sherman: I also wouldn't try to litigate this in any recommendations. I wouldn't guess where these lawsuits are going to go if a town says no 5G or something like that. I think we can certainly recognize that there is the risk of litigation or some would say with certainty if you try to close the door to 5G. I find that very troubling that an entire community would not have ability to say no to something that has some significant evidence that it may be harmful.

Kelting: How many of you own RF meters? For those of you who believe that RFs are safe, buy a meter and defend its safety based upon what you meter.

Heroux: I can recommend for you a meter, the GQ EMF390 for about $200 you can get an ELF meter that goes to about 10Ghz and also has a frequency analyzer. It is truly a quantum leap in what is available to the consumer. It is made by an American company. It can monitor the fields every second for 24 hours and download it into your computer. So a lot of the measurements you are talking about for protection of housing and buildings become feasible when you have that kind of sophistication available to everyone.

Ricciardi: I wanted to make a couple of comments and thank Senator Sherman because I echo what he is saying. There are a few things we have to remember. We definitely have enough science and evidence to show that things are unclear and unsafe. But if we were to go and say, ok the Telecommunications Act, the FCC has not provided us with proof that is safe. That is the problem. When you are putting 5G in front of people's homes, we have to remember that it doesn't work alone. It has to have 4G with it so essentially you are forcing someone to live in a soup of microwave radiation because the science is there with the 4G. Really, that is unconstitutional.

In addition to that, we are not a town deciding whether we should roll out 5G or not. We are a group of people that have been selected on what is the best thing to do for the state of New Hampshire. It doesn't mean we have to talk about litigation because our job is to make strong recommendations on our findings whether it's agreed upon or not but that's what we have been tasked to do. That's what we have to do. We are making what we find to be an important decision for the state of New Hampshire.

Abrami: Yes. We do but again I still feel that they have to be, I don't want to say reasonable but that would not violate federal law. I think that one of the recommendations may be that our federal legislators need to do more. I think this is something we need to continue to discuss how far we want to go with this.

Woods: I have a technical question. What chance are we going to have to sort of have an executive session? I don't need to get into detail but some things that Paul and I have raised and Ken and Kent as well. I think some of the basic science things need to be reiterated perhaps. Again, we don't know all of the outcomes but if we can provide a little bit of discussion about the real basic science like we talked about proton tunneling. Our presenter brought up the issue of precursors. I think that is an important issue and I don't think people understand what a precursor is but that can have a significant impact from a quantum mechanical perspective. We have done a couple of things. We have brought this down from concern only about the ionizing radiation. We did point it out to one of our presenters no, that doesn't count. You need to talk about the non- ionizing radiation. I think even though we don't have all of the answers, I think we can provide in our report the concerns that we have and point out that there is some basic science at the quantum mechanical level that will support that. That needs to be done because of A, B and C consequences.

Getting back to my original question, are we going to be able to do some exec sessions where we can talk about that among ourselves and flesh out some of these other issues?

Abrami: We can't have exec sessions as a whole. They need to be public. We can meet as subgroups I think up to 50%. I would love to see that actually of the more technical folks in the group. All this information is great. We have gathered a lot of good information that we need to not lose. That should be available in the report to all our communities in New Hampshire. Here are some of the facts that we found so far.

Sherman: I was just thinking that maybe before you start your subcommittees maybe the next Commission meeting could be free discussion among the Commission. There is enough resource here, people with enough knowledge. I have some questions about some of the testimony both today and in the past that I would love to just bounce off other Commission members.

Abrami: Tom, at this point I am not planning on inviting any other guest speakers because I think it's time for us to do exactly what we are talking about here. We have to start talking among ourselves and I see a lot of heads shaking yes. I think that is what we will definitely do next meeting.

Woods: That is sort of what I had in mind when I said exec session. I didn't mean exec per se but what Tom is referring to about having an open discussion.

Sherman: And then the subcommittee could take that and I know there has been some really great feedback from Commission members, great questions, and a lot of information. So having a session where we can distill that down and then the subcommittee can then go get to work. We can get a little clearer from all of us, where each of us is. Pat, I don't know maybe it would make sense for each of us to maybe start out with saying where we are and then have a discussion after that of where we are as a Commission.

Abrami: I think that is a good idea. Assume the next meeting will be two hours of discussion among ourselves about where we are at. Everybody will have a chance to weigh in on their position. I think I have a sense but you never know. Then we talk through what we think the structure of a report will look like, too. I don't want to lose some of the knowledge that we have. The report will include the minutes of these meetings as an attachment. Our minutes are quite extensive. I know when I did the report for the marijuana Commission, that report was 200 pages long with all the attached minutes we had to it. There is a lot of information in those minutes that I think is valuable.

Chamberlin: The reason I go back to relative risk is because with a number of things available to us there is a risk associated that we decide is acceptable. Here is an example: We drive cars and yet we lose 30,000+ people per year with traffic accidents. They die but we consider that to be acceptable. With something like 5G, it will clearly have benefits associated with it. Is the risk relatively low that we can go ahead with it? Or is it such that we can't? That is the one thing that hasn't come out in all the testimony that we have heard. How much of a risk is it? Is it comparable to smoking five packs of cigarettes a day? I don't know. If we are going to get traction with this politically, we need to be able to impose the realism that this is a significant threat or perhaps it isn't. But that's one thing that I haven't yet found out in my reading either. Can anybody shed any light on that?

Woods: To me, there are two parts to the risk. One is the relative risk and the other is exposure to risk. With driving a car, you can take the back roads and stay off the highways but with 5G, you may not have that choice. There is exposure risk vs. personal acceptance risk and that has to be differentiated as well.

Wells: Just a couple of things that Dr. Kelting said today that I wanted to make sure didn't get lost. He talked about disclosure with real estate, etc. and also about RF trespass on my body or on my home. I am thinking there might be a parallel here to 20th century strip mining in Pennsylvania where a farm owner didn't own the mining rights and found himself sitting on a pile of gravel the next day. I am wondering if there is some sort of precedent here that we should be looking at.

Abrami: Herman are you still on with us?

Kelting: Yes. I am here but I am not familiar with strip mining or the case law associated with it.

Abrami: Ken, I am not sure myself but that is a good question though.

Wells: The idea of signal trespass onto my property. Dr. Woods was just talking about whether you can choose to expose yourself to the risk or not. In the case of driving, you can. Whether you decide to smoke or not, you can. But this is more like a second hand smoke kind of thing. You can't protect yourself from it under the current circumstances.

Abrami: the other thing is 5G hasn't really been rolled out extensively yet. The other problem we have with 5G is that it's a marketing concept. Each company, it means something different. Ken, I know we have talked about antennas. What's inside the antenna? How are they configured? I think one thing we can grapple with is how much energy is coming out of the antenna. I think we have boiled it down to that. The FCC standard is set so high that even if we said as a community there would be periodic monitoring of the levels that seems like it's pretty high intensity to have on top of a pole twenty feet off the ground. I think the industry would say no it's not that level of intensity coming out of that but we don't know. A lot of that is proprietary information. We don't know what the intensities are going to be.

One of my thoughts was let's monitor. Let's say a community in agreement with the cellular company says that it should not exceed FCC standards. But those standards are way high. The cellular company shouldn't object to that since they feel that things are safe within the FCC limits. My instinct is that 10 W/m^2 is very high level. As I said before, why did New Zealand set their standards at 5% of our levels? I don't know. Maybe they are just being more cautious. But it makes you think. Why do some countries have totally different standards than our standard? Some would say they are erring on the side of caution as Tom would like to say. Well, how can they get away with their 5G at their standards and we have standards set at 10 W/m^2 ? These are conversations that should be happening at the federal level really. We would love to talk to the FCC. We would love to have them on our zoom meeting right now answering our questions.

Ricciardi: I just asked when you say that FCC says this is safe then why does the Telecommunications Act say health cannot be a consideration? If it's so safe, why would that be in there?? Just a question.

Abrami: and it's a good one.

Kelting: I would like to mention one thing here. For 4G, you could insulate your body with silver embedded cloth. With 5G at the higher frequencies, you will be required to use tin foil only. It will go right through cloth even with silver threads.

Gray: Beam forming is something that I don't know that we have explored very well. It would seem to me that beam forming would cause very short time increases in radiation during the time the beam is formed. But may reduce radiation during times when we are just in monitoring or not in beam forming mode. Things like that are things that are unique to 5G. I don't think we have had sufficient discussions to understand what would happen.

Kelting: When you connect the 5G, if you move your source, it automatically transfers to 4G. So what you are really doing is communicating with 4G in all likelihood. The purpose as I indicated earlier, is that they want to put 4G into residential neighborhoods so they can increase the capacity of the system. It's not to get 5G in there.

Abrami: Help me out here. My understanding is that the 4G cell towers will be communicating with the 5G small cells, is that correct?

Heroux: 5G is an engineering concept that is designed to increase the capacity of the environment to transport data. What industry is really adept at is to transport a lot of data through wireless and essentially with the IOT concept, there is no limit to the opportunities there are to increase the amount of data being transmitted whether you use beam forming or to broadcast it. All of these avenues will be exploited and you will get to the maximum allowed standard ultimately in your environment. This is something that is expected because engineers develop applications in as much as they have the opportunity to do it. What is missing in here is that these agencies like the FCC are essentially blind on impacts on the electro-sensitive people certainly and the other health impacts of this radiation. But the intention of industry is to facilitate communications. Ultimately, wireless is a dead end. It's a little bit like oil because the spectrum is limited and you have to have more and more expensive techniques to transport more and more data. What we should be thinking about is society will need a lot more data. Let's favor optical fiber over wireless because it is not only hygienic, very safe and it has a lot of virtues not being promoted simply because of commercial reasons. Thank you.

Abrami: I just noticed we are getting a lot of chat comments. Kent, is there a way we can save the chat messages?

Chamberlin: Yes. I will save them all.

Abrami: Some of it looks like they will be helpful. There is one that says China and Russia have science-based standards on their evaluation that non thermal effects exist. There standards are certainly set a lot lower than ours. European countries have set precautionary limits. If you can share this with me and I can share it with everybody. There is one on India, which dropped its limits to one tenth of what it was before. Parliament addresses issue of beam forming and measuring issues. There is a report that some of the more technical members are interested in and we can have a discussion around. I guess I am not that much of a Zoom expert. I should have been following some of this chat going on here. We will save it and send it out.

Sherman: on the select committee, we incorporate the chat into our minutes. You may want to do that.

Abrami: We have at least fifty people on and I was told there would be people on from around the country, which is good. Herman. Thank you very much for sharing your information with us. It was very helpful. I want to thank everybody. We are getting applause here from everybody. Again, I wish we didn't have that pause for four and a half months. Got a little rusty here but I think we are back in the groove.

Roberge: Rep Abrami, I have a clarifying question. This was a very helpful discussion. As I sort of prepare for our next meeting on our position and open discussion. I need a little clarity on the charge of the Commission because what I continue to hear and this is a little bit challenging is that 3G/4G and 5G really aren't separate. They are necessary in order for the other to exist. My question is, as we begin to think about recommendations, are we looking strictly at 5G? Is that the charge of the Commission? And how do we differentiate that? That's where I am struggling.

Abrami: Thank you Michele for the question. If you go back to one of our early meetings and it's in the minutes. We early on discovered that you can't talk about 5G without talking about 3G and 4G or RF radiation in general. So, we have to talk about it all. We have learned that you can't uncouple 3/4G from 5G because they do interact with each other. We are going to try to focus on 5G but it's going to spill over to the other technologies as well. Are there any other comments?

Thanks to Kent and UNH. We are using their zoom to hold this meeting. We used your space yesterday too, for a House meeting. Kent and Ken were you there yesterday? I couldn't find you. Maybe I didn't look hard enough.

Woods: Yes. I was here.

Wells: I was wearing a mask. It was hard to recognize me.

<u>V. Zoom Chat from 7-1-20 Commission meeting</u>:

00:26:12 Ken Wells: Does NH have any recourse to Communications Act of 1995 insistence that municipalities and states cannot prohibit installation of antennas?

00:35:28 Ken Wells: Meeting again July 24 @9am via Zoom

01:22:30 EH Trust: I think the case is this: https://ehtrust.org/federal-court-overturns-fcc-order-which-bypassed-environmental-review-for-5g-small-cell-wireless/

01:23:08 EH Trust: Here is the link to the case decision https://www.cadc.uscourts.gov/internet/opinions.nsf/4001BED4E8A6A29685258451005085C7/$file/18-1129-1801375.pdf

01:49:22 Ken Wells: GQ EMF390

01:49:45 Ken Wells: RF meter

01:57:10 Bruce L. Cragin, PhD: You just don't want to hear from any more physicists!

01:59:12	Paul Heroux, Dr.:	I am amazed that we could not get the FCC to appear.

02:00:09	Bruce L. Cragin, PhD:	More good sense. Thanks for that.

02:00:59	EH Trust:	The FDA should do a risk analysis f this type but has refused. Dr. Melnick states this should be done https://ehtrust.org/statement-by-ronald-melnick-phd-on-the-national-toxicology-program-final-reports-on-cell-phone-radiation/

02:01:34	EH Trust:	“A quantitative risk assessment of the data from the NTP studies on cell phone radiofrequency radiation needs to be performed by the FDA and that information should be used by the FCC to develop health-protective exposure standards. In fact, it was the FDA that nominated cell phone radiofrequency radiation to the NTP, and I quote “to provide the basis to assess the risk to human health of wireless communication devices.” Therefore, I urge the FDA to immediately conduct the risk assessment of the NTP data."

02:04:06	EH Trust:	Plus there should be an assessment of the impact to birds bees and trees but none has been done. There is no health agency tasked to evaluate and develop a federal safety standard regarding impacts to trees, bees and birds. It is a gap

02:06:01	EH Trust:	Montgomery county - Maryland did monitoring and found FCC limits were breeched until 10 feet around the antenna facility.

02:06:34	EH Trust:	China and Russia have science based limits based on their evaluation. That non thermal effects exist.

02:07:15	lori:	State Law 12’K:11 e) needs to be amended to allow testing and monitoring of RF . How can we even know if the FCC standards are being met without monitoring, sampling and testing

02:08:10	EH Trust:	Several European countries have set “precautionary” limits . I have these details. And some of the documentation can be found here https://ehtrust.org/policy/international-policy-actions-on-wireless/

02:08:51	EH Trust:	China- https://web.archive.org/web/20120413171654/http://www.salzburg.gv.at/Proceedings_(20)_Chiang.pdf

02:09:09	EH Trust:	Russia- https://www.researchgate.net/publication/228104887_Scientific_basis_for_the_Soviet_and_Russian_radiofrequency_standards_for_the_general_public

02:10:23	EH Trust:	India dropped their limits to 1/10 th pf what it was before because of this report https://ecfsapi.fcc.gov/file/7520958381.pdf

02:10:29	EH Trust:	asI understand it

02:11:04 EH Trust: India published their findings as detailed here https://ecfsapi.fcc.gov/file/7520943486.pdf

02:12:14 EH Trust: European Parliament reports adress the issue of beam forming and measuring issues in this report https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/646172/EPRS_BRI(2020)646172_EN.pdf?fbclid=IwAR3cD0TDOqGHpOmCWPnANN-Y6RBaa0eoQ4ZN0nuUwpVaLL8MIDtt6aKtiYM

02:13:57 Bruce L. Cragin, PhD: Don't confuse legislation with science!

02:14:11 EH Trust: European Report here also https://www.europarl.europa.eu/RegData/etudes/IDAN/2019/631060/IPOL_IDA(2019)631060_EN.pdf

02:15:22 EH Trust: According to Belyaev 2019, "the health effects of chronic MMW exposures may be more significant than for any other frequency range." The abstract states that, " Various responses to non-thermal microwaves (MW) from mobile communication including adverse health effects related to electrohypersensitivity, cancer risks, neurological effects, and reproductive impacts have been reported while some studies reported no such effects. According to Belyaev 2019, "the health effects of chronic MMW exposures may be more significant than for any other frequency range." The abstract states that, " Various responses to non-thermal microwaves (MW) from mobile communication including adverse health effects related to electrohypersensitivity, cancer risks, neurological effects, and reproductive impacts have been reported while some studies reported no such effects.

02:15:36 lori: Thank you for all your work

02:16:59 EH Trust: Brillouin precursors can be formed by high-speed data signal as Microwave News 2002 pointed out "Introducing Brillouin Precursors: Microwave Radiation Runs Deep." When a very fast pulse of radiation enters the human body, it generates a burst of energy that can travel much deeper than predicted by conventional models. This induced radiation pulse, known as a Brillouin precursor. Brillouin precursors can also be formed by ultrawideband radiation and, in the near future, by high-speed data signals." The 2002 Microwave News article discusses the controversy over the Pave Paws radar system which used phased array radiation. In 5G communication systems, the phased-array antenna is one of the lead front-end components. https://microwavenews.com/news/backissues/m-a02issue.pdf

02:17:29 EH Trust: ""When a very fast pulse of radiation enters the human body, it generates a burst of energy that can travel much deeper than predicted by conventional models (Oughstun 2017). This induced radiation pulse is known as a Brillouin precursor. Brillouin precursors can be formed by ultrawideband radiation and by high-speed data signals as used in 5G."found in https://ieeexplore.ieee.org/document/9002324

02:18:29 Augustinus.Ong: Thanks for the meeting.

VI. Important questions need to be answered for NH 5G Commission:

(Questions included in the minutes sent by D. Ricciardi to FDA and FCC)

From: "Shuren, Jeff" <Jeff.Shuren@fda.hhs.gov>
Date: June 24, 2020 at 4:28:49 PM EDT
To: Denise Ricciardi <dricciardi@bedfordnh.org>
Cc: OC Ombudsman <Ombuds@OC.FDA.GOV>, Patrick Abrami <abrami.nhrep@gmail.com>
Subject: RE: Important questions NEED to be answered for N.H. 5G health task commission

[External]

Dear Ms. Ricciardi,

Thank you for reaching out to me. I have forwarded your questions to the FDA's Intergovernmental Affairs Staff who handles inquiries from State and local governments. I have included Karen Meister, their Acting Director, on this email, as well.

Best regards,

Jeff

-----Original Message-----
From: Denise Ricciardi <dricciardi@bedfordnh.org>
Sent: Tuesday, June 23, 2020 10:38 PM
To: Shuren, Jeff <Jeff.Shuren@fda.hhs.gov>
Cc: OC Ombudsman <Ombuds@OC.FDA.GOV>; Patrick Abrami <abrami.nhrep@gmail.com>
Subject: Important questions NEED to be answered for N.H. 5G health task commission

Dear Dr. Shuren,

We would appreciate an answer to these questions regarding cell phone radiation. If you could number them one by one it would help with clarity of your response.

Regarding the FDAs report "Review of Published Literature between 2008 and 2018 of Relevance to Radiofrequency Radiation and Cancer<https://www.fda.gov/media/135043/download<https://www.fda.gov/media/135043/download>>

1. Why did the FDA only focus on cancer as a health effect?

1. The FDA said of the National Toxicology Program findings that the FDA was unsure if the tumors were a causal effect or if these results were "due to weakening of the immune response due to animal stress from

cyclic heating and thermoregulation"Does the FDA think that cancer could be an effect of whole body heating, that cancer is a thermally induced effect? If so, what other studies show that heating causes cancer?

1. Did the FDA review in a systematic way the research on impacts to the nervous system?

1. At the Commission, a study on how millimeter waves interact with insects was discussed. Did the FDA review in a systematic way the research on impact to bees, insects and pollinators?

2. Did the FDA review in a systematic way the research on impact to trees and plants?

1. Did the FDA review in a systematic way the research on impact to birds.

1. If the FDA did not investigate impacts to insects or trees, what US agencies have done so?

2. The FDA website page Scientific Evidence for Cell Phone Safety<https://www.fda.gov/radiation-emitting-products/cell-phones/scientific-evidence-cell-phone-safety<https://www.fda.gov/radiation-emitting-products/cell-phones/scientific-evidence-cell-phone-safety>> has a section entitled "No New implications for 5G". Does the FDA believe that 5g is safe or that 5G has the same health issues as 3 and 4G ? What is the FDA opinion on the safety of wireless?

1. What is the FDA opinion on FCC limits in terms of long term health effects. Does the FDA believe the current limits protect the public, children, pregnant women and medically vulnerable from health effects after long term exposure.

1. The FDA is aware that cell phone can violate FCC SAR limits at body contact on high power. The FDA has written that because there is a safety factor. What is the safety factor for the SAR the FDA relies on. At what SAR level above FCC limits will the FDA intervene?

1. What actions specifically is the FDA doing now in regards to 5G and cell phone radiation in terms of research review? How often will the FDA be releasing reports?

1. Will the FDA be evaluating the safety of 5G cell antennas? If so how? If not, what health agency is ensuring that 5G cell antennas are safe for people, wildlife and trees.

2. Cell phones and wireless devices emit several types of non ionizing radiation in addition to radiofrequency radiation. For example the devices emit magnetic fields and when a pregnant woman holds a laptop on her lap the measured fields can be high even into the baby. What agency ensures safety

related to extremely low frequency (ELF-EMF) electromagnetic fields- also non ionizing? Currently we have no federal limit, no federal guidelines and confirmed associations with cancer and many other health effects. Kaiser Permanente researchers have published several studies linking pregnant women's exposure to magnetic field electromagnetic fields to not only increased miscarriage<https://www.nature.com/articles/s41598-017-16623-8<https://www.nature.com/articles/s41598-017-16623-8>> and but also increased ADHD<https://jamanetwork.com/journals/jamanetworkopen/fullarticle/2763232<https://jamanetwork.com/journals/jamanetworkopen/fullarticle/2763232>>, obesity<https://www.nature.com/articles/srep00540<https://www.nature.com/articles/srep00540>> and asthma<https://jamanetwork.com/journals/jamapediatrics/fullarticle/1107612<https://jamanetwork.com/journals/jamapediatrics/fullarticle/1107612>> in the woman's prenatally exposed children. A recent large scale study <https://www.sciencedirect.com/science/article/pii/S0013935120303662?fbclid=IwAR11X_74FIT7y_RpO9WvbkE8AmAlBHAVU67yjKW8A6ZWPnPsLRioLxGsy1o#<https://www.sciencedirect.com/science/article/pii/S0013935120303662?fbclid=IwAR11X_74FIT7y_RpO9WvbkE8AmAlBHAVU67yjKW8A6ZWPnPsLRioLxGsy1o#>> again found associations with cancer. Please clarify which US agency has jurisdiction over ELF-EMF exposures?

1. Will the FDA be initiating any research studies on 5G and health effects?

We As a health study commission on 5G/ take these duties very seriously. We are unbiased and we are seeking all answers And facts. We are requiring your answers to the above questions.

Thank you,
Denise Ricciardi
Committee Member appointed by Governor Sununu.

The Right to Know Law (RSA 91-A) provides that Town email communications regarding the business of the Town of Bedford are governmental records which may be available to the public upon request. Therefore, this email communication may be subject to public disclosure.

V. Next meeting via Zoom: July 24th 9-11

Meeting Adjourned at 3:02 pm.

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS OF EVOLVING 5G TECHNOLOGY

Meeting held:
7/24/20
9:00-11:00 am EST
Via Zoom (https://unh.zoom.us/j/93912769762)
Via telephone-US (+1 646 876 9923) ID: 939 1276 9762

In attendance: (12)
Rep. Patrick Abrami-speaker of the house appointee
Rep. Ken Wells- speaker of the house appointee
Kent Chamberlin-UNH-appointed by the chancellor
Denise Ricciardi-public-appointed by the governor
Michele Roberge-DHHS- Commissioner of DHHS appointee
Dr. Paul Heroux- Professor of Toxicology, McGill University- speaker of the house appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee
Senator Tom Sherman-president of the senate appointee
Brandon Garod-AG designee, Asst. AG Consumer Protection
Bethanne Cooley-CTIA , trade association for wireless industry and manufacturers
Carol Miller-NH Business & Economic Affairs Dept

Not present: (1)
David Juvet-Business and Industry Association
.

Meeting called to order by Rep Abrami at 9:03 am

Abrami: For the sake of time, I am going to open the meeting. This is the New Hampshire Commission to Study the Environmental and Health effects of evolving 5G technology. I have a short version of something I have to say. Due to the Covid 19 virus and the Executive order signed by the Governor this public meeting is allowed to be conducted via Zoom. It is open to the public for viewing and was duly posted as a zoom meeting. With that said, if you are not a member of the Commission, can you please turn your cameras off and mute yourselves? That would be much appreciated.

I. Approval of minutes from 7-1-20:

The first order of business is the minutes. I sent them out about a week ago. By the way, Deb you did a great job of compiling them once again. I did get an email from Michelle asking for two corrections. I think we misunderstood for Augustus Ong, listed under attendees. Michelle was in attendance. Also, on page 29, “this was a very helpful discussion”. Those are the changes that I have gotten so far. Were there any other changes? So without objection, the minutes are approved as amended.

II: Around the table member thoughts:

Abrami: The first thing we are going to do today is go around the room. The zoom room if you will. What we would like to do is talk about where we are at and the kind of recommendations, possibly that we would like to see in the report and where you stand on the whole issue. I am envisioning the room as it was at the State House and will go to my left. That means, Tom you are up first. Again, it's a general discussion and your thoughts as to where we are at and what we should be doing.

Sherman: Thank you, Patrick. I think I said it and it was in the minutes from last time. My overriding thoughts on this are that there is enough evidence to raise concern but I'm not sure there is enough evidence to show causation between exposure and specific health impacts. So, what the means to me is that there is more than ample evidence that a non-biased large scale study or studies needs to be done to demonstrate that we are not going to be implementing an entire system of communications that would put either human health or the environment at risk. I think of the Precautionary Principle. I also recognize we have several other examples where industries have said to us, this is safe. I can think of my own profession where we used to say, "Trust me. I'm a doctor".

I think we all know that phrase, trust by verify is the very least where we need to be. In this case, there is ample distrust because the Commission has already seen the amount of industry influence on the regulatory bodies. By the way, that's nothing new in Washington, DC or in some states. When I was in Virginia, our entire oversight for agriculture was from people who had formerly been in the industry. So when you think of some of the chemicals like glyphosate, people from the industry were regulating the industry and we know where that gets us.

My overriding New Hampshire response to this is, I would like to see the ability of communities to control their environment until such a time that an independent, scientifically based study or studies have been done to demonstrate the safety of this technology. I think that is consistent with Precautionary Principle of public health. I think it is consistent with the way many of us in New Hampshire view our personal freedom. And I don't believe we have ever been shown a compelling need to, right at this moment, on an urgent basis, implement 5G technology. I guess that's my summary statement.

My plea would be to have to start working on these studies and to ask our federal delegation, as they've done with PFAS, to start looking at where there has been exposure and what has been the impact. And start funding some of these studies at a federal level outside of the different regulatory agencies. I was really impressed by the consistency of response or I guess the consistent lack of response from the EPA and the FDA. It's amazing to me, that they seem to not want to respond even to a statutory state commission. So, I guess I'll close by saying the parallels to other exposures that we have, are really clear. And the lessons that we've learned from something like PFAS, where a few years ago, I started working on PFAS back in 2014. The industry knew about those dangers from the 1950s. They continued to profit with manufacture until at least 2003 when DuPont pulled out. 3m continues to and at this point, we have over a 100 communities and/or water systems in the state impacted and those are just public systems. Now we're playing catch up. But at the exact same time this week coming out and Lancet are two, scientific articles looking at the data on PFAS and broadening the concern to diabetes, obesity, breast cancer. None of which, we have talked about on our way through this. So here we have an opportunity before the industry has an ability to expose us. To say, let's put the brakes on, let's get the data. You show us that it's safe in independent studies, not funded by you, but funded by an independent body and overseen by an independent body. And then we can move forward together to implement this new technology. That's my feeling I and thank you for the opportunity.

Abrami: Thanks Tom. I forgot to mention that once we're done with the round table, I'm going to ask Denise to just briefly discuss our non-response from the FDA in relation to the FCC. That is a discussion that we need to have. The other thing is that this meeting is being recorded, so everybody knows, It’s pretty much for the ease of doing our minutes at the end for Deb. And that, any chat room discussions that are going on will become part of the minutes. We did make them part of the minutes from last meeting. Ok. Let's continue around the room here.

Wells: Yes. Thank you. In looking over the materials that we were previewing for this meeting, I came up with a number of recommendations, about seven of them. And it seems to me, that there are three levels of issues here. One is *general RF* radiation from Wi-Fi, 5G and all that. Then there *specifically 5G* and then on top of that, and I would give it the highest priority is the 5G *small cell antenna network*, which I think poses particular hazards. And I think that we should explore ways that New Hampshire can take unilateral action to protect our population, our environment, our forestry industry, and also supply the fastest broadband and communications to our population. I have a couple of things that I think would be worthwhile here. If this type of technology is to be developed, the state of New Hampshire could require that installers and owners of these systems carry enough insurance to cover the potential claims of New Hampshire residents who are exposed. We should require also insurance to compensate based on potential losses in the forestry industry, agriculture, hive losses, etc. Here’s another separate issue. It occurs to me there's a parallel here with 5G and the mining rights in coal country where farmers found that they didn't own the rights to the mineral below them and their farms were turned into strips of gravel. I think it's a private property and liberty issue.

Broadcasters must be specifically granted rights for their signal to intrude on private property. And if they don't have those rights, they must not do that. Senator Sherman mentioned the problem that many of the studies, clearly there are conflicts of interest. I think that, that following the example of Jersey City and some others where they there's been a moratorium placed until, say, a UNH study is completed when that is not funded by industry, but where there's a demonstrable freedom from conflicts of interest.

Abrami: I guess there is some debate on whether Jersey City moratorium is in place or not.

Wells: Yes. I understand. I saw the petition that was circulated as a possible model. Then I wonder if the state of New Hampshire can impose its own maximum intensity limits and require that equipment have an accessible off switch if they're found to be out of compliance. And with that, I think I'll conclude my remarks and listen to what others have to say.

Abrami: Okay. That's very good, Ken. Thank you. There are some good points from both you and Tom so far.

Chamberlin: So as I listen to the previous two speakers, I'm in agreement. I echo their concerns. And essentially Sherman in particular, what you had to say is very much along the lines of what I feel both what you said just now and what's in the minutes. My belief is that we have a serious issue with exposure. The scientific data is pretty overwhelming. Although those data, the data is, is being completely ignored by the regulatory bodies. And that's kind of the elephant in the room here is we have a regulatory body that says that these standards set 30 to 50 years ago are acceptable. Yet the evidence, scientific evidence suggests that it's not. So that clearly is something that we have to address, explicitly in whatever report we have. Other issues, is the yes, we can ask for things like insurance. We can mandate that the providers have insurance to cover any issues that may come about as a result of this. The property rights, is also a good angle also.

But at this point, I don't feel like I need to see any more scientific evidence. I'm pretty convinced. Since I got on this, I'd been reading article after article and that's pretty convincing that yes, there's a problem. The one thing that we don't know that would be nice to know is the degree of risk. How much risk do you encounter by having a cell phone? being near a cell phone tower? We need to, to get that. And I think that we can and we should pursue something like a moratorium until we figure out and get answers to some of these very important questions.

As was pointed out earlier, this is not new. We have seen these types of issues. That is where industry just says it's no problem. This won't hurt you. We've seen that from smoking doctors, from the tobacco industry. We've seen from the fossil fuel industry dealing with things like climate change, which they knew 50 years ago that this would have an impact. So we keep seeing this pattern again and again. And what happens is that the industry makes an investment before we're able to find out or to demonstrate that whatever they're investing in, causes problems. And once they've made the investment, it's kind of hard to turn back, but I think that we have this opportunity now to just move forward to come up with moratorium so that they won't invest they won't get too much of an investment, won't get ahead of the curve as it were, before we figure out how much of a risk this imposes. Thank you.

Abrami: Thank you, Kent. Good points.

Ricciardi: I, too concur with everyone who has spoken. I think the one thing we can agree on all of us is that whether some of us believe it's unsafe and maybe some of us are uncertain. I think the biggest thing we can agree on is that there's a lot of disagreement in the scientific community. I feel that the science that we have seen and the evidence that has been brought before us and all of the materials we've been reading and speakers we've been listening to. I am convinced have a serious issue. And I really believe that it will harmful to just put this out. And I think we have to put stipulation on how things should be. I feel that the state could impose mandatory hard wiring for technology. In the meantime, continuing studies that are real studies. We're having a problem with the FCC. They haven't changed anything after all these years. It's a captive agency. They are a non- health agency. I made some notes. We could as a suggestion, call for a halt to 5G and its infrastructure until RF limit has been set by federal health and safety agencies. There is no health agency overseeing any of this.

Again, state could call for wired infrastructure which is safe, and actually is faster. Not only that, it's safer in the ability to not be hacked. So, there are many measures there. We can call a halt until the scientists determine how the adequate methods of measuring should be. We can also pass bills that support further research for transparency and education on 5G and wireless devices to be used in the Internet of Things. In my opinion, it would be completely irresponsible for this commission to just blindly roll this out with all the compelling evidence. I don't want us to be like the PFAS or the tobacco industry. And there are some huge differences with this than anything else. If this is put in front of every other home, you are now robbed of your choice. You know, if you don't want to use a cellphone, you don't have to use a cellphone. If you don't want to live near a tower, you can look to where you want to live. This robs you of your choice. And that goes against our New Hampshire constitution. I have a full report on all of this, but that's sort of the gist of it. Do you want me to go right into segue into the questions that I've sent to the FCC and the FDA, or do that at the end?

Abrami: Why don’t we do that at the end? I've got Carol Miller next.

Miller: Morning everyone. Here are my thoughts on this… I mean, the science is the science whether it's true or false, it's overwhelming. Every article that I've read, it's just overwhelming. But having said all of that, RF is RF. We've RF with 4G, 3G, Wi-Fi, whatever you name we have RF in our lives. And there are people who are sensitive to RF. And depending on the degree of RF they're getting it could cause the health issues or whatnot. We have some big challenges ahead of us. Cell services not regulated at the state level. It's regulated at the federal level. So I'm not sure that towns in the state can dictate anything to the Cell carriers. There are strict rules in place and we could be setting ourselves up for major lawsuits. So that's where some of my concern goes.

My recommendations really are more practical. And I agree with everyone else's recommendations that have been said so far. What can the industry itself, due to its devices and to its antennas and its system, to reduce the effects of RF to the public? Is there a technology that can do that shielding in phones that that creates less RF to the individual? And, and I think, it could be a costly solution for the industry. But if we're going to have any effect by, I think that that's where we really need to focus our efforts, along with all the other recommendations. Yes. Let's study it. I mean, it has been studied. We need to study it. Can towns literally put a moratorium on it? I don't know. Can the state say that everybody has to have a wired connection? I don't think so. So what we need to do is look at things that can be accomplished and through this committee, get that information out there. And I'll close my comments.

Abrami: Somewhere along the line over the over the years a left turn was taken. We were heading on the journey to fiber optics. And then then now we got, you know, the evolution of 5G. And we know fiber optics is actually more robust. They carry more information and they're less likely to be hacked if you will.

Miller: yeah, but that doesn’t solve mobility problems. That's the lore that cell cellular coverage is. It’s the ability to have your phone on you and your data anywhere any time. But that does not mean to say that fiber isn't important. Fiber is the infrastructure of the future and where New Hampshire should be funneling any investments, or all investments, right? (I like the thumbs up) to fiber connectivity and stop putting band-aids on a sagging telecommunications infrastructure. I have very strong feelings about that. But cellular is a different creature altogether. It actually needs fiber to be able to transport data. e Everything comes into the wired network, even by cellular. So it's the mobility, the ease of use, it's the instant connection, instant reach ability that the mobile industry has captured. And so therefore, there needs to be some work on their part to abate all of this RF bubbling to the surface. And, you know, I agree with everyone else, but I just wanted to offer a practical solution or I guess sound check to what we're actually doing here.

Abrami: Thank you Carol. Beth Cooley, you are up.

Cooley: Alright, can you see me? Hear me? I am having some issues.

Abrami: I like those things behind you. Looks like Star Trek.

Cooley: Yes. I am in outer-space. Well, good morning everyone. I appreciate the opportunity to provide our thoughts at this point in time. You know, in terms of recommendations at this point, my thoughts are, I think we need more experts because everyone has been anti 5G at this point. And in fact, some of the "experts", their research on this topic has been called "junk science", quote-unquote. So my first recommendation and Rep. Abrami, you and I talked about this before the pandemic is Dr. Swanson didn't get to finish his presentation back in November. So I'm sure he'd be happy to answer questions because he ran out of time. I understand some folks may not agree with his point of view. But I think Rep Abrami, you and I discussed offline that we want a balanced approach to this commission. So that's sort of point one in terms of the experts in the science. I think the other side has some questionable credentials. Second, I think it would be helpful. We sent around, I think maybe three weeks ago, a recent study from the radiation safety journal on 5G a new study. I think it would be helpful to hear from the authors of that as well. And Rep Abrami, if you're open to it, I'd be happy to see if we can do some outreach to those authors. And that's sort of my first recommendation on the on the expert side.

I'm the first to admit I'm not an expert. CTIA is not an expert. We defer to those that are. We think we need to hear from the people that are smarter than us.

Abrami: Beth, I've always said to you, I'm open to hearing from all sides. And you gave us Dr. Swanson and he was sort of out of time, but we could probably dedicate some time more or any other experts that you may have.

Cooley: Yeah, that would be great Rep Abrami. And I want to say they're not, you know, industry experts. They're speaking their thoughts, their research. So I'd be happy to do that outreach.

The only other item I'd like to raise that I'm not sure that we've talked about. I think it's been distributed. But it's important to note that other states have done this. They've done the research and even your neighbors in Vermont and Connecticut have done this. And I think it's important to look at those recommendations. Other states like Louisiana, Oregon, Hawaii have also done reports on this as well. So I believe some of those have been distributed, but I don't think we've talked about them. I know there have been a lot of things distributed into this group in terms of articles and studies. So I'd just like to highlight that other states are doing this too. And rather than re-invent the wheel, I think it would be helpful to look at what they looked at.

Those are sort of my two recommendations at this point in time. I appreciate a given me the opportunity.

Abrami: Well, Beth, if you have any documents from these other states that you could share with us, that would be fine.

Cooley: Absolutely.

Abrami: Okay. Well, thank you.

Ricciardi: Can I interject to make a comment?

Abrami: Yes.

Ricciardi: Okay. Since Beth did bring that up, I actually have in front of me what other states have done. And she referenced Hawaii. I can send this link out to everyone. Hawaii county planning board passed a resolution to halt 5G. Farragut,Tennessee has a resolution calling on state and federal governments to halt 5G until health risks are evaluated. The Washington DC advisory 3G/ 4G committee resolution opposing small cell wireless and 5G technology, wants studies confirming safety. I have a whole list here that does speak to what Beth just said. I'll make sure that committee gets that.

Cooley: Yeah, Denise, I think that's a good point to look at what other states have done, but I think it's important to understand the context. For example, in Hawaii county, the council passed the resolution this week. It's a nonbinding resolution. As you well know, it is illegal to stop infrastructure at the state and local level on the basis of RF, as that is regulated at the federal level. So the Hawaii county resolution that was passed is non-binding, and I believe Rep Abrami sent out our comments when it was before the planning board a few weeks ago.

Abrami: Yes I sent it out and I also want to know if theses have teeth or not. That's the question, you know, in the legislature we do resolutions to Congress and to the federal government but they're not binding to anybody other than it's a statement of a position. In this case, we have a commission that that's looked at this very closely. And that is a bit different than some of these other commissions from other states. I would say we have more technically minded people on this commission and then some of these other states may have, you may know more than I do about that Beth. Tom has his hand up.

Sherman: But I just have a quick question for Beth, you used the term “junk science”. I was wondering which science you were referring to when you called some science “junk science”.

Cooley: So this wasn't a quote from me. Another scientist called one of our previous speakers, research on cell phone RF issues, “junk science”.

Abrami: Okay. Thank you. Okay, we will move on now. Brandon Garod.

Garod: It's Brandon, that's ok. It's a very common mistake. So I am a little bit leery at this point of continuing to hear from experts on either side because I think that we could call experts for the rest of the Commission. I think we there is a difference of opinion. Some people think it's safe. Some people think it's not safe. I think there is enough evidence to suggest that it might not be safe that we should as a commission, have an obligation to flag that for the state. And you I don't think that hearing from more experts is going to move us in one direction or the other in terms of a commission deciding definitively yes, this is safe or no, this isn't safe. I think that there is some evidence it is not safe.

It is not, in my opinion, a foregone conclusion that this is definitely not safe, but if there is evidence to suggest that it might not be safe, I think that it is important that it is thoroughly vetted and tested before there's an enormous roll out in the state. And I think that's even more important, echoing what Senator Sherman said at the beginning, which is that there really in my opinion, does not seem to be immediate compelling need to have 5G in the state of New Hampshire at this point. My cell phone works great, almost anywhere I am. I can get on Wi-Fi, almost anywhere I am. We're able to meet as a commission remotely. We're able to do our jobs remotely. I'm not sure what the benefit is of having 5G if it's not thoroughly vetted and tested and confirmed, definitively, to be safe before it's rolled out. It would be great. You know, the faster things are, the better things work. Obviously, it's better for us moving forward technologically as a society. But at this current juncture, I don't see an immediate compelling need. I think that it's clear as a commission that we have some evidence that it's safe and some evidence that it's not. And now it turns to, you know, what are we as a Commission going to do in order to fulfill the task that we've been given as a commission, which is to make a recommendation.

And that's where I really struggle. Because like others have said, you know, I'm I think I'm the only lawyer on this commission. I spent some time doing some legal research yesterday and in anticipation of today's meeting. The Telecommunications Act of 1996 is very clear. The state cannot pass a law or regulation that prohibits the telecommunications infrastructure from coming into the state. It is preempted. It's completely regulated by the federal government. There's a carve-out for public health and safety but that is limited because there's a lot of litigation that has come from that in terms of whether that only applies to the state, or whether that can be attributed to local government as well, towns and municipalities. And overwhelmingly, for the most part, it's only the state that can pass a resolution that directly correlates to protecting the health and public safety. I don't think that the science is there in order for us to pass any sort of law that would prohibit or inhibit 5G, in order to say that it is in a direct correlation to protecting the health and wellness of citizens of New Hampshire. Any sort of recommendation that is passing a law or passing a regulation or a barrier to entry is going to be heavily, heavily litigated. And you know, whether it's successful or not, as, you know, is always an open question. But I think that to the extent that we decide to recommend any sort of legal barrier, we need to be prepared for that. That's going to result in a very long drawn-out legal battle.

I do certainly support any recommendations that we can make that are not likely to lead to extensive litigation that we may not have a leg to stand on. I think that the public needs to be made aware of the findings of this commission. I think that there needs to be more public awareness about the issues. And I think the people in New Hampshire have a right to know about the science and about the studies that have been done. Anything we can do as a commission to increase public awareness even if it is like the Hawaii resolution. Yes, it's non-binding. But it’s something. It's at least the community saying, yes, we have concerns about this. And this is what we're going to do to take the steps that we can in order to make people aware and to do our part to say that we as a community have concerns. And I think that is probably the sort of recommendations that we need to be looking at moving forward as a commission.

Abrami: Ok Brandon, that’s great. When I speak at the end, I want you to react to one of the things I am going to say whether we even think it has potential of being a legal issue. So thank you. Michelle Roberge.

Roberge: I represent the department of Health and Human Services on this commission. We feel, where this is regulated at the federal level, that certainly more work needs to be done at the federal level to ensure that the standards are protective of public health. We know that the standard haven't been reviewed for a number of years. We know that there are a lot of studies that have come out and certainly more studies that we've heard, and what we're learning from this commission. More robust studies need to be done to ensure that they are protective of public health.

So we really need to make sure that at the federal level those agencies that include FCC, FDA, EPA really need to look at the science. I know there was a recent publication put out by FDA, I think it was in February 2020. They did look at number studies but didn’t move forward with a standard review but again, more support of looking at those studies where they are not just looking at heat, but they're looking at other biological effect as well. The department at that point is supportive of that. And that's where we stand at this point. And I know there's other recommendations that are coming forth and that would be something we'd have to reevaluate as we pull the report together.

And I know Representative Abrami and I shared in an email that where we are, our role in this commission depending upon what recommendations that come out, being an executive agency put us in a conflict of interest situation if the legislature tries to implement any of the these, we essentially could be the body or agency that regulating it. We have to be careful of conflicts of interest. We definitely agree that more needs to be done at the federal level where it is regulated.

Abrami: I did respond back to Michelle's request or query about specific recommendations. And given that Michelle's representing the Department of Health and Human Services, there's concern whether that's an official position of Health and Human Services. When I chaired the marijuana Commission, we had a disclaimer that the recommendations in the report don’t necessarily reflect the position of certain state agencies. So, I'll share that language with everybody down the road. We can take a look at that. And that's a problem with a commission when you have State agencies on them. They're between a rock and a hard place. That will go for the AG’s office as well. They have to be careful. Their input is very valuable but it gets a little bit sticky once there are recommendations being made. Okay. Dr. Heroux.

Heroux: Yes. Thank you very much for the opportunity. I am going to propose some strong measures, but I realized that we have to avoid conflict with the FCC. I also realize that the measures have to be low cost and potentially reversible as well. So I think of this in terms of protecting various populations. So first, to protect people from radiation from portable phones, I think that we should make it a law that cell phones do not work when they are held against the head, in other words using the proximity sensor. This is a simple alteration in software that when you put your phone against the head, it stops radiating. That means that you'd have to use your phone in front of you. So it doesn't change at all the functionality of the phone, but it practically eliminates the strong radiation to the brain. When you consider that the cost of assessing this SAR is from $50 to $200 thousand per phone. You eliminate a whole area of conflict. Of course, industry is not very eager for this because it reduces emphasis on the issue of heat from cell phones. But you maintain functionality. It's a very simple alteration. These sensors are already there and you eliminate connections with glioblastoma or auditory tumors. So that's one thing.

Now, to protect people from radiation from base stations, without making any comment on levels of radiation, I think that a 500 meter hold back and there was a distance should be should be that much. If you can deploy 5G with that kind of hold back, you know, fine. But we have data that shows that proximity to these towers is a health risk.

Thirdly, to protect young children, I think we should adopt the same measures that were adopted just a week ago in Russia in relation to wiring schools, limiting strongly the use of wireless, and forbidding the installation of base stations near schools. This is something that they have concluded to be a good idea on the basis of their most recent evidence.

Then to protect electro sensitive people, I think that we have to take measures that give them recourse, in terms of protecting themselves. I think that we should maybe train a few physicians in New Hampshire to become expert in this area so that they can confirm that some people are electro sensitive. And when they are confirmed, they would be entitled to some form of protection.

Lastly, it would be a good idea to protect citizens and businessmen because if in the future radiation becomes a stronger issue than before, some people who buy property might not be aware of the radiation levels on the property that they are buying. And they may face big losses as a result of this ignorance. So probably in New Hampshire, you already have specialists who are capable of assessing radiation. Maybe there should be some sort of framework that would make it practical for these people to give information on the levels of radiation in various places when there are transactions occurring. And in this way, you could build a picture of exposure in the state, as well as give these businessmen some form of protection. Thank you very much.

Abrami: Thank you, Paul. And Senator Gray.

Gray: morning. I am old enough to remember back in the late fifties when there was a big to do about high tension power line and cows that would be grazing underneath the high-tension lines. Since then, you know, we've done lots of studies on lots of different things dealing with the electro- magnetic radiation. Part of what's going on here, in my opinion, is that we have created a fear. People don't like change. And certainly if you have a fear of getting cancer, that is going to create strong emotion in various people.

I'm not saying that there are not people out there who are hypersensitive to RF. I am not saying there is no problem with RF. I'm saying that most of the data out there that we see needs a good peer review. And in some cases, those peer reviews that have been conducted, have pointed out flaws in that data.

There is a big problem when I hear, well, gee, the industry paid for a particular study and therefore that study should be discounted. I don't believe that to be, you know, what should happen. Like any other study, whether the industry pays for it or does not pay for it, it, you'd be peer-reviewed. And the results of those peer reviews would tell you whether or not there is validity in the study, whether this study should be questioned further on that. We don't have, and the studies that I've seen, and there's not that many good scientific studies out there. That is, a lot of these articles that we've seen go back and reference either the same studies or they are redone.

Let's go back. It's the fear of change that tends to make us believe that there is a bigger problem out there than I believe that there is. Having the ability, if I own a piece of property and say, you can't generate any RF signal that's going to come across my property, that's just never going to happen. Okay? That's like saying you can't use perfume when the wind is blowing across my property because of the smell the perfume. I mean, this borders on the absurd.

The photo that we saw with the tree and half of the foliage being gone and the cell tower there, I want to tell you that that there was a new cell tower put up and there were two trees next to each other. One of those trees had to be removed for the cell tower to operate properly. And you know what? It looked very much like the picture that we saw. So, you know, a lot of this information I would claim is anecdotal at best. The information needs a good peer review.

Right now, I don't know of any studies that are out there that have been using any of the technology that 5G employs with the beam forming and all that, which would in my opinion, tend to decrease the radiation that's normally being put out there. But we're not there. We're not in a place where we can make a recommendation. And when you have somebody have insurance for this or that, I don't particularly see that one either. I don't see that we have a good scientific basis to make much of a recommendation at all.

Abrami: Thank you, Jim. Here's what we got before us. I think municipalities would be looking for us to give them some guidance. That's at a level that this really plays out at. It's really cell companies coming into a city or a town and saying we want permitting rights to put on top of telephone poles or install new polls or small cells. I think the majority report really has got to focus back on the small cell towers because that's the issue, that's the 5G. And as I've said over and over again, 5G mean something to every cellular company. It is just a concept. Each interacts with 3G and 4G differently. And a lot of its proprietary, so we have no idea what's inside those antennas and how those antennas are configured. What we do know and we can measure once installed, is the power intensity coming out of those towers. But we should say that a town should be able to say yes, we'll allow you to put in a cell tower but want to be able to periodically measure the intensity coming out of those small cell towers. Gary, did you just sign on?

Woods: Yes, I did. I'm in Nashville and I don't know what happened. I saw the notice that Kent put out to start at nine. Then, I got a notice that it was cancelled. My apologies.

Abrami: OK. Well, let me follow through and we will give you a chance to weigh in. Okay?

So, right now the, the standard's at, let's call it ten watts per meter squared is the US standard. But some of the other countries have set the standard much lower than that. Australia is two watts per meter squared. Canada is three watts per meter squared, but we're way up to ten watts per meter squared. So, I would think at the very least, and I don't see why this would be a problem for us to say to the cellular companies yeah, if you install these, a municipality has the right to monitor the intensity coming out. And I don't know why cellular companies would have a problem with that. There's going to be a working group where we'll put it in a recommendation from for the next meeting that we could go one by one and have a discussion around each of these. All of the things that were mentioned today will be grouped and, and then we will have to as a group at our next meeting really have that discussion around each. But for today, we're just talking about ideas.

So again, this comment is for Beth. I don't know, why the cellular company would object to a town being able to measure what's coming out of those towers and having us have that part of the agreement with the town. If those towers are on our end are out of sync with what the standard is, then those towers have to be turned off, something to that effect. So that's just one thought.

And one that Brandon, I'm going to have you weigh in on too is I looked at the documents that came out from other municipalities of what they've tried to do. One states requiring permittees to defend and indemnify the municipalities from any liabilities arising from installation, operation and maintenance of small cell installations. But why would the cellular industry, if they feel this is safe, not be willing to sign off on a permit that that allows this? Because it's the town that's bringing in the cellular companies and the towns are going to be, why should we have our municipalities be unprotected if there is indeed damage? We, as a commission are hearing both sides of this. And there could be. It's hard to say definitively. We've all heard and I think everybody's kind of agreeing that there's evidence of potential harm. But cellular companies are saying, no, there's no harm. And the FCC saying, no, there's no harm. The FDA says, no, there's no harm. Well good. If there's no harm, then why hold our communities liable for damages? So that's, that's one that I think we should we should be talking about.

I think we should be pressing the FCC. That's my third point. As a statutory commission, as Tom points out, I would just stress with them why are standards set so high? We know there are no biological effects that play into this standard. How can Australia or New Zealand be at .5 watts per meter squared and successfully roll out 5G? They are going to roll it out,I would imagine, with a lot less power intensity. Remember, those towers are going to be at the height of the telephone pole. Most of them are going to be stuck on top of the telephone poles. We also know, as commissioners, that we see the push back going on around the country. You know the industry likes it or not, there are a lot of people looking at this getting the message out that there's this potential danger. So the public is aware of this and there's going to be push back for communities on town selectmen and other boards to deal with this. My fourth point, I agree with some of those that said that we should as one of the recommendations, which is kind of a neutral recommendation that we would share this with the federal government agencies that a more robust study should be done on 5G. That should be pretty neutral.

Other communities have looked at simple ordinances and loopholes. How many streets are off limits? Now, I don't know how enforceable that one really is. But some communities have that, are trying to do that. Others have mentioned setbacks. I think Dr. Heroux mentioned that. There are towns that are talking about setbacks, a 500 feet from residences, businesses, schools. Again, that's something that that we could talk about. But if it's on top of a telephone pole in front of your house, you walk under the telephone pole and that's where the greatest intensity is going to be right by the pole. That's something that we will address.

Something that came up from the last speaker we had is requiring power density disclosures for renters and buyers, public buildings, locations where general public may go. That's something that I think we should discuss to see if we can make that into a recommendation of some kind. Another community was trying to say, let's have all poles with 5G antenna have warning signs that RF radiation is being emitted above. That's a simple thing. Again, I don't know why the industry would object to that. Some people would want to know that there's RF radiation being emitted above. So those are some of the things that we can look at as a group.

Brandon, in terms of the liability issue, do you have any comment on that?

Garod: What specific liability issue here you're asking about?

Abrami: Well, I'll read it again that some communities are requiring, permittees, meaning the cellular companies, to defend and indemnify the municipality for any liabilities arising from permits and installation, operation and maintenance of small cell installations. The point is to hold the municipality harmless if someone could prove that they were damaged from the small cell towers.

Garod: I think that to the extent that municipalities are making that a condition of receiving a permit, it would be a law or regulation that's specifically preempted by federal law. This is really where the rub is. The communities, the municipalities, the towns, the cities… they're the ones that control the permitting. You have to go through a permitting process and you have to be approved and any law that's passed, that is a barrier to telecommunications coming in that's passed by state, is specifically preempted unless you can meet one of a few carve outs. The carve outs create another barrier. Unless the state has specifically delegated to the towns and municipalities, the ability to regulate telecommunications in any capacity, that doesn't even apply. It's only the state that has the ability to use those carve outs as like a safe haven for a law that serves as a barrier for telecom. And I'm not clear as whether New Hampshire has delegated any of that authority to the municipalities. But there's a lot of litigation since this thing was enacted in 1996 and it's usually a municipality trying to pass something. And the way that the telecom companies are able to beat it is by saying that they're trying to say that it's for public health and safety or for consumer protection, or to protect right of ways. Those are the specific carve-outs. But unless this state has specifically delegated to those communities, you can't even use those carve outs as a defense. I think there's a good chance that it would be preempted. Really, I'm not an expert. That's basically what I've come up with so far.

Abrami: I agree that the state legislature would have to enable the municipalities to do that. Is that what you're saying?

Garod: If there was a specific delegation from the state of New Hampshire to the municipalities to be able to regulate telecommunications coming in, in any capacity, then the municipalities would have to show that any regulation that they passed, which served as a barrier to telecommunications coming in, fits one of the few carve outs under the Telecommunications Act of 1996. And in trying to find a good case to use as a standard, it's almost never been done.

Abrami: Ok, well, so that's why we have the AG's office is represented to give us those insights.

Sherman: Brandon, I have a question for you from what you said. Why do the telecommunications industries have to come in and get a permit if everything is federal? On what basis could a town deny a permit? So in other words, is the permitting process just a rubber stamp? If you don't permit, they're going to take you to court. You know, they can come in any way with or without a permit with or without municipal law, with or without state law. Is there anything that a municipality can do to stop the installation of these antennae and 5G technology?

Garod: To answer your first question, which I believe was, why would they need a permit? They might not under every circumstance. But imagine what the companies are trying to do is come into a town and build several new towers, to build several new receiver or to build infrastructure they would have to apply to the town for, you know, building permits or in order to do construction within the town. There are laws that determine what sort of process you have to go through in order to be able to come into the town and build something. If there is a specific limitation on telecommunications, being able to do that, that is passed by the town…that's specifically what is preempted by federal law. Because federal law determines when telecommunications can come in and what they can do. So it's frustrating because you would think that at the municipal level that would be who is in the best position to determine what's best for your individual town. I think what I can say for certain, I don't know if there's anything that can be done, but what definitely can't be done is any sort of regulation that amounts to any sort of barrier to telecom coming into the town and installing new infrastructure.

Sherman: So the follow-up would be if a town doesn't want 5G, they just deny the permit.

Garod: Well, I think you have to have a basis to do it. I'm not a local government guy, so I don't know.

Ricciardi: I can answer the question what Senator Sherman was asking. So the reason there is a permitting process is each town has zoning laws in place. And the telecommunications company, when they come into your town and they want to put a cellphone tower, they do have to show that there is a need and that this is the only location and that they checked everywhere else. So it does go before our zoning board here in Bedford. Everybody's zoning has different regulation. The zoning we have in place is not a barrier to the telecommunications, but it is definitive things that we have put in place that are allowable by law. So for example, we have the 750 foot setback from any residential neighborhood in our town now and was put before the voters and voted on. So there are things like that that you can do. The other thing that you can do that is legal, that we have just completed is a "wires and poles" town ordinance. So we did not single out the telecommunications. We did not say this is just to keep the rules in place for them, but it is all utilities, wires, and poles. And in that section, there are some very strict but allowable bylaw criteria. If 5G were to come and it's beyond our control because the FCC, so we put allowable things in place. And when you do this, you're protecting the residents of your town. But you'r making it more difficult, but it's across the board for all utilities. So by not singling out, then it can't be done. Anyone on our commission, and your towns, I'd be happy to provide a copy of what we just completed.

Abrami: Okay. Well, that that's something that I think would be helpful and that, you know, I think you have some specific recommendations that we're going to vet as a group in the next couple of weeks. Ken, do you have another leading question? I think Beth wants to respond. Would you mind if Beth responds?

Cooley: Yeah, I think the only thing I'd add to Denise's comments in terms of what a locality can do, technically, every locality should be complying with the FCC order that went into effect in January of 19. There could also be state laws as well. We've got 29 states and Puerto Rico that have passed laws that also need to be in compliance with their state law. But in terms of what Denise already outlined, localities also have say over aesthetics. In the FCC order, so long as aesthetics are reasonable, objective, and non-discriminatory. And that's what Denise was talking about when she was saying all utilities in the right away. That's the nondiscriminatory part. So in terms of an ordinance, that's also what you can outline is if everything in the right away is green, then we needed to be green and things like that. So just to piggyback off of what Denise outlined, that's how the process works. You do need to get a building permit. You can't just go in and build. Local governments also have the ability to deny a permit on the basis of public safety issues. So for example, if you're doing sidewalk work and the sidewalk is no longer wide enough for wheelchair that can be denied under ADA compliance. Public safety can also circumstance can also be where if a small cell would impede the vision of a driver around learner or a traffic light, things like that. So there's a process passing ordinances helpful to outline where control is retained in terms of the build out, but we'd also be happy to work with you. There are other communities in New Hampshire that have also passed small cell ordinances that we'd be happy to share. So thank you Rep. Abrami for allowing me to comment.

Wells: Looking at this as a physicist, it seems to me that there is an artificial distinction made between different types of RF emitters when in fact RF differs only in intensity and frequency and polarization and so forth. I'd like to see if we could get someone to look into why telecom is subjected one set of standards where say in FCC Class D, broadcast transmitter is limited to a certain number of megawatts per square meter at the property line. And so I think that this is something to look into. Why is there an inconsistency in what the power levels are allowed to be because the power levels on 5G are astronomically higher than they are for broadcast.

Abrami: We will see what we can do there. Ken, thanks. Gary, what we've been doing is everybody's been chiming in with some thoughts and potential recommendations to get the juices flowing here.

Woods: I have some thoughts thinking more as a physicist and where we are and our understanding of some of the basic processes or lack of understanding of the basic processes are, to me still troublesome. I tried to think of this in a number of dimensions. One of which is what I call the sort of the “arc of understanding”. This is a little bit of sidebar, but hopefully it'll all come together in a second. When we looked about the human body, we had gross anatomy, the dissected anatomy, microscopic anatomy, cellular anatomy, chemical anatomy, synthetic biology. Then we focus down and then we've got the genetic code with at all we got all the answers now. Well now we don't have all the answers even though you have the genetic code. We know there's now epigenetics and we're learning more as we go along. To me, we're at the sort of the almost gross anatomy levels with microwaves. We're still talking about the impact from what we call a bulk material, irradiate a mouse total and see what happens. And it doesn't give us an understanding of the potential mechanisms.

You say, well, why do we need to understand the mechanisms? Well, let's give an example of a tornado. Sort of normal atmospheric conditions exist and all of a sudden a tornado appears because you've got a very confluence of a lot of factors that come into play that can create an isolated event. And we see that in a variety of things where seemingly normal processes result in a very abnormal event. And we know how to look at that. Chaos theory from a mathematical perspective has done that. And I'm sure Dr. Chamberlain probably teaches courses on for what are called Fourier transforms, where you'd take seemingly very, very benign smooth waves, you put them together and you get this big spike. So these things that occur and we're at that point, from my perspective, of beginning to understand the confluence of these things at the molecular level. And so this arc of understanding has not come down far enough for my perspective, for me to feel comfortable.

And I think there is a line in the Cyprus thing that I thought sort of synthesized my thoughts. And it said “that the potential aggregation and dynamic interaction with other signals”. I think that's really crucial for us to understand. It's not just 5G coming in. And our last speaker talked about precursors, which is sort of the same sort of thing. You have a signal coming in and then it turns out it interacts and creates a different signal. And we'd make use of this in biology already in orthopedics. Being a retired orthopedic surgeon, we use magnetic pulsed impulses to enhance bone healing. And that's you’re creating a field at the molecular level. Because we know our bone is basically what's called a piezoelectric material and it depends on electrical currents to do its job and stay strong. That's why you go up in space. You don't have gravity, that piezoelectric phenomenon doesn't exist. And you'd have bone loss. But that's an example of the kinds of interactions.

Epigenomic part is another example. And a lot of these processes, and we touched on this very briefly when the issue of proton tunneling came up. That’s at an extraordinarily low energy level and secondary internal processes make that occur and change all the time. And we know that things, simple, things like the configuration of an enzyme is a configuration of proteins in general. It is highly dependent on these hydrogen bonds, which are susceptible to proton tunneling. And as a consequence, all these processes we have, we really don't have an idea of how these work and some of the secondary processes. We're back up the “arc of understanding” at the bulk material level. And until we can get further down. And we will eventually, but to me, we're not there yet. So I just wanted to offer that as a concern, At least from my perspective, a concern of where we are in terms of the science. And I'll leave it at that.

Abrami: That said. We don't know what we don't know. Thank you for dialing in from your vacation. Everybody's had a chance to weigh in. And what let's talk about next steps here. What I mentioned, the last meeting, I think we should form a work group to take these ideas.I asked for volunteers. I got Representative Wells, Dr. Chamberlin, Denise Riccardi, Carol Miller, Dr. Heroux, and myself that will meet as a work group, to at least put some ideas on paper. We threw a lot of the ideas around here today. We have to do, as a group is take each one of those ideas and see if it will pass muster as a recommendation in our report. And so that's what I think what we'll do. I will work with those people and set up a meeting to do that and then maybe have to meet once or twice before our next meeting. We're running out of time now. We have three months left. I did say I was going to try to follow up to see if we get an extension on the date, but because we go to the next Legislature, I think they really want us to have our report out by November first. So that's what we'll continue to shoot for. So any objection to what I just said? I think that we've got a small work group that will work on this and put recommendations on paper and will get that out to everybody.

And at the next meeting we'll go through each one of those and have a discussion around each one of those to see if there's support for it or not support for it. And having the discussion, some of the discussions we just had, the science discussions, but also the legal discussions as to what we can make work for municipalities. What message we want to send to the federal government about this delegation or other ways.

Sherman: I just wanted to remind everybody, you know many of us have served on many commissions and committees. And I believe if there is a dissenting view to whatever the majority wants, there is the capacity for Minority Report. Is that not correct?

Abrami: That's correct.

Sherman: So I'm just saying that not because I'm encouraging a Minority Report, but because for people who haven't served on commissions or members of the public, the goal is to reach some level of consensus, but perhaps not unanimity. And, and so we may end up with two reports and that's just the way Commissions work.

Abrami: Yes. I think I mentioned that the past. Yes. That's the way commissions work. Okay. Which brings us to Denise. I want you to just weigh in a little bit on the lack of the response to nonresponse response we got from the FDA.

Ricciardi: So I sent several questions to the FDA and the National Cancer Institute regarding answers that are very important to this commission and our decision making. The questions were ignored at first. After I kept at it, I got a response that was not an answer to the question. I point blank, asked and numbered the questions and said we need an answer to each question not linked to their website that we already know that we already have. That's very frustrating. And that was the situation on both counts with the FDA and the National Cancer Institute. So I tried to reach our United States senators offices and finally yesterday I spoke with a staff member in constituent services. And I have forwarded our questions to that office. And I feel at this point, it's going to take our U.S. senator to insist they answer the questions. And I find it very telling that they don't want to answer them. We are a commission with a very important task and I don't understand why they want to answer these questions. I'll give you an example. I'll read one of my questions. The FDA is aware that cell phones violate the FCC SAR limits at body contact on high power. The FDA has written that because it's safety factor and that's what they do. What is the safety factor for SAR the FDA relies on and at what SAR level above the FCC limits will the FDA intervene? So they have written that that it is not safe on body contact, but then they don't do anything about it. And why will they answer one simple question? That's just an example. So that's where we're at. I'm still waiting.

Abrami: Tom, I'm going to ask you to help us out with that and try to get maybe Senator Shaheen or someone to help us out with that.

Sherman: I am happy to.

Ricciardi: It’s her office that I spoke with. It wouldn’t hurt to have you follow up as well.

Sherman: I can call l their state directors. I reached out to them about the FCC and we didn't get anywhere. It’s not because they didn't try but because they didn't get a response. It’s frustrating.

Abrami: So if, if the commission doesn’t mind, you all remember Theodora from Environmental Health Trust. She had reached out to me about the FCC and if you don't mind if we give it a few minutes and then Beth, if there's anybody on this that from the industry that wants to respond, we will give them that opportunity as well. So if you don't mind, we'll have Theodora spend a few minutes. We have about a half hour left.

Scarato: Thank you so much. I had sent over and just wanted to make everyone aware of the documentation that I received from the EPA with a lot of questions. Their response to my questions was that the EPA's last review was in 1984 in terms of biological effects and they gave they cited that you should all have a copy of the questions and the answers. Just to go over what the EPA said. I said what's the research? Has EPA reviewed the research on damaged memory? They say they don't have a funded mandate for radio frequency matters. And in regards to the birds, bees, and trees, what's really important is that the limits were not set of course for birds, bees or trees and the EPA seem to confirm that in the answers that they sent. Also in regards to the safety factor, I would note that I think this is a really important question, so I'm glad it's being asked because it said that there's a 50 time safety factor. But when it comes to phones against the body, is certainly couldn't possibly be a 50 times safety factor for that in terms of the heating effect. So want to make sure you have that as well as the scientific letters that were sent to the FDA in regards to their report, their literature review on only cancer. They didn't look at other end points comprehensively. And you'll notice that Dr. Albert Manville, the former fish and wildlife lead, who is now retired, wrote stating that the current FDA statement is irresponsible, unfounded, and sets a dangerous precedent and so on. But please take a look at those letters that were sent by the scientists regard to the FDA. So thank you.

Abrami: Thank you. I think I did send that out to everybody. And if I recall, each response to each one of those was “that's not our mandate”….Something like that. Is that correct? Right. So we have got it because Congress has mandated us look at this, something to that effect. Again, next steps are going to be getting the working together a couple of times. In terms of the next meeting, we could try to put a stake in the ground and come up with a date while everybody's on the Zoom meeting here. Are people on vacation? Are they staying local? August 28th? Who cannot make August 28th at 09:00 AM? Brandon can't. I want to make sure the Working Committee has enough time to do what they have got to do.

Sherman: I'm on vacation on the 28th, but I can do it anyway. I could do Monday, the 31st if that worked. I don't mind dialing in. It's no problem.

Okay. Okay. How about Monday the 31st? Anybody can't make money to 31st? Okay, why don't we save that date, the 31st at 9 am. I'm going to reach out to the folks who volunteered and we'll come up with some dates for us to get together in between. So well, we've got about 25 minutes. Is there any other general discussion we would like to engage in? If not, I'd like to open this up to any other folks on the on the Zoom meeting that our guests, if they'd like to weigh in. I would allow that now because we have time. Does anybody else want to weigh in? Questions? Comments? suggestions?

Bloede: Yes. Oh, can I speak? I am Paul Bloede from Coloradans for Safe Technology. We had a meeting recently, Zoom meeting with an attorney that I wonder if your organization is familiar with this national level Attorney. His name is Julian Gresser. And he had a lot of comments about the legal state around the country of this whole issue and I thought he was very incisive and we have a transcript now with his presentation to us, we have that transcript just from last week as a PDF file. I didn't know if that would be of interest. How I could get that file to any of you, should that be of interest?

Abrami: Can you get that to me?

Bloede: Yes. Do you have an email address?

Abrami: Yes. Use abrami.nhrep@gmail.com.

Bloede: Yes, definitely. I will get that out to you. I think you will find it interesting hopefully.

Abrami: I'll get it out the others. Okay, thank you. Cece?

Doucette: Thank you Rep Abrami. When I first started investigating the wireless radiation issue, I thought as soon as we saw that it's especially harmful to children, that my school would have jumped up immediately and shut off the wifi in schools.

Abrami: Cece, why don't you back up and explain your involvement in this.

Doucette: Okay. I spent several years at Ashland Public Schools in Massachusetts doing fundraising for what we kept hearing our kids would need to succeed in the world. And that was basically the 21st century classroom, which is an industry campaign to introduce wireless into our school systems. And I had spent many years doing fundraising because our town didn't have the budget for that. I started looking and an engineer friend of mine tipped me off that there could be harm. So I started my investigation and I came up with a few studies that were saying no harm. I didn't understand at that point that "no harm" is not the same thing as "safe", right? So I started looking a little bit deeper and then I start finding peer-reviewed studies all over the world showing great biological effects. And the set of studies that got me on my feet were the sperm studies, where they've taken male human sperm and expose it to a laptop with the antennas on. And it changed the DNA, it slowed the motility in it cause far fewer sperm to be viable in just four hours of exposure.

We had just bought my youngest daughter a laptop going into high school. And of course she's using it right on top of her reproductive organs. So that was the day that I got involved in this. I have helped introduce legislation here in Massachusetts and I wish we were as swift as New Hampshire is. My bill has been in play for six years. There are others on the utility smart meters that had been in play for eight years. But even during this pandemic and the racial justice movement that's happening, our legislature is finally advancing three of our bills, so we're hopeful that that will happen here.

Early on in my journey, others who talked to me about legal action and I don't know anything about that. I didn't want to see lawsuits come into play. I just wanted us to do the right thing and especially protect our children. But then I got to listen to a conversation with somebody who was referencing Martin Luther King Jr. And what MLK was teaching us is that in order for important societal changes to happen, it happens through three channels. 1. The public gets educated and speaks up and thank you to Deb Hodgdon for being the catalyst in New Hampshire who then spoke to Rep Abrami, who then drove down to my kitchen table here in Massachusetts. We had a long conversation about wireless. 2. There is legal action that happens to hold those who have infringed upon our rights, accountable. 3. Public policy ultimately catches up with the science or whatever else the issue is. So as much as it makes me uncomfortable to think about legal action, it's part of how change happens.

So to our Attorneys General, I hope you will look at this as seriously as you looked at tobacco and do the right thing, reach out to your colleagues and other states, get this conversation going. My understanding is the industry has already set aside billions for the lawsuits that are going to happen. But we cannot afford to continue to expose our children even during this pandemic, handing out hot spots without any information on how to use technology safely. So I implore you as a mother, as a woman who fell down this rabbit hole which I never wished to be in. But once you know the harm, you can't “un-know” it. And we have to use every resource that is available to us to start protecting our children, especially right now. So thank you for your time. I hope the commission will report out favorably something that we can hold up with pride and say, thank you to New Hampshire for being our nation's leader. And then we can follow suit in our states too.

Abrami: Thank you, Cece. Is there anybody else that would like to weigh in at all? Okay. I don't see any.I I guess we will be adjourning. We will see everybody on August 31st at 9. And then, in the meantime the subgroup will be meeting. Did I mention that we're recording the meeting? I thank everybody for your time. Thank you to those who have tuned in from afar. Those on the Working Group, I will get an email later today with some dates that we can get together. Okay. Is there a Motion to adjourn?

Woods: I was the latest but I will make a motion to adjourn.

Abrami: motion to second by Carol. Without objection, we're adjourned.

V. Next meeting via Zoom: August 31st 9-11

Meeting Adjourned at 10:43 am

Text chat during Zoom meeting:

00:30:12 Bruce L. Cragin: ???

00:30:45 Bruce L. Cragin: ???

00:41:30 Bruce L. Cragin: Yes bring back Swanson!

00:43:58 Cece Doucette: Hawaii County Council just passed their 5G ban

00:45:51 Bruce L. Cragin: Ha

00:50:10 EH Trust: There have been attempts to overturn the Telecom Act section 704. Some links her ehttps://ehtrust.org/policy/the-telecommunications-act-of-1996/

00:51:17 christine.melkonian: YES, to public awareness

00:54:54 Cece Doucette: It was our state attorneys general banding together and suing the tobacco industry that finally brought the toxic effects mainstream. Perhaps the Commission can recommend that NH lead an effort for attorneys general to band together on wireless too, which if successful, would help to provide the funding to put safe, fast, sustainable technology in place. I believe NH still receives funding from the tobacco industry lawsuit today.

01:01:20 EH Trust: Also the Telecom Act Research continues to show effects from power lines. See studies here https://ehtrust.org/science/research-on-magnetic-fields-extremely-low-frequency-electromagnetic-fields-cancer-and-miscarriage/

01:02:08 EH Trust: Many countries have protective limits in regards to power lines, over a dozen. They set limits at the level linked to cancer in children. But the US has no limit at all. https://ehtrust.org/policy/international-policy-actions-on-wireless/

01:02:29 Bruce L. Cragin: Exactly, Sen. Gray. So much fearmongering.

01:03:56 EH Trust: Two published studies by the Ramazzini Institute "Carcinogenic Synergism of S-50 Hz MF Plus Formaldehyde in Rats" (2016) and "Life-span exposure to sinusoidal-50 Hz magnetic field and acute low-dose γ radiation induce carcinogenic effects in Sprague-Dawley rats" (2016) found that ELF exposed rats had statistically significant increased incidence of several type of malignant tumors when combined with a known carcinogen.http://onlinelibrary.wiley.com/doi/10.1002/ajim.22598/full

01:04:44 Bruce L. Cragin: And here comes some more ^^^

01:12:17 Bruce L. Cragin: Re. A., you're hearing ONE sde, not both.

01:33:08 Bruce L. Cragin: Physicians are not physicists.

01:33:27 Ken Wells: Bruce: This one is

01:33:48 Bruce L. Cragin: You, Ken? or Gary?

01:34:08 Ken Wells: Dr. Woods

01:34:35 Bruce L. Cragin: Thabk you. I will contact him.

01:37:54 Bruce L. Cragin: http://bobpark.physics.umd.edu/WN10/wn121010.html

01:39:17 Bruce L. Cragin: Sorry, I meant https://quackwatch.org/related/signs/

01:44:10 Bruce L. Cragin: https://americanbeejournal.com/why-we-shouldnt-fear-5g/

01:45:48 EH Trust: The FDA scientists letters are found here https://ehtrust.org/doctors-slam-fda-report-on-cell-phones-cancer-and-health-effects/

01:46:04 EH Trust: Dr. Manville https://ehtrust.org/press-statement-from-dr-albert-manville-on-the-fda-report-on-cell-phone-radiation-2/

01:46:38 EH Trust: The EPA letter can be found here https://ehtrust.org/epa-birds-bees-trees-5g-wireless-effects/

01:47:05 Bruce L. Cragin: "FDA scientists" or activist scientists?

01:47:24 EH Trust: The letter from scientists to the FDA.

01:47:42 Bruce L. Cragin: Yes that's more honest.

01:47:49 EH Trust: NIH scientists, experts internally signed, several on the world health organization emf group

01:50:20 EH Trust: Several of the scientists are expert advisors to the World Health organization who are asking the FDA to retract their flawed report on the studies.

01:54:13 christine.melkonian: YES

01:54:20 Bruce L. Cragin: I give up. You people are just lost. The idea that a commission of legiislators has the scientific capability to meaningfully question the standards is ridiculous.

01:54:26 EH Trust: Resources on Wi-Fi in School https://ehtrust.org/wifi-in-schools-tool-kit/

01:55:14 Ken Wells: Aug 31 at 9am

01:55:47 christine.melkonian: Thank you so much

01:56:28 Cece Doucette: Thank you to the commission members and others, please feel free to reach out if there is anything I may help with. c2douce@gmail.com

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS OF EVOLVING 5G TECHNOLOGY

Meeting held:
8/31/20
9:00-11:00 am EST
Via Zoom (https://unh.zoom.us/j/95489344931)
Via telephone-US (1 312 626 6799 (US Toll) ID: 954 8934 4931)

In attendance: (12)
Rep. Patrick Abrami-speaker of the house appointee
Rep. Ken Wells- speaker of the house appointee
Kent Chamberlin-UNH-appointed by the chancellor
Denise Ricciardi-public-appointed by the governor
Michele Roberge-DHHS- Commissioner of DHHS appointee
Dr. Paul Heroux- Professor of Toxicology, McGill University- speaker of the house appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee
Senator Tom Sherman-president of the senate appointee
Brandon Garod-AG designee, Asst. AG Consumer Protection
Bethanne Cooley-CTIA , trade association for wireless industry and manufacturers
Carol Miller-NH Business & Economic Affairs Dept

Not present: (1)
David Juvet-Business and Industry Association
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Meeting called to order by Rep Abrami at 9:05 am

Abrami: Due to the Covid 19 virus and the Executive order signed by the Governor this public meeting is allowed to be conducted via Zoom. It is open to the public for viewing and was duly posted as a zoom meeting. With that said, if you are not a member of the Commission, can you please turn your cameras off and mute yourselves? That would be much appreciated. In addition the meeting is being recorded as an aid to doing the minutes. All chat room discussions will be included in the minutes.

I. Approval of minutes from 7-24-20:

I have not received any comments or changes to the minutes. Are there any changes? Without objection, we approve the minutes from that meeting.

II: Proposed report format/ Procedural Discussion:

Abrami: We also sent out a copy of the agenda and the proposed final report format and recommendations the work group has been working on. That's the primary reason for the meeting is to talk about those and if there are any other recommendations. This is what I am thinking about the report: Preamble, Definition of Terms, Physics, Study process (who we heard from, etc.), then a section of the questions posed by the Commission in the legislation and the answers, our recommendations.

What we consider firm recommendations for lack of a better word and also listing some other things that we decided not to make recommendations. There will also be appendices and supporting documentation for the recommendations and of course the minutes will be attached to the report. This is what I am thinking but I am open to any changes. Are there any questions on that?

Cooley: Rep Abrami, just one question on that. In the outline, where would a minority report or dissenting opinion fit it?

Abrami: I will double check this but it's a separate report that gets attached to this report. I know there will likely by a minority report which is fine. I will get clarification on that. It was easier when we were at the state house and I could just walk over and ask but I will get clarification on that. OK?

Cooley: Yes, thank you.

Abrami: There is a work group that consists of seven members: Carol, Denise, Gary, Ken, Kent, Paul and myself. There are seven of the twelve members that have been active. The working group met three times. We started with a baseline of ten recommendations and we have done several iterations on these. Obviously, these are open to discussion today whether you think they should or should not be in the report, etc. Since I sent these to you I have gotten two updated versions that I sent to you this morning. Sorry it was late. One is from Paul with some minor changes. One is from Jim with some major changes. Hopefully, you have seen them.

Sherman: Pat, I also sent some minor edits to Paul's version this morning.

Abrami: ok. I didn't see those. So can you chime in when we get there? What we will do is take them one at a time and have a discussion around each one. I had a communication with Beth about, do we really want to take a vote on these today given that you have just received them this weekend. What we can do is take a straw poll to see where we are on each one of them and not be an official vote. When we do a final vote on these, if the majority votes yes, it will be in the report as a firm recommendation. If not, then it's not. After that, we will have a vote on the report with everything in it. There are twelve members that are active, so if it ends up 6-6, I will have to figure out what that means.

What I would like to hear from you today possibly three things. 1. I like it the way it's written. 2. I would like to make some changes then I could support it. 3. No matter what, I don't think this recommendation is needed. Certain members of the working group took charge of certain recommendations so I will ask them to describe the recommendation and what the motivation was behind it. If there are any other recommendations please let us know in this meeting and we can deal with those.

Sherman: Before we go to Recommendation 1, can I just make a comment on the first paragraph?

Abrami: Sure

Sherman: This is a great sentence but it's very long. On the last one it says ", thus the commission …" I think it would be clearer if you had a period and the words, "given these considerations, the commission yields". My feeling is that it's fine but I would have the last sentence be independent. That's in my edits for what it's worth.

Abrami: I get it. That's a good one.

Wells: I submitted an edited version of this one and changed it into a bullet list.

Abrami: ok. Boy, I am behind in my email. I missed that one too.

Miller: Which document should we be looking at? The original and everyone can chime in with their changes? I have multiple versions open and I don't know which one I am looking at any more. I think the one that you sent was Revision 3. Correct?

Abrami: Yes. If you see red in there, that means there were changes.

Sherman: which one did you send?

Miller: It was Revision_3 5G Recommendations.docx

Gray: since we are commenting on the first paragraph, I took out a couple of different things in my revision. I think that whoever puts this thing together at the end should consider removing and only presenting facts and not things that aren't facts.

Abrami: What you are saying is that the things that you crossed out aren't factual.

Gray: Right. You talk about the whole insurance industry, well that's not true, ok? The insurance industry if you leave it like that is more accurate. In the next sentence down you say "because of" instead of "due to potential harm". Thank you.

Abrami: I agree with those. These are good ones.

Gray: The word "determined" is used many places. In my edits part of my suggestion is that we take that out and replace it with the word "believe". The definition of determined is that it's found to be a fact or conclusive. In the first paragraph of the report we say that none of this is found to be a fact so again… take that word out and replace it with believe or a word of your choice. That would be a good revision.

Sherman: If you are anticipating a Minority Report, then wherever you have "the Commission has concluded" should be changed to the Majority or this Majority of the Commission has concluded… because you are going to have a Minority Report that has not concluded that necessarily. I think you will be a little more accurate using that phrase in the Majority report. That's only if there is going to be a Minority Report to recognize that the entire commission does not agree with this report.

Abrami: That's a good point, Tom. I anticipate there is going to be a Minority Report.

Gray: I will write it.

Abrami: Ok. So we are going to have a Minority report. Anyone who wants input into it can send me their comments.

Roberge: I haven't had a chance to talk with my leadership from DHHS on any of these recommendations so I may have additional comments from a resource perspective once I have had a chance to look these over with leadership. Also, I know we talked about this at the last meeting about not formally taking a position on the recommendations just due to the role of the department. I think we would just want to have a statement in the report reflective of that.

Abrami: right. It will say effectively that the recommendations do not necessarily reflect the position of any agency, Attorney General's office or Dept of Health and Human Services.

III: Work group recommendations and discussion:

RECOMMENDATION 1- Propose a joint resolution of the NH Senate and House to the US Congress and Executive Branch to require a review of the current radiofrequency (RF) standards of the electromagnetic radiation in the 300MHz to 300GHz microwave spectrum, used to measure exposure and health study to mitigate the health risks associated with the use of cellular communications and data transmittal, promulgated by the Federal Communications Commission (FCC).

Cooley: With the whole caveat that I received these Saturday morning and have not spoken with my members or with legal dept. so that will be my disclaimer throughout all of this discussion. My one question about this recommendation…. The first sentence of the last paragraph that says, " this commission believes that EMR is on the path to be confirmed as a class I carcinogen, where does that information come from? Is there a footnote? How is that assumption being presumed?

Miller: Recommendation 1 is a merger of something that I had written and Paul had written. That particular phrase came from Paul. Can you speak to that?

Heroux: Essentially that would refer to an article by an epidemiologist Anthony Miller who is very active with IARC. In other words, IARC has agreed to review the situation and in the last report what was missing was animal evidence and its likely there will be an upgrade to the classification because you have two major studies NTP and Ramazzini that now provide animal evidence.

Abrami: We need to refer to the papers either as a footnote or in the appendix.

Cooley: I think a footnote, Mr. Chair might be helpful because this is someone who has not presented before the Commission. I don't know who they are and it's the opinion of one person. I think backing up that claim or allegation would be helpful.

Abrami: The gist of recommendation 1 and I don't know Beth, why your organization would not think it's a good idea saying that we do have more to study. That's basically the thrust of this. There are a lot of organizations asking for this. Carol , why don't you spend a few minutes on this.

Miller: This is a joint resolution of the New Hampshire Senate and House to the US Congress and Executive Branch just requiring a review of the current RF standards and asking for a health study. The un-highlighted text is just back up and could probably be moved to the appendix. I don't know if anyone has any questions about that particular recommendation. I think it's pretty straight forward.

Sherman: I thought the recommendation was fine. It was straightforward but I thought there was a clearer way to describe what we are trying to get done. The edit that I suggested would read: " Propose a joint resolution of the NH Senate and House to US Congress and Executive Branch to require the FCC to conduct or commission a review of the current RF standard of EMR in the 300Mz-300GHz microwave spectrum as well as a health study to assess and recommend mitigation for the health risks associated with the use of cellular communications and data transmittal". I just think it's the active which makes it clearer than passive.

Miller: So you are suggestion after the word "require" to put the "FCC" right there.

Sherman: yes and after the word, "spectrum" I would use the words "as well as a health study to assess and recommend mitigation for the health risks associated with the use of cellular communications and data transmittal".

Miller: I am ok with that. Anybody else have an opinion about that?

Abrami: That's fine with me. Does anybody have a problem with that?

Gray: Again, I have made many changes in my edits and I don't object to many of the words that Dr. Sherman has put forward but I still think the rest of those paragraphs need to be looked at. When I read this report for the first time, it was very clear to me that someone who was a very big proponent of eliminating 5G or wifi, entirely, wrote this thing. That's not our job as a commission. I encourage you to take a look at my edits. I tried not to gut your proposals but to make it more neutral while still putting forth your proposals. Thank you.

Abrami: The work group will be meeting again on Friday. We have got our work cut out to try to pull all of these together. I am sure some of your words are going to make it into the report, Jim. The bigger question right now is who is opposed to having a joint resolution where we say that more study is needed on this topic? Who is opposed to that? We can tinker with the words.

Gray: I am not opposed to having a study but I want you guys to know that the reality of having a joint House/Senate Resolution is practically nil. The Senate has these resolutions and has determined that it's better for the citizens to go out individually contact their Congressmen than to do one of these resolutions.

Abrami: It is our understanding on the House side that the Senate doesn't like joint resolutions. We were trying to give it a little more umpf. No matter what we do, it will be a sell to whether it's just the House, where we will have to get 201 members to agree to it. We thought it was important that as a commission that at very least, we make a statement that further study is needed, bottom line. Having the full House and Senate would give it more umpf than just the commission.

Ricciardi: I want to make two statements if I could with all due respect to everyone. I am going to speak for the seven of us on the working group. I don't believe any of the six of you are against technology by any means. We are for it and we presented solutions that are safer, quicker, better latency. I don't appreciate that we are called out as saying we are against it. That's simply not true. I've got my cellphone right here ok? I want to clear that up right now. We are not against it. We are against the way it is now and we have shown a better solution as you get down into the recommendations.

The second thing is, we are tasked with a job based on the findings that we found. We don't sit here and not put them forward because the Senate or the House won't go for it or we didn't do our job. Our job is to present the truth. You don't, not present the truth because you are afraid of the outcome. The truth is the truth. You place it there and see where it goes. The seven of us with the testimony, the evidence and the science came to these conclusions. Anyone else who disagrees is allowed to and I respect their opinion and they can follow up in a report. But I do think we should get through it so we all have a good sense of where we are at. I am going to reiterate this. It is unconscionable to not tell the findings because you are afraid it won't sit well with someone or won't pass. That's my two cents.

Abrami: Thank you, Denise.

Sherman: Pat, I have a few edits on the paragraphs following recommendation one if this is the right time to mention them and they are minor. The words "living things" at the end of the second paragraph. I would replace that with "organisms" which is a slightly more scientific term for living things. The Obama-Biden plan to combat cancer, I am concerned about including that if it was never adopted by any elected body. If it was 2008, was that a campaign plan they had in 2008 because certainly the FCC would not be held to any campaign plan. My recommendation would be if it was adopted, then include it but if it was a campaign platform, I would delete it and just have the first one which was the National Cancer Act.

Miller: I am ok with that. I didn't write that particular piece.

Abrami: I think Tom has a good point, Paul. Was that ever enacted?

Heroux: I am trying to find out what type of formal approval this had but I think I should do it later.

Abrami: yes. Please do it later.

Gray: Sometimes these things are done by Executive Orders. But the paragraph ahead of that, where you talk about the FCC, all needs to be restructured also. Rewording that so it flows much better is something that you should consider.

Sherman: I agree with Jim on that wording because rather than have the word “favorable” in that paragraph with the Ninth Circuit Court, I would use what Jim said which was what the ruling was and what it will result in. I haven’t seen Jim’s version of this but I would favor being as clear as possible. The word “favorable” leaves a question as to who is it favorable to? Is it favorable to the FCC or the plaintiff?

Abrami: Carol, I am looking at you.

Miller: I am ok with removing that and I am not that invested in the surrounding documentation and it should probably be moved to the appendix. With regard to this, there is a lot of information in there and I think it just muddies the water.

Abrami: Ok, you heard all the comments Carol to modify.

Miller: If people send their recommendations directly to me, I am happy to do that or its going to get lost in the shuffle. I have Senator Gray and Senator Sherman, who else had comments?

Cooley: I just had a footnote on the article by Anthony Miller.

RECOMMENDATION 2- Establish a State position that protects the State and all its Municipalities from any liability from harm caused by small cell antennae placed on the public rights-of-way. Specifically liability of the State of New Hampshire and its municipalities connected to harm caused by claims of personal damage or harm from the deployment of 5G small cell towers or the attachment of 5G antennae on telephone poles, electric poles, lamp poles, or other structures on the public right-of-way is by state statute transferred to the Federal Government. The Federal Government shall be required to defend and indemnify the municipality from any liabilities arising from permits and the installation, operation, and maintenance of small cell installations.

Abrami: We had some discussion about this. This had to do with protecting our municipalities from harm. Do we really want this recommendation or not because the feeling is that it will put citizens in a bad position. I actually originally wrote this and Paul took it from there. Our communities are being forced to deploy small cells at telephone height and I thought about holding them harmless. This was an attempt to protect our municipalities, but what about people?

Heroux: Well, this is a rather legal question. I think we all recognize the motive of Rep. Abrami's original statement. But, if the federal government cannot be sued and if this recommendation goes nowhere, what is the means by which we can support municipalities and individuals who might feel helpless in relation to this problem in the sense of congealing their actions together and make sense of it and rationalize it.

Woods: It seems as a discussion, we went over this very point and the complexities of having a liability element in there as a recommendation. We wanted to include it but perhaps put it at the end as an observation. And couch it in terms that we understand that this very well may be an issue that will come to the fore that we did not have a recommendation but wanted to recognize that this is an issue that will perhaps need to be addressed in the future.

Abrami: right. I put in my notes…discussing whether to demote to something less than a recommendation.

Sherman: Brandon is with the AG's office. Could we get an opinion whether this is even possible? What's happening is states and municipalities are being asked to approve these but based on FCC rulings, they don't really have a choice. As a result, if the people of the town are harmed, and go after the municipalities because they can't go after the federal government (FCC) then they are stuck. I am concerned that municipalities will bear the brunt of liability without being able to say no to the request from the cellular company. Do we have any wiggle room on this? Or is it something that is not worth mentioning because there is nothing we can do about it? Can Brandon weigh in?

Garod: I'll do my best with the caveat that gets into the question of what is civil negligence and what establishes the liability for civil negligence. That is pretty far outside the realm of what I typically do in the consumer protection world. But, I had two initial thoughts when I looked at this. Because municipalities are being forced to this and don't have a choice. To bring a suit for negligence there has to be some sort of negligent action like setting aside the standard of care. If they are being forced, I don't know how a community could be held liable for that. If they did have an option and did not do their due diligence and allowed this to happen, that's a different story. It's very clear that other than aesthetic regulation, the placement, design, size of something in a public space, municipalities have no authority to say no to 5G technology being moved into their town. I don't think there is a huge risk of liability for municipalities.

When I went back to the legislation, and looked at what the commission is supposed to do, I think this is a bit of an outlier. I think it may be worth mentioning that there are concerns about who would be liable. I don't see anything in the commission's tasks as to what steps we need to take legally protect municipalities or the state from possible liability. It's more getting the information out there, developing strategies to limit exposure, public policy statements rather than developing a plan to protect municipalities from liabilities.

I think that likely if there are lawsuits in the future, that they will be directed at cellphone companies who are pushing these things out aggressively without doing their research and they have acknowledged the risk of harm as they recommend not putting it near your head but if they are then going to implement towers everywhere and not give anybody a choice, that's really their choice. I am not sure that their choice and actions can be imparted onto municipalities that don't have an option and trust the FCC that they are doing what they are supposed to be doing about safety. Those are my takes.

Ricciardi: The seven of you know that I have been against recommendation 2. I feel it's a dangerous recommendation and we should omit it. State government needs to make these antenna safe not indemnify or protect government from liability or responsibility when they allow them to be deployed unsafely. We need state government to say no to these transmitters and challenge legal cases around Section 704 of the 1996 Telecommunications Act that prevent them from even considering health and safety. I don't think we should have Recommendation 2 in there at all.

Abrami: My original thought on this one is…the new twist is that these antennas are going to be in the public Right Of Way. In the back of my head I'm thinking there is something different about these being in the public Rights of Way. We have two, the municipal and the state ROW. We have town roads and state roads. So, that's the game changer for me. That's what's different about this. We have no control of those antennae and what's coming out of them. I am okay with eliminating #2 or demoting it.

Sherman: The real problem here, as Brandon said is that the municipality and the state can only object on the basis of aesthetics. We should be asking our federal delegation to bring legislation that would allow or expand the ability of municipalities and states to challenge the placement of 5G/small cell technology based on concerns about health risk. That is getting to the meat of the problem here. The reason that #2 exists is because municipalities and states have no ability to challenge FCC ruling on the basis of health risk. To me, that's the crux of the problem. What needs to happen is we need to allow local control with regard to health concerns for this technology. Local and state governments should have some regulatory impact on whether or not this is rolled out.

I can't believe that the FCC can do this without any consideration of health impact. I would change #2 or I would change the concern to: the Commission will write a letter to our federal delegation urging them to bring federal legislation that would expand the ability of states and municipalities to object to implementation or placement of 5G/small cell technology based on their concern for health risk. That's the way I would take this, rather than going down the liability corridor which gets us into the issues that Brandon was talking about.

Abrami: Right, the courts are not reviewing whether it's good or bad. They are just following 1996 statute.

Sherman: Frankly, if the industry wants to bring Xenon ray guns out that transmit data quickly, they can do it if the FCC says they can do it. The FCC has the power to say, you have no right to object to whatever technology that the telecommunications industry brings forward based on health risk. That's it. That's the problem.

Heroux: what the FCC says is that certain levels of electromagnetic radiation and power density are not harmful. It has a stranglehold on that because this was a main preoccupation of the engineering community. It also says that you have to provide telecommunications service. But these two requirements leave a lot of ground for other arguments. I think aesthetics is a very weak word to describe the leeway that you actually have. Without confronting the FCC, you can probably do lots of things.

Chamberlin: My point is that we might want to wrap #2 into #1 since they are pushing for basically the same thing having our federal delegation become involved in changing the policies for objecting to cell tower placement.

Abrami: that's a possibility. Also, I should have mentioned this earlier. We had a discussion in the working group about even using the term 5G but broadening that to a certain bandwidth of RF because 5G may be passe in a year or two with 6G. 5G is just a marketing concept. It's being rolled out differently by all of the cell companies. Some are using small cell towers and others aren't. I don't want to burden this here but we are looking for words to use in the report that would be broader then 5G.

Sherman: I would fully support that.

Wells: I agree and I can write some language about that.

Abrami: #2 won't stand the way it is and we will take a crack at it by either incorporating it in #1 or coming up with some additional language here. Basically, the change that would have the most impact is for the U.S. Congress to act. We all know that. That's a tough one. There are bills filed every once in a while but they tend to go nowhere at the federal level but as New Hampshire we will throw our two cents in. Or at least the Commission will.

RECOMMENDATION 3- Require the New Hampshire Department of Health and Human Services or other New Hampshire agency to include links on its website that contain information and warnings about RF-Radiation from all sources, but specifically from 5G small cells deployed on public rights-of-way as well as showing the proper use of cell phones to minimize exposure to RF-Radiation. In addition, public service announcements on radio, television print media, and internet should periodically appear, warning of the health risks associated with radiation exposure. Of significant importance are warnings concerning the newborn and young as well as pregnant women.

Chamberlin: the part that we were most recently looking at in our subcommittee is an establishment of a registry that would be on a website. The reason for that registry would be for people to log their concerns. How I became aware of this being at the University in electromagnetics, a number of calls from concerned citizens get routed to me. I tell them what I know about exposure to electromagnetic fields and they are sometimes concerned that they don't have an avenue for reporting their concerns. I tell them that there is not much they can do about exposure at this point because of the 1996 Telecommunications Act and so they are stuck. Where do they go? Do they go to the FCC? That doesn't seem to be a very productive avenue. I feel by having a registry, we can get a sense of how many people are concerned in the state of New Hampshire and to build essentially ammunition if there are a lot of concerned people so we can go to the federal delegation and have them do something.

That's the second part that I really addressed and that is have a registry where citizens can report concerns so we can get a sense of how many people do have concerns. If it's only one or two then maybe the point is moot but if we are getting hundreds that's something that we should know. Paul, did you want to address the other aspect of this?

Heroux: You are right. We wanted to give an access point to monitor this situation and the access point could be for either individuals or organizations or a separate access point for both of these.

Gray: This is Jim. This recommendation first of all should not be for the Dept of Health and Human Services. It should be for the state because we don't care what department it is as there may be a better place to put it. It's more realistic if you have the state collect data. What we are talking about here is a man year of effort and supervision and if the volume is high, maybe more than that. That would be a budget issue and again, do we really want that and will the legislature approve it?

Abrami: we know most of these will have to go to the legislature for approval but first someone has to file the bill. Those discussions will happen there. We decided that we want to make the recommendations and let that process work through.

Chamberlin: I have done websites like this and to provide information and add links as we have done with the website associated with the Commission. In terms of a registry, it could be something as simple as a survey. I have created those in an afternoon. We could create a survey that is appended to the website. I think we are talking about a man week as opposed to a man year worth of effort.

Heroux: I echo that comment because with automation today, it's fairly easy to create a link and a person from within the state can access this link and file a pdf document automatically. If you have many requests then you might face the labor of assessing these requests but as Kent pointed out, you wait until you have many and then you know it's worth it. Thank you.

Roberge: As I said earlier, I have not had the opportunity to talk with leadership about this so I may have some additional comments. One thing that I thought of and it's been talked about a little bit here is funding for this. If the department is required to do a registry, there are obviously database requirements and an evaluation component. One thing that concerns me is that if we are collecting this information, at this point, we don't have any authority to do anything with it. That's somewhat concerning to me because if we are collecting all of this information, what is the dept doing with it? I know DES has been mentioned, I am not sure if they are appropriate either.

I know DHHS has a radiological program. It's a small program that is focused on ionizing radiation. We license and inspect sources of ionizing radiation including x-ray machines in dental offices or hospitals or industrial radiography in industry or a radioactive materials program. Again, that is focused on ionizing radiation. The department also participates with Homeland Security Emergency Management and an emergency response program specifically for Seabrook Station. Again, it's ionizing radiation. I'm not sure that DES is the correct agency. That being said, any additional requirements to do inspections, monitoring or in this case PSAs and things like that, there is a funding mechanism that would be an issue. If you had a registry, what are you doing with that data? Is it confidential? Will there be private health information if people are talking about radiation sickness? How involved are we going to be with these activities?

Also, I am not sure where the PUC falls in any of this. They do regulation of power lines so the radiological health program does not do power lines. That falls under the Public Utilities Commission. I am not sure where Telecommunications falls and if that would fall under PUC or not. I just wanted to offer up those thoughts and certainly I am going to take this back to my program and I may have additional thoughts to share at a future meeting or through email.

Abrami: It is my understanding that telecom is not really regulated like the utilities because it's not considered a utility.

Sherman: I have a few thoughts. We have a commission to study environmentally triggered disease and we have been working on this kind of database on that commission. We have been disrupted by Covid and it's a senate commission so we have not been allowed to restart but what we have learned is DES has a site where private property owners can put their well test results in. I don't believe that required legislation or if they did that through rules. Individual well owners could enter their data into the site and make it possible for DES to develop a database for private well owners.

There is also on the public health side, and Michelle knows there is an entire infrastructure of public service and the ability to generate public service announcements. One concern I would have is with well testing you have a certified report from a well tester. But with this, if you have people self- report with what is on their digital read out on their EMF monitor that has not been verified. I would be concerned about any agency being compelled to report non verifiable data. Just a few thoughts but this might be something we could take up with the environmentally triggered disease commission. There might be a softer language to recommendation 3 and I agree with Jim that we should not say which departments would do this because it could be one of several departments.

Abrami: My concern is what data? What are people reporting? It's one thing if it's data but just feelings? I don't know we have to be careful…. feelings based on what?

Chamberlin: We will talk more about data collection in another recommendation but for this one, this is just a way for citizens to say I don't like the way the current legislation exists, Section 704 of the 1996 Telecom Act. Whenever people hear about it, they get very concerned about it because there is nothing they can do because of this legislation. How many people are concerned would be helpful to us as we move forward. If only a handful of people go on this registry and register a complaint, that tells us one thing but if we have hundreds then that tells us something quite different. It would only be so people who register could have their voices heard. Right now citizens who are concerned have no place to go. They can write letters to the FCC as I have and very likely nothing will happen. This just makes it a state initiative to identify people who are concerned so we perhaps can do something.

Roberge: Is this appropriate for an advocacy group? I don't know that it's an agencies responsibility to survey the feelings in New Hampshire. I would want to go back and talk to my leadership about this. Any data that we hold, we would have to make sure that the data is safe and valid. I just wonder if it's more something that an advocacy group would take on.

Abrami: Michelle, after you talk to your leadership, can you just drop me a note so I get a sense of where they are?

Chamberlin: So, actually the registry was an add-on to the first part which is a website that contains information about exposure to electromagnetic fields. This is informational and the add-on is to assess how many people are concerned. So what about the first part does this seem to fall within the purview of your organization?

Roberge: Before I make any comment on that, I would want to talk to my leadership. Right now, we are knee deep in Covid, as you know. I would want to talk with them and I can come back and share with this group what I learn.

Abrami: We have another six to go through and we have forty five minutes so we are going to move along.

RECOMMENDATION 4- Require every pole or other structure in the public rights-of-way that holds a 5G antenna be labeled indicating RF-Radiation being emitted above. This label should be at eye level and legible from nine feet away.

Abrami: Basically, with antenna being in the public right of way, I thought it wouldn't be a bad idea to have the poles labelled to that effect as they may be on telephone poles or light poles, etc. Current towers are usually surrounded by barbed wire fence or some structure around it at the base with a sign saying….don't climb the fence. Obviously, there are different reasons for that. That's all this is, to label the pole. Beware of the device on the top of the tower. Industry would have to label the poles. Can we open that up for discussion please?

Cooley: Just more of a comment and again, I still have to talk to my membership and my legal department. There are other entities in the public right of way that also use low level non ionizing radiation. So, I question if this is discriminatory. In the public right of way, you do have utilities, electricity lines and you also do have the cable industry deploying micro-wireless facilities also using 5G. Again, I have to talk to my members and legal and I wonder if this is a discriminatory practice should the commission endorse this in the majority report.

Abrami: So what you are saying is any device in the public rights of way emitting RF should have this sign. That way, it's not discriminatory. Is that correct?

Cooley: I don't know. I will have to speak with my attorney. I flag that as a concern. There are other entities in the right of way and this is targeting one.

Abrami: Brandon, do you have any comment on this one?

Garod: It's close. I think it's dangerous to apply if it only discriminates against one type of entity then it's definitely preempted. That's actually contrary to what the Portland case said. In the Portland case, they found that different types of restrictions can be applied to different types of infrastructure. Really, the key takeaway is if the effect of whether something discriminates against a particular company of particular type of infrastructure would have the effect of prohibiting their entry into the state to provide services, then that would be preempted. But, if it's simply requiring a certain type of infrastructure to provide a warning that is consistent with the type of radiation that is emitted by that type of infrastructure and placement of that type of infrastructure, I think there is an argument that could be made that that is permissible and wouldn't be preempted.

All of this is sort of fuzzy. I think that is in line with the court when the court prohibited the FCC from regulating too broadly a state or municipality's ability to regulate aesthetics that may be discriminatory against one particular entity but as long as there is a reason for it and it's not prohibiting their entry, I think there is an argument that can be made that it may not be preempted.

Sherman: I agree with Beth in a way. If there are multiple devices emitting RF, we should not have that warning limited to the telecom. Maybe the warning should read that there is an RF emitting device on this pole, no matter what that RF is. We know that cell towers look like. Right now, we don't know what 5G or small cells look like and we may not recognize that that emission is occurring from that pole. Rather than being specific about the industry, we should be specific about that which we are trying to protect the public from which is this level of RF exposure and that would get around Beth's concern. If it's a cable company or telecommunications company or wireless company, the point is to identify that that exposure is occurring.

Gray: The first thing you need to say is who is responsible for putting the sign up there. If it's the owner of the antenna, you need to say that. Second, your problem with this recommendation is that you go back to your preamble, nothing has been proven about the health effects so you are talking about potential health effects. Do I have to put a warning on the side of my house because it has a transmitter that transmits my water usage and electric usage to people who go by? Again, this needs to be looked at carefully because it could be a whole lot of impact if it's not done right.

Abrami: That's good, Jim. Thanks. I will take a crack at modifying this one and we will talk about it again.

RECOMMENDATION 5- Require that schools and public libraries migrate from RF wireless connections for computers, laptops, pads, and other devices, to hard wired or optical connections within a five-year period starting when funding becomes available.

Wells: This is mostly about schools and public libraries where the environment has already been fitted out with wifi. There is strong evidence that the RF associated with wifi might have greater impacts on young children. The Precautionary Principle would indicate that alternatives to RF would be preferred. Two possibilities would be to go to hardwired connections to every device or use a different frequency range and go up into the optical range where there are not likely to be any health effects to that. One of the things that the state of New Hampshire could look into is that classrooms could be fitted out with a device like Lifi which is an LED lighting fixture based optical data transmission. We need to look at how we fund this but Carol recommended one possible fund may be the FCC's E-Rate program for telecommunications and IT for schools and libraries. We figured if funding was procured then five years would be a reasonable amount of time to complete a project.

One thing that I think is an important point to note is that the optical means for data transmission is much faster than RF. So, essentially you would be saying, let's just skip RF and 5G and go into the next generation directly.

Gray: Certainly the opposition report on this one would be that if you link it to funding, and implementation, you take out the word, "require" and its better and the schools will do it because you are paying for it and its better. I don't have a major thing on this except the word "require".

Abrami: So just encourage schools and libraries to look at alternatives including Lifi.

Gray: you would want to put in there that when public funds or whatever funds are available.

Abrami: right. The reason we put about the funding in there is that schools have spent a lot of money putting this infrastructure in place and it would take a lot to reverse that course. Hardwire is an option but Ken's suggestion of Lifi and our understanding at this point, is that it wouldn't be an expensive option relatively speaking.

Wells: It appears that Lifi would be plug and play. It also involves an upgrade to a more cost efficient lighting. You might actually come out ahead on this. We would have to look into what the actual costs would be and savings but there is a possibility it would offset quite a bit of the cost with energy savings.

Gray: Just as a caution when you put something in your report that you don't have to do it until the funding is available, you are already that it's not that bad. Certainly, the cheaper that you can make it would mean that a parent of a child that is sensitive to electromagnetic radiation, could fund the conversion of one classroom or whatever. Just think hard about this one if you go forward with it. What if your data from studies proves that it's not harmful, then mandating is the wrong thing to do. In my example, the funding will dry up if the radiation is not harmful.

Wells: The E-Rate funding is not tied to harm. It's tied to telecommunications and IT in schools and libraries. But it's a good point you raise about taking federal out of the description of the funding. It is possible that you could get a charitable donation to convert school buildings. That's a good idea.

RECOMMENDATION 6-Establish new protocols for performing signal strength measurements in areas around cell tower radiators to ensure compliance with regulatory radiation thresholds and to evaluate signal characteristics known to be deleterious to human health as has been documented through peer-reviewed research efforts (e.g.,[1]). Those new protocols are to take into account the impulsive nature of high-data-rate radiation that a growing body of evidence shows to have a significantly greater negative impact on human health than does continuous radiation. The measurements should be taken in regions surrounding the tower that either are occupied or are accessible to the public. Commissioning measurements are to be performed when the site is installed and at regular intervals if required by state statute or municipal ordinance such as those required by the town of Burlington, MA [2]. Measurements should also be collected when changes are made to the tower that might affect its radiation, such as changes in software controlling it. Measurements should be performed under worst-case scenario conditions when the site is transmitting at its highest levels.

Abrami: One thing as a state that I think we need to know is…. if these antenna generating RF are even generating within FCC guidelines? This recommendation talks about what the state should be doing about this.

Chamberlin: This recommendation really has two parts. The first is to come up with new protocols for performing the measurements. The way we measure RF right now is the way we have been doing it for 50-60 years. It averages signals and does not take into account the summative effect of having multiple transmitters. One thing the FCC guidelines do not take into account at all and that is, in the last thirty years think of how many transmitters have been added to the RF spectrum. Now we are not being illuminated by a single source like a local tv station. We are being radiated by cell towers, our own cell phones, wifi and the way that measurements are taken now don't take the summative effect of those radiation sources into account. The first part of recommendation six takes that into account and prescribes a different way of performing these measurements. Also, what's being found is that it's not the continuous radiation that has the greatest effect on us but it's the transient nature and impulsive nature that has the greatest deleterious effect on health. The way this is worded, takes that into account and specifies a new way of doing measurements.

The second part says, you have to make the measurements and I could find no evidence that a cell tower ever has to be measured unless maybe there is a report of someone thinking the radiation is too great. The FCC doesn't have a commissioning for cell towers. I am familiar with this from working with the FAA. Any time you install anything, you always have a commissioning measurement to make sure it's performing according to specs. The cell industry from what I have read has basically made calculations about what power should be radiated from certain antennas and they say these calculated powers are below the FCC threshold so we are good. However, I know from experience that you can get what is called terrain or building focusing of electromagnetic waves that gives you far greater signals than you would expect from simple calculations. The second part of this says whenever you commission a facility, you have to go and make measurements under worse case scenarios and you have to do it using the new protocols.

Just basically wanting to make sure that the towers are putting out the types of power that have been calculated and that those powers are below the FCC thresholds.

Wells: Thank you, Kent. That's really excellent. I would make one suggestion though. When you talk about focusing by buildings and terrain, could you also add beam forming?

Chamberlin: You mean beam forming from the antennas? I wasn't sure how much detail I should go into but I am thinking when you set up a test protocol, you specify the beam forming will be at the location of the receiver. It's actually buried in the worst case scenario statement.

Wells: right. I was just thinking that you acknowledged that the radiation can be focused by buildings and terrain but it can also be focused deliberately.

Chamberlin: I will add that in. Thank you.

Roberge: I just had a question in terms of implementation of this recommendation. How do you envision that? Is that something that the cell phone company would do after installation? Do you envision a reviewing body of that or an independent analysis? It is unclear to me how this would be implemented.

Chamberlin: I was thinking it would be a third party or some independent measurement organization, perhaps even the FCC.

Roberge: I come at this from a regulatory standpoint. If you put a requirement out there and a measurement happens. It's fine if it all works out great but what happens if the measurement comes in and it's not consistent with what requirements are or is it a true requirement? Or is this just a recommendation? It's challenging to implement something like this if you don't have a true standard and you don't have consistent measurement protocols. What happens if it's above? Who will be the authority to make corrections or enforce? If you are thinking of this from an enforcement standpoint, for instance if this cell tower measures above, what happens then? From an implementation standpoint there can be challenges with that.

If you are thinking of implementing this as a licensing or commissioning and enforcement of it then there would be a cost associated with it establishing a protocol program whether it's on the federal level or state level. Who is the regulating body for that? Just a couple of thoughts there.

Abrami: We talked about this. We can get lost in the weeds on the detail. This isn't words or legislation. For that we would have to have a lot more detail than what you see here. We are saying we need a better protocol and the state has the right to ask for an independent person to measure at the worst case scenario that it's within FCC standards. This is not trying to change FCC limits on this. I understand asking, who do we go to if it's out of compliance. It could go to the courts. Either this is a good idea or it isn't a good idea. To me, this is a good idea. I don't have a comfort level that the industry is taking into account all the other towers and RF soup in the area that they aren't really above the federal limit.

What we are saying as a commission is, we think it's a good idea to use and independent body to measure and if it doesn't pass the test, then we as a state want to say you have to turn that tower off. Now they may come back and say, it's not our tower, it's the one down the street. These are the discussions that should be done at the federal level but it's not. We need to move forward with this recommendation and then the detail comes in if someone picks this up to write a bill where we would add more detail on some of the things you are bringing up Michelle.

Chamberlin: I can make this really brief. Cece linked in the text chat with some certification requirement from Burlington, Mass. I will read that and see if I can add some of what they have done to our recommendation and move forward with that.

Heroux: Actually, this kind of a situation has been taken into account in the past in relation to the tops of buildings where you have forests of radiating structures and this is why advanced equipment that has frequency analysis capability was created. If these locations exceed, for example thermal limits, there is a requirement that says you have to have a power intensity reduction. But it has never been taken into account for the general environment outside these facilities. Essentially, because it's assumed that outside this region there is no hope that you will ever reach thermal levels. But if you are taking into account crest measurements and peak characteristics, of course the situation can change very substantially.

RECOMMENDATION 7- Require that any 5G antennae located on a public right-of-way or new cellular phone antennae of any type, be set back 1,640 feet (500 meters) from residences, businesses, and schools within a municipality enforceable by the municipality during the permitting process unless all owners of a residence or business or a school district waives this restriction.

Abrami: We went back and forth of this one in the work group. I will let Paul explain.

Heroux: Essentially, here there is no desire to challenge the FCC on power levels. There is no desire to challenge the availability of wireless services. There is just a desire to have these towers with a setback from dwellings where people live or work.

Gray: Your 500 meters is .31 of a mile. The recommendation doesn't take into consideration anything about the transmission, what the power level is at any particular point along that .31 of a mile. I went to look up the things that were listed there and found it very difficult. It took me to Google Docs. I looked also at our webpage to find them. Again, I think if you are going to include something like this then you need to start getting into more detail. But a third of a mile would eliminate cell antennas. There are an awful lot of people you can pack into a third of a mile.

Cooley: Again with the caveat that I need to discuss this with members and legal department. I do think there is an argument that can be made that this violates section 332 of the Telecom Act. That is, you are trying to tell providers where they can and cannot site facilities which could have the effect of impeding service thus increasing the cost and providing a barrier to entry. You are saying where we can and cannot go which has been ruled as a defacto moratorium and has been ruled unlawful. Again, I need to run that up the chain but that is my initial impression.

Wells: this is a section where we need to make a distinction. It is referred to as 5G and we need to have an RF definition. The thing that is unique about 5G is not the frequency or the power levels but the proximity to people. This recommendation talks about a setback which is dealing with the unique quality of 5G. It's very close to people. There are some other applications and implementations like smart meters that might also fall into this. We need to come up with a definition of what sort of transmissions we are talking about because to call it 5G is to give it a trade name rather than a physical definition.

RECOMMENDATION 8- Require power intensity disclosures for renters and buyers and for public buildings (locations where the general public may go)

Wells: This recommendation requires power density disclosure for renters and buyers and also public buildings. The idea here is that some agency of the state would also be a recipient of those readings so the public has some idea of what they are exposed to. I understand that the objection has been made many times that there is no safe threshold that has been specified. But we know that just as kitchen appliances have an energy usage scale on them showing where they fall on the range of low energy and high energy use, the same sort of scale could be understood by buyers and renters that perhaps less intense energy is more desirable than more intense energy. They can figure out where they stand in that continuum.

One other part that is important on this, in order to make this practical, the instruments used need to be affordable and available. We have identified one particular example, the GQ 390 meter and the price is under $200. Some agency of the state could loan them or real estate agents may find it's more convenient to own their own.

On the state owned ones, it would be easy to get the manufacturer to verify they are all benchmarked and consistent in their sensitivity.

Abrami: the more thought I give to this one, there are really two pieces to this, the buyers and the sellers and then any public place. I think any public place would be really unwieldy. But the buyers and sellers, it's akin to getting a water test and a radon test. That's, basically what we are talking about.

Sherman: I have a concern. I see this running smack into the realtors. You and I have worked with them in the past and I am just thinking of a pre-recommendation compromise and one thought would be rather than requiring of a measurement and Michelle would probably tell us would require funding to have this program. In other cases, haven't we required full disclosure if you have knowledge of issues on the property. The seller would be required to disclose radon levels, lead paint, all of these other things. Couldn't we say the owner would need to disclose potential RF exposure or known RF when you sell a property?

Rather than putting in a whole new infrastructure, I think this is going to run into pushback at the fiscal level and at the regulatory level. But a lesser would be to require any known exposure to RF or RF levels.

Gray: This one is so broad reaching. What happens when I change one of my routers? Do I have to go retake the measurement and redo the posting? Again, we don't know what the safe level is. One of the things that could be done if we did know what the safe level is would be to set a limit up to this. And I know Dr. Chamberlin says it's the way we do beam forming and all that. This would be very difficult to do.

Abrami: the real estate folks have already weighed in by the way. You can imagine which direction they weighed in on.

Roberge: I was going to add in. Senator Sherman touched upon it. Depending upon how you envision this being implemented, there could be costs associated if this gets delegated to an agency to implement.

Chamberlin: we would definitely have to specify the conditions under which the measurements would be taken. I would say that when you are going to take these measurements for real estate purposes, you would turn off all internal sources so everyone would be on the same level playing field.

Abrami: Ken, you mentioned the Bio-initiative 2012 report, the 1,000 microwatts per meter squared.

Wells: There is a recommended maximum level by the Bio-initiative 2012 report of 1,000 microwatts per meter squared. This is a pretty high level. This is a peak exposure. These meters could measure peak and averages over 24 hours and could measure frequency. There is quite a bit of information that would be available and I think it would be valuable for the agency that collects this. It would allow them the basis for building a map of RF around NH and give them data for pursuing future public health investigations about say cancer clusters in relation to transmission or cancer clusters that are not related to transmission but perhaps some other environmental sources.

Abrami: This, ties back to Kent's proposal about a database but this would be real data. There could be hotspots in a neighborhood or a town. All we are saying is, maybe before you buy a house, you want to know about it. We went through this with radon and lead paint. The more we see radiation flying every which way, I think this is prudent. It doesn't have anything to do with the industry or the federal government. It's just informing the buyer or the renter that you might be in a pretty hot zone.

Heroux: Actually, Senator Gray is right. If you install another antenna, the levels will change. Essentially, this is what you are trying to determine by a number of these measurements to see what the evolution in a particular place or state how radiation is evolving. These measurements are fundamentally fairly easy to perform if they are performed by an instrument. They are probably preformatted so compiling them could be relatively simple.

Woods: Going back to the fact that we could sort of massage this. The concept is very good and this is a recommendation that says to the public besides the legislators in this report that this is an area that we need to consider. Now, the details are going to be a morass to say the least. But I think as you pointed out earlier Pat, these are areas that we see as a commission that need attention. As Tom said, the realtors are going to have some input but I think that's for another day. To the Legislature and to the public, we are saying we feel this is an important issue.

Ricciardi: I just wanted to say that maybe an RF map would be good for people who are already microwave sick. That way they would know where the transmitters are the highest and could avoid them.

Wells: I think that's a great idea. I just wanted to point out that Cece Doucette put something in the chat that there is already an RF meter loan program in Ashland, MA through the public library. This would not be hard to do. They are not terribly expensive.

Gray: It appears what you really ought to do after listening to Dr. Chamberlin, is split it into two. If you are transferring real estate then taking measurements with wifi turned off etc. may be appropriate.

But if we are talking about posting for the public, then it's radiation when I walk into that building which would include all the sources inside the building. It is unclear what you are really trying to do with this. Are you trying to mix these two concepts together? You've got to remember that exposure for most people would be a long term thing that would affect them and not a short term thing.

Abrami: I agree. I think I said this earlier. Comingling the purchase of property vs posting measurements in public areas in the same recommendation is a tough one. If anything, we could split them out and vote separately.

Wells: How about if I take the public building part of it and make that a separate part or possibility for future consideration?

Abrami: that would probably be better.

RECOMMENDATION 9- Require all new cell phones sold in New Hampshire come equipped with a sensor that will stop the phone from radiating when positioned against the body.

Heroux: This speaks to the fact that there is an opportunity in cell phones themselves, to mute the radio emissions when the phone is held against the body. There are various ways of implementing this. Initially, I presented it as the fact that the phone should be hardwired to do this. There are many other ways to do this. The weakest way is to say we require that you can download an application that will make your phone behave that way. The most sensible one might be to have a toggle on the phone or a menu item that allows the phone to function in this manner. If you choose not to have your brain radiated, you can choose that function on the phone itself. Between these extremes of you having it hardwired or you having to do a lot of things to eliminate the radiation. Or there is another possibility the phone could come with the toggle switch installed and you could disable it if you wish. That means you choose and you agree that you believe that this risk is not substantial so you prefer to use the phone against your head rather than avoid the risk.

Abrami: I think it has to be individual preference. We want to give those who are concerned about it a chance to have something that will help them.

Wells: this is the first that I have heard of that last suggestion and I think that is a good one that the phone is delivered to the customer with the safety option on and the user has the option of disabling the safety function.

Sherman: One other option in this would be I believe this is true that they have this capacity but have opted not to install it on phones, the idea of instrinsic shielding that would protect the customer from radiation. There was a move about fifteen years ago to develop sleeves that you could put over your phone to shield against the RF that was emitted toward your head. I like the toggle idea. I would not go for the requirement that all phones shut down if you put them by your head. The toggle and personal choice is a great option. Or the other part you could put in there would be the intrinsic shielding.

Gray: Are we creating a scenario where phones are not going to be sold in NH anymore?

Abrami: this is simply a recommendation to the cell phone manufacturers to consider.

Gray: We are not as big as the state of California who has driven emission regulations by state regulation. I don't know that the cell phone industry is going to modify what is available to customers because of the state of New Hampshire.

Abrami: the cellphone industry knows that holding the phone against your head may not be the best thing because it's in their legal section. There must be a reason why they are saying that. So, if you believe that then why don't you install an option where a user could turn it off. That's all we are doing as a commission is recognizing this issue and making a recommendation. It's got to start somewhere. It's my understanding that other states are following us on these proceedings. If we take that first step, other states may also weigh in on it.

Ricciardi: I just want to add to that is that our job is to protect the residents of New Hampshire. That's what we are doing with these recommendations. Again, they are recommendations, not law. We have to do that. With all due respect to everyone, here all opinions are appreciated but as we know, the majority will write one report and those who are in disagreement are entitled to write their own. I would caution on making too many changes to the one we did if the majority agrees with it. Since the other report will be written anyway. Thank you.

Gray: The point that I was trying to make in a lot of this thing is that if we go right back to the first paragraph and we say these things aren't proven. So to make recommendations that may impact the cell phone may cost more in NH. There are reasons why we should be cautious in the recommendations that we make.

Heroux : I take Senator Gray's point that New Hampshire is not as large as California and in some instances may not have the same influence. But I have to say, I am a fan of New Hampshire and maybe you are as big as you feel.

Wells: I just want to remind everyone about New Hampshire's role in MTBE. We are not without influence.

Abrami: Let's do number ten. Eleven is still under consideration and twelve we can talk about next time.

RECOMMENDATION 10- Propose legislation that would facilitate the implementation of fiber optic cable connectivity deployment and internal wired connections to serve all commercial and residential properties statewide.

Abrami: it's just basically a statement that the state should promote fiber optic cable. Carol had to leave. I am going to let her weigh on this next time. Members of the work group, I want to work on their recommendations based on this input. Jim has some good comments in his as well as the others and should take those into consideration. We are running out of time. Unfortunately, we lost almost four months. I couldn't even get zoom time from the House. Good thing Kent has been gracious enough to let us use the University of New Hampshire's zoom account.

I think we need to have more than a meeting a month.

Sherman: We are having trouble on the Senate side with all the zoom meetings we need to have. So if we could have all the materials we need for the next meeting well in advance and preferably have a longer meeting rather than three shorter meetings and just get the work finished as best as we can.

Abrami: I'd like to do it in three weeks. How about Tues the 22nd at 9? We will make it a 2.5 hour meeting. Kent will set that up. Thank you everybody. We will make our way through this.

V. Next meeting via Zoom: Sept 22nd 9-11:30

Meeting Adjourned at 11: 15 am

Text chat during Zoom meeting:

00:51:58 Paul Heroux, PhD: Identify Health Impacts of Environmental Factors: Barack Obama and Joe Biden believe it is critical to understand the relationship between environmental factors and risk or onset of disease, particularly cancer.
They support the efforts of Senators Clinton and Hatch to expand CDC biomonitoring programs, and as president, Obama will expand the collaboration between the CDC and state public health agencies across the country to increase understanding and improve treatment of individuals negatively affected by environmental factors.

01:19:35 Cece Doucette: For Recommendation 2: Might NH consider taking a leadership role with peers in all other states, share the Commission's final report, and encourage them to make a similar request to their federal delegations? This approach might help to get meaningful action to protect the public sooner rather than later since the 4G/5G small cells are going up in real time, and children are being given wireless devices to access their education with no safety instructions.

01:29:43 Cece Doucette: Thank you, Dr. Sherman. It would be helpful to the public to label every RF-emitting device, including utility smart meters and the collection devices mounted on poles outside of residents' homes.

01:36:19 Cece Doucette: For Recommendation 5: Please vet all new technology through non-industry funded scientific investigation before exposing our collective children. LEDs and Li-Fi may have risks, but hard-wired technology to the premises with Ethernet cables and adapters is proven safe.

01:43:13 Cece Doucette: For Recommendation 6: Please see Burlington, MA Small Cell Policy, which requires an annual recertification by an independent expert, and the wireless vendor pays the town to complete the annual recertification.
http://www.burlington.org/town_government/small_cell_information.php

01:48:36 carol.a.miller: I apologize but I have a hard stop at 11am this morning. I will just disconnect when that happens.

01:48:53 Beth Cooley: Same here

01:56:29 Cece Doucette: For Recommendation 8: We have modeled an RF meter lending program at Ashland Public Library, MA. Others are emulating this too. It was based on kill-o-watt meters put on loan in our libraries by the energy industry.

02:04:35 carol.a.miller: Again I apologize that I must leave the meeting now.

02:06:10 Cece Doucette: Thank you, Ken.

02:09:00 Brandon.H.Garod: I apologize put I have to leave for another meeting.

02:09:26 Cece Doucette: Please consider adding a new recommendation to educate the public. I drafted a fact sheet with the MA Department of Public Health, and have built a non-profit with quick on-line courses that the public could take today and have the right to choose how they wish to use the devices within their control. Please see https://www.wirelesseducation.org/store/l2/ and https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnx1bmRlcnN0YW5kaW5nZW1mc3xneDo2OWYxMmNhY2ViNDcwMmQx

02:15:05 Cece Doucette: For Recommendation 9: Shielding can be helpful, but unless the shield absorbs the radiation, it will deflect it back into the hand, other body parts, and other people/children in the vicinity. We have seen hand cancers from cell phones too. See attorney Jimmy Gonzalez testimony in Florida: https://www.youtube.com/watch?v=XitM4Ikpvgo

02:17:31 Marty Feffer: Unfortunately, only humans will be able to make the choice to limit their exposure to cell phone radiation with the ideas you are discussing. The natural world who are also being irradiated, and have been, are suffering just as much, if not more, from exposure. Our responsibilities run deep and wide if we honestly look at the complete picture.

02:21:09 denise ricciardi: to sign off

02:22:51 Paul Bloede: My apologies for asking if I was being spoken to, earlier; I hadn't studied my notes from last time, closely enough, apparently, to realize there is a Paul who is truly a member of the commission: Dr. Paul Heroux. Again, my apologies.

02:23:51 Marty Feffer: Thank you for your work. Inspiring to other states.

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS OF EVOLVING 5G TECHNOLOGY

Meeting held:
9/22/20
9:00-11:30 am EST
Via Zoom (https://unh.zoom.us/j/95115866784)
Via telephone-US (1 301 715 8592 (US Toll) ID: 951 1586 6784)

In attendance: (13)
Rep. Patrick Abrami-speaker of the house appointee
Rep. Ken Wells- speaker of the house appointee
Kent Chamberlin-UNH-appointed by the chancellor
Denise Ricciardi-public-appointed by the governor
Michele Roberge-DHHS- Commissioner of DHHS appointee
Dr. Paul Heroux- Professor of Toxicology, McGill University- speaker of the house appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee
Senator Tom Sherman-president of the senate appointee
Brandon Garod-AG designee, Asst. AG Consumer Protection
Bethanne Cooley-CTIA , trade association for wireless industry and manufacturers
Carol Miller-NH Business & Economic Affairs Dept * *(joined meeting in progress)*
David Juvet-Business and Industry Association

Not present: (0)

Meeting called to order by Rep Abrami at 9:03 am

Abrami: Due to the Covid 19 virus and the Executive order signed by the Governor this public meeting is allowed to be conducted via Zoom. It is open to the public for viewing and was duly posted as a Zoom meeting. With that said, if you are not a member of the Commission, can you please turn your cameras off and mute yourselves? That would be much appreciated. In addition the meeting is being recorded as an aid to doing the minutes. All chat room discussions will be included in the minutes.

Since we are going to be taking some votes today, I am going to have to do a roll call. That is also a requirement. The votes today will be in the order going to my left as we were seated in Concord for our meetings. Please say where you are and if anyone else is in the room.

Tom Sherman- I am here alone, Rye NH
Ken Wells- I am in East Andover with my dog.
Kent Chamberlin- I am in Durham, NH and I am alone.
Carol Miller- absent for roll call. (*Joined meeting while in progress later*)
Denise Ricciardi- I am in Bedford and I am alone.
David Juvet- I am at the BIA office in Concord. Others in the building but I am alone in my office.
Beth Cooley- I am in Sarasota,FL and I am alone with the exception of my dog.
Brandon Garod- I am at the AG's office, Concord. Others are in the building but I am alone in my office.

Michelle Roberge- I am alone in my office at DHHS, Hazen Dr. Concord.
Paul Heroux- I am in Montreal and am home alone in my office.
Gary Woods- I am in Bow, NH and am in my study at home alone.
Jim Gray- I am alone here in Rochester alone in the kitchen having breakfast.
Pat Abrami- The Chair is here in Stratham, NH and I am home alone.

Ok. Thank you. So we have 12/13 present at the moment.

I. Approval of minutes from 8-31-20:

I have not received any changes to the minutes. Are there any changes that anyone wants to make? Seeing none, I will say …without objection, we approve the minutes from that meeting.

II: What remains for the Commission:

Abrami: I spoke to the Speaker this week to see if there was any wiggle room with the November 1st date. He said it would be very difficult to change. So, my intuition is we strive to get to the November 1st date to get the report done. Just keep that in the back of your mind. We have had a work group of seven working on recommendations and we are going to vote up and down on those.

There will be a Minority Report. My goal is to give those involved with the Minority Report proper time to react to the Majority Report in their report. My goal is to have the total report done by the middle of October, if we can. We have a lot of pieces of it. Joel Anderson, staff member appointed to the Commission will be helping put those pieces together.

So, that's where we are at. My goal is to have one or two more meetings. The Majority work group will have to meet to put finishing touches on the report and get it to Jim and whoever wants to work with Jim on the Minority report to give them a week or two. I am thinking the full Commission needs to meet the third week in October just in case we need another week to do some adjusting.

III: Minority Report and Agency Disclaimer:

I sent out to everybody some sample reports of Minority reports. In this case, I think what we will do is make the Minority report part of the report and it will be the last section where the Minority can say what it's going to say. It will have a header that it's the Minority report. So it will be one report that will include both.

As far as the agency disclaimer, Joel dug out my old marijuana Commission report. At the end, the agencies had trouble saying they agree or disagree. Brandon, Carol and Michelle are the three that work for the state. This is what I think it's going to sound like: Members of the Commission of the study of the environmental and health effects of evolving 5G technology agree to the filing of the report by the chairman. This action should not be construed in any way as an adoption of any particular position of a commission member or the state agency or organization they represent on the underlying issue of the deployment of 5G technology. It's as simple as that. I think this may make the members who feel uncomfortable more comfortable with their position on the report. Brandon and Michelle, any reaction to what I just read?

Garod: I think at first glance, that language probably will work for DOJ but I would like the opportunity to run it by the Attorney General to make sure that he is comfortable with it.

Roberge: I agree, same thing. I would like to run it by our folks here.

Abrami: I will retype it and send it so you have a hard copy to share with them.

I am going to move this along. We had a meeting and talked about most of these recommendations and a few new ones did come up. It would take a lot to change a recommendation. If someone says, if you change it this way or that way and I can vote for it, understand that the work group pretty much agreed to the language here. Obviously, grammatical things will be accepted and if you have a real issue with a particular recommendation, my sense is you would probably be in the minority report. I apologize in advance, but I am going to move this fast. I just want to make sure we get this all in today so we can move on to finalizing the report.

IV. Work Group Recommendations and Vote:

The rule is, we need to have a roll call vote on each of these per Joel and the folks that know about these things. We are going to talk quickly about each of these and take a vote. When you vote, you will vote … yes, no or abstain. The majority of those who vote yes or no will make it into the majority report. That's what the ground rule is. Is there any objection to that ground rule? I don't see any. Thank you.

If you read the intro to it, what the work group concluded is that (in my words) the science is conflicting in some regards but there is enough science out there that's showing more study needs to be done on this topic. Given that we tried to reach out to federal agencies and they didn't really answer our questions and all the other things I mention in this intro, the conclusion of the majority is that we have to use the Precautionary Principle here. You will find that we have softened some of the recommendations from the last meeting. I am assuming that there may be enough that these are the majority position but it may not be. It may be the minority. I kept the numbering the way it was so we didn't confuse anyone even though we will be taking #2 off the table. After we are done voting, we will reorder these for the report in a logical way.

Juvet: Mr. Chair, could I ask a process question before we start on each of the recommendations?

Abrami: Absolutely, Dave.

Juvet: As a part of voting, are you looking for just an up or down vote? Or can we, as members of the commission explain why we are voting the way we are for the permanent record? I don't want to make this process any longer than it needs to be. I just need some clarification.

Abrami: You can do that during the discussion.

Sherman: I know we are going on the recommendations, but before we do, in the version I have which says 5G commission recommendations at the top of it. I think it's the Sept 17th version. Is that the latest?

Abrami: yes.

Sherman: There is a sentence that to me does not make sense. Would this be an appropriate time for me to point that out?

Abrami: Yes. Please.

Sherman: It's in the introduction, midway through. You will see the words, "the effect of the soup". Then it says, "today, which will only be growing in the world of if the roll out continues is not known" That phrase grammatically does not make sense to me. I don't know what the intent of that phrase was.

Abrami: if anything, the amount of RF will be expanding over time.

Gray: I took it as "the soup" is going to be growing, the amount of RF. That's what I took from it.

Sherman: But if I could just wordsmith that just to keep it simple.

Abrami: Yes. Absolutely.

Sherman: The effect of the soup of RF waves surrounding us today, which is likely to increase over time. Perhaps, you could do something like that, because it was unclear.

Cooley: We will be providing comments to Senator Gray's Minority Report (CTIA). Second, I would just like to publicly object to the entire introduction, most notably the first sentence. The Commission has indeed not heard from many experts on both sides of the issue. As you recall, the Commission heard from one pro-5G Physicist on November 20, 2019 who ran out of time. I do understand that the pandemic did lose us many months. However, upon learning of new research during the summer regarding the safety of 5G, I offered to reach out to the authors of that study and I was told in no uncertain terms that there were to be no more experts. However, funny enough, I then hear of a so called expert presenting before the working group at their Sept 11th meeting. We would just like as an industry and CTIA to highlight that this biased approach and preordained outcome of the Commission has not gone unnoticed, and we will be making these facts very clear to the General Court. Thank you, Mr. Chair for the opportunity to speak.

Abrami: right and how many times did I say to you even before the virus, give me your best shot and any time you want another speaker, let me know. It isn't like I didn't do that. We lost about four months with the virus. The group argued that we really didn't have much time to hear additional testimony. Yes, Paul suggested we hear from this lawyer, who wasn't a technical guy to possibly help us with some of the language.

Ricciardi: I just want to address something since Beth has brought up the word "biased". I think you represent the CTIA and having been in a lawsuit in Berkley, not wanting to have the fact that the information about the proximity of the phone to the body that is hidden inside the information for the phone, not brought out, which was the lawsuit. That could be considered biased too, seeing that you are on the Commission. Thank you.

Abrami: I understand. I had many emails about this, Beth. I batted them away. There were people out there who wanted you off the Commission and I said absolutely not.

Cooley: Yes. I heard both the allegations and personal attacks against myself, CTIA and the industry. Again, the facts will be made clear to the general court.

Abrami: That's fine.

Gray: This is Senator Gray. We need not to be defensive about comments that are made today and try to rebut them. We just need to accept them as a comment and move on or we are not going to finish anywhere near eleven.

Abrami: I agree, Senator. Again, that's what the Minority Report is for.

RECOMMENDATION 1- Propose a resolution of the House to the US Congress and Executive Branch to require the Federal Communication Commission (FCC) to commission a review of the current radiofrequency (RF) standards of the electromagnetic radiation in the 300MHz to 300GHz microwave spectrum as well as a health study to assess and recommend mitigation for the health risks associated with the use of cellular communications and data transmittal.

The Telecommunications Act (TTA) of 1996 was adopted before the health risks and biological effects of RF-radiation to the human body were fully known to the scientific community as well as the public. The Commission believes that the FCC has not exercised due diligence in its mission to manage the electromagnetic environment, failing to support technical means and investigations aimed at reducing human exposures to electromagnetic radiation (EMR) in telecommunications systems, and optimize wireless modulations to reduce biological and health impacts. Commissioned research should study the health effects and should be conducted by an independent research organization with standards which have been mutually agreed to by all the stakeholders. The FCC shall then ensure that the findings and recommendations are adequately disseminated to the public.

Abrami: First we had #1 as a joint resolution and I agree with Senator Gray, that the Senate does not like joint resolutions and they would never do one. So, we put a resolution of the House. Basically, what #1 says is more health studies are needed. We broadened the range to include anything in that range, not just 5G. Discussion?

Chamberlin: This is just wordsmithing. The section that says, "investigations aimed at reducing human exposures to EMR". Well, we are not really trying to reduce radiation, necessarily. The wording that I suggest is: "we want to set exposure limits that protect against negative health impacts". I would suggest making that change.

Sherman: I have a change as well. It reads, "require the Federal Communication Commission (FCC) to commission a review of the current radiofrequency (RF) standards". I would say, "an independent review". It's already been determined that the bulk of the FCC is comprised of Commissioners who have spent a significant component of their career in the telecommunications business. So, for them to have an in-house review of this, is like having the fox watch the hen house. That's true of any federal agency. They would typically do an independent review.

Heroux: Is it necessary to point to the FCC? We know historically what the FCC does and they just performed a review that they will just repeat. So, why not say the federal government?

Ricciardi: I agree with Paul. Also, the industry says that the biological effects are not health effects. We know that it is so I think the wording has to be in there that you have to have clarification about the impacts of biological effects.

Abrami: It's interesting that most of these changes are coming from the work group. So we are saying the federal government.

Ricciardi: and add protect against the biological adverse effects.

Heroux: Yes. This is what I was suggesting.

Sherman: She is referring to the non bolded section. I would leave it because it's more inclusive the way it is. It's in there twice already.

Sherman: Mine was independent review and Paul's was federal government. I kind of like leaving the FCC.

Abrami: I didn't have a problem with the FCC either.

Woods: I would leave it as the FCC and I think the important part would be to have fabricated that it's independent.

Sherman: Why don't we go ahead and vote on this one?

Abrami: So, keeping the FCC, adding independent review and changing to exposure limits to protect against health impacts, any other discussion?

Juvet: Mr. Chair, before you call the roll I just want to let the Commission members know that I am going to be voting against this recommendation. It states in the non bolded area that the commission believes that the FCC has not exercised due diligence in its mission and my organization just doesn't believe that is true. So, I will be voting against this recommendation.

Abrami: Ok. Thank you, Dave.

Gray: What I would put into the Minority Report on this one is that we don't have a problem with further research. You could even fund the research from the federal government. The way you conduct that research though and some of the other in here is what we would object to. In principle, the research I am good with but the rest of it…no.

Abrami: Thank you Jim.

Heroux: Just to be clear, I would vote for this recommendation whether it's FCC or federal government. It's just with the federal government somebody would have to make the decision to ask the FCC, which will be a further decision. But, both carry the same idea.

Abrami: Ok. Thanks, Paul. Ok. Here we go. I will call the roll: Tom Sherman (yes), Ken Wells (yes), Kent Chamberlin (yes), Carol Miller (absent), Denise Ricciardi (yes), Dave Juvet (no), Beth Cooley (abstain), Brandon Garod (abstain), Michelle Roberge (abstain), Paul Heroux (yes), Gary Woods (yes), James Gray (no), Patrick Abami-Chair (yes). There are 7 (yes); 2(no); 3 (abstain) and 1 absent. The motion passes.

RECOMMENDATION 2- Establish a State position that protects the State and all its Municipalities from any liability from harm caused by small cell antennae placed on the public rights-of-way. Specifically, liability of the State of New Hampshire and its municipalities connected to harm caused by claims of personal damage or harm from the deployment of 5G small cell towers or the attachment of 5G antennae on telephone poles, electric poles, lamp poles, or other structures on the public right-of-way is by state statute transferred to the Federal Government. The Federal Government shall be required to defend and indemnify the municipality from any liabilities arising from permits and the installation, operation, and maintenance of small cell installations. Since the State of New Hampshire and its municipalities are being forced by Federal Law to deploy 5G small cell towers and antennae on public rights-of-way, the Commission has concluded that that the State and its municipalities should be held harmless from any litigation claiming harm for any reason, including damage to health. The Committee feels that this recommendation should not be of any burden to the Federal Government or to the cellular industry and related industries who support the cellular industry, since they believe that 5G technology is safe and thus there will be no harm caused by having these antennae so closely deployed to the public on the public right-of-way. **DEMOTED TO SOMETHING THE COMMISSION DISCUSSED**

Abrami: The workgroup has decided to take this off the table. We kept it here for numbering purposes. It will be demoted to a topic of discussion in the report saying the commission discussed this issue. The position of the workgroup was to not include this recommendation. So are we ok just skipping this? If you want to say something, raise your hand or just speak out. It's quicker. There is no one monitoring this other than myself. Ok.

RECOMMENDATION 3- Require that the most appropriate agency (agencies) of the State of New Hampshire include links on its (there) website(s) that contain information and warnings about RF-Radiation from all sources, but specifically from 5G small cells deployed on public rights-of-way as well as showing the proper use of cell phones to minimize exposure to RF-Radiation. In addition, public service announcements on radio, television print media, and internet should periodically appear, warning of the health risks associated with radiation exposure. Of significant importance are warnings concerning the newborn and young as well as pregnant women. Even without further study, there is compelling evidence that the public should be warned of the potential dangers of RF-radiation and be told simple steps to lessen the risks of unnecessary exposure. Attachment XX shows an example of a simple cell phone warning.

The website must provide an option for visitors to register their concerns about current FCC exposure guidelines. In particular, this registry should provide a convenient and formal mechanism for New Hampshire municipalities and residents to weigh in concerning the contentious 1996 Telecommunications Act Section 704 that disallows using radiation-related health concerns as a reason to challenge cell phone tower siting. The primary use for the data collected on this registry will be to gauge the level of concern about RF-radiation exposure there is on the part of New Hampshire citizens.

Abrami: This has to do with public information related to RF radiation in general and public service announcements and postings of certain warnings. Kent, I think you and Carol worked on this.

Chamberlin: This is part of informing people about potential problems associated with exposure to fields. Now a lot of people do not realize that there are any negative effects. This would be an opportunity to provide warnings both on the signs and on the webpage indicating what those potential hazards are. The other aspect of this is to allow people to provide an opportunity for New Hampshire citizens to register their concerns about the current legislation, for example the Telecommunications Act of 1996. It would be just a way for them to air their concerns. The data would be used to inform us or the state about what the level of concern is. As I mentioned the last time, if only a handful of people are concerned, then perhaps it's not that big of an issue. But my own experience having people call me at the University to have me come out and make measurements and ask what they can do about cell tower exposure. I haven't been able to send them any place where they got satisfaction. This would be an opportunity to provide a registry for people to log concerns about exposure to RF fields.

Abrami: Kent, I think a lot of what you are saying relates to another recommendation. This was really Carol's. This was more about public service announcements and things on the website.

Chamberlin: I am sorry. I did mention that but my apologies that does relate to another one.

Sherman: there is a typo in the second line: "their" is what it should be.

Juvet: I just have a question about the first sentence in the bold where we are suggesting that the most appropriate agency or agencies of the state include links. As a commission that's been studying this, are we unable to name which agencies we think should be responsible for this?

Abrami: Originally, we had DHHS but we decided that it could be more than one. It could be others like environmental. So, we just kept it broad.

Heroux: In the version I have, the last paragraph, it does mention that the website must provide an option for visitors, as Kent had indicated. Does this mean that this paragraph has been transferred elsewhere? It means that there are links for people and perhaps by filling out a form.

Sherman: He is saying it reads that the website must provide an option for visitors to register their concerns about current FCC exposure guidelines.

Chamberlin: The intent was not to go to the FCC but would be a registry for the state of New Hampshire.

Heroux: What Kent is saying is that there is no way for any citizen who is concerned to voice that concern and their situation and it is not wise for New Hampshire to be totally deaf to such a situation. It could be fairly simple. There might be a standard form that can be uploaded and simply kept on file until for some reason it is decided that this needs to be analyzed.

Juvet: Mr. Chair, can I make a comment on this point? Two things: If we are only allowing a vehicle to only register concerns, you will get a very one sided point of view and I am wondering if that could be changed to say register their opinions.

Abrami: I think you are correct.

Juvet: the second thing is more of a procedural thing. I am unclear if this is established, what happens then? I am not quite clear on how this information will be used.

Abrami: The data could be accumulated and then interested parties would have a place to go to look for opinions of the public.

Juvet: One final comment about midway through that paragraph, you are labelling the 1996 Telecommunications Act as “contentious”. I think that is a little pejorative also and I would remove the word “contentious”.

Sherman: I would go one step further and take out that middle sentence because it is judgmental.

Abrami: you are suggesting that we take out the section that says: this registry should provide a convenient and formal mechanism for the New Hampshire municipalities and residents to weigh in concerning the contentious 1996 Telecommunication s Act.

Sherman: I would get rid of the word “contentious” no matter what. I agree with Dave. I would change it as a way of people logging opinions rather than telling people what they should be discussing.

Abrami: Most of the public has no idea what the 1996 Telecommunications Act is. Municipalities would because they are doing these sitings all the time.

Sherman: I would just get rid of” contentiou”.

Gray: The first objection I have is the word “compelling” in the first non-bold sentence. If we look back to the preamble, we say the science isn’t all in and throughout this report I don’t believe we should set up a new division in the state anywhere that summarizes all this stuff and has action etc. But, we will put all that into the Minority Report.

Sherman: I agree with Jim. We are saying we are going with the Precautionary Principle because we don’t know. So, saying “compelling” says we know. There is evidence that the public should be warned. There is evidence but there is some editorial comment in this report that is stronger than what I am comfortable with. Get rid of the word “compelling” and “contentious”. I think it sounds a little less judgmental and a little more acceptable to your audience.

Juvet: Mr. Chairman, along those lines, in the very last sentence of the non bolded section says "the primary use of this data collected on this registry will be to gauge the level of concern. I would be more comfortable with "opinion" in place of "concern".

Abrami: I am ok with that as well. Are there any other changes?

Roberge: I request some qualifying language around "appropriate funding" if this was to go to a state agency and the agency was required to do PSAs or whatever. There might be a funding issue that may come up.

Sherman: Michelle, you make me smile.

Abrami: … this cannot occur unless the legislature provides proper funding. Is that ok?

Sherman: you could say that the legislature fund the most appropriate agency in the state of New Hampshire. The first step as Michelle is saying and those of us in the legislature know the first step is you need the funding. You could put "supported by funding granted by the legislature".

Gray: When this goes to the legislature for adoption, it will get reviewed and if there is funding required, it will be part of it. So, I don't even think you need to talk to the funding specifically. Thank you.

Wells: Back on the last item where we talked about the level of "opinion". I think it would be more appropriate to say level of "interest" about RF radiation exposure on the part of the public.

Juvet: I don't have a problem with that. I agree.

Abrami: I think I got all the correct changes. We have the funding piece. We have the correction on the "there" to "their". We got rid of "compelling". We got rid of "contentious". We replaced "concerns" with "interest".

Juvet: Mr. Chair I am going to be voting against this recommendation and the reason why is related to the budget and potential fiscal issues. I am not ready to commit the BIA to supporting that before we have a chance to review the context of the entire budget.

Abrami: Remember, with any of these recommendations, it would take someone to put some of these in bill form to propose to the legislature and make it through a difficult legislative process.

Juvet: I appreciate that but if I vote for this, it could be construed that the BIA is in favor of that as a part of the overall budget. I'm not there yet.

Sherman: Could I just ask Dave a question? You do have the option of abstaining. If you are voting against it, my interpretation is that you are opposed to this moving forward as a recommendation….that the recommendation is something that the BIA could not agree to.

Juvet: Thank you, Senator. I agree with you. So, I will be planning to abstain on this one.

Cooley: I will be opposing this because of the implied risk of wireless radiation.

Abrami: Any other discussion? I will make a motion that we accept this.

Sherman: I will second.

Abrami: I will call the roll: Tom Sherman (yes), Ken Wells (yes), Kent Chamberlin (yes), Carol Miller (absent), Denise Ricciardi (yes), Dave Juvet (abstain), Beth Cooley (no), Brandon Garod (abstain), Michelle Roberge (abstain), Paul Heroux (yes), Gary Woods (yes), James Gray (no), Patrick Abami-Chair (yes). There are 7 (yes); 2(no); 3 (abstain) and 1 absent. The motion passes.

RECOMMENDATION 4- Require every pole or other structure in the public rights-of-way that holds a 5G antenna be labeled indicating RF-Radiation being emitted above. This label should be at eye level and legible from nine feet away. In the view of the Commission, the State of New Hampshire has the right to warn the public of potential harm of 5G antennae deployed in the public rights-of-way. Large cell towers all currently have fencing around them at their base to protect the public. This will not be the case with small cell towers or any pole with an antenna on top in the public-right-of-way. These public rights-of-way are the jurisdiction of our municipalities and not of the Federal Government. The Telecommunication Act of 1996 did not contemplate antennae being placed on the public rights-of way of municipalities. Thus, the State of New Hampshire has the right to warn the public harm by requiring the owners of these antennae to inform the public of potential from RF-radiation harm. See Appendix XX for an example symbol.

Abrami: We talked about his last time. The game changing with 5G, not all cell companies are rolling out small cells in the right of way but some may be. For many, that's a game changer. All this is saying is that if that is the case, there should be some sort of labelling that there is an antenna on top emitting RF radiation. Beth, I know you had some concerns about this as there is RF related to power lines and all that. The subgroup decided to keep this recommendation.

Juvet: Mr. Chair, I'm going to be voting against this recommendation. I think it sends a conflicting message. I think it potentially makes NH different than every other state in terms of 5G rollout. I think if this is an issue then it's something that should happen at the federal level as part of federal legislation so the requirement is the same for all states. I can't support this recommendation.

Ricciardi: I just have a question. Is there any rule for participation in these groups? When someone misses a lot of the meetings, I don't think they have all the information they need to make an informed decision. It's just a question, Mr. Chair.

Abrami: Let's go way back. Dave and I chatted early on and certain days of meetings Dave could not attend because of a conflict with his board meetings with the BIA. Plus we were into the science and I know Dave was pretty eye rolling. So after the virus hit and we finally came back, I just assumed that Dave didn't really want to participate. That was a false assumption on my part. Dave reached out to me and said he is officially appointed to this commission. I cannot take him off this commission. None of us can other than the person who appointed him. So, he is still a formal member of this commission and yes he missed a lot of the meetings. The minutes are out there on our site. I don't want to make a big deal about this.

Sherman: Denise, I just want to point out the minutes and presentations are on the site. If you miss commission hearings, you do have the ability to catch up. And I am assuming that anyone who is participating in voting is up to date. That's what we do in commissions as we have that capacity. I am on more than 20 commissions and committees right now. There is no way I can make every single hearing. I agree with the Chair. We should move on and assume that Dave has done his due diligence and has every right to vote as an appointed member.

Ricciardi: It was just a question. I wanted clarification. Thank you Senator.

Abrami: Just for the record, our minutes are basically almost verbatim of what's being said. They are very extensive minutes. I move to call recommendation four for a vote. Tom?

Sherman: on the discussion side, I just have to say I have a concern about this one. First of all the labelling, I agree with the industry that there are many sources of RF and I think the public should be warned but I'm not completely comfortable with this one. I am going to hold off on seconding it and give myself a few more minutes to think about it before we vote.

Woods: I will second it.

Gray: my problem with this one is we have regulations and if the emissions from the cell tower meets the current and if we are saying that the future ones of our recommendation number one if it exceeds those then a warning label might be appropriate but again, we haven't done the research from number one. It meets current regulations and therefore the added expense of putting that sign on there and if there is still anybody who climbs poles without a hydraulic lift then that sign could be hazardous to them climbing that pole. For those reasons, I will not be supporting it.

Sherman: Patrick, the more I think about this one, the legibility of the sign, I have to agree. Right now under current law, we have already said there needs to be more study. I really am uncomfortable with this one. I think I am going to have to vote against it.

Wells: We have had quite a bit of discussion on this because the current standards don't talk about energy density in watts per square meter. When you have antenna in the public right of way, there are orders of magnitude closer to people than existing antennas. So, the RF exposure is very high.

Heroux: The other thing is that if you require it to have a full survey of all RF sources other than 5G, I realize that this may seem discriminatory. Essentially, it's because there is densification that this has provided and it would be a substantial task to inventory all sources of radiation and make sure that all of them are labelled. But at the threshold of densification, I feel this is justified.

Abrami: any other discussion? Alright. I am going to call the roll: Tom Sherman (no), Ken Wells (yes), Kent Chamberlin (yes), Carol Miller (absent), Denise Ricciardi (yes), Dave Juvet (no), Beth Cooley (no), Brandon Garod (abstain), Michelle Roberge (abstain), Paul Heroux (yes), Gary Woods (yes), James Gray (no), Patrick Abami-Chair (yes). There are 6 (yes); 4 (no); 2 (abstain) and 1 absent. The motion passes.

Abrami: Carol, were you here when I called for the vote?

Miller: I am abstaining anyway.

Cooley: I'm sorry, a clarification on that last vote. So was it 6 (yes) 4(no) and 2(abstain) because Carol was not here before the roll was called?

Abrami: yes.

Cooley: so was it 6-6 and does not pass?

Abrami: no. It's the majority of those who did not abstain.

Cooley: got it.

RECOMMENDATION 5- Schools and public libraries should migrate from RF wireless connections for computers, laptops, pads, and other devices, to hard wired or optical connections within a five-year period starting when funding becomes available. There is strong evidence that the younger the child the more susceptible they are to the negative impacts of RF-Radiation. Hard-wired connections or optical wireless do not subject children to RF radiation. The Commission is aware that school districts and public libraries have invested much in wireless infra-structure and that a movement to radiation-less connections would require additional investment of resources.

New optical networking solutions for the classroom and office spaces (such as LiFi) offer faster, healthier, and more secure connections than RF-based WiFi. This technology utilizes visible light, which organisms can withstand without any harm at far higher intensity levels (such as direct sunlight) than required for transmission. Such optical data transmission using visible light offers giga-byte speed, as well as plug-and-play replacement of current RF WiFi routers. The optical wireless system can be incorporated in an upgrade to cost-efficient LED room lighting, which can save schools and public libraries significant energy dollars.

The hard-wiring and/or optical projects should be completed within five years from when the federal funding (via say through the FCC's E-Rate program for telecommunications and IT in schools and public libraries) is procured.

Abrami: so this one is encouraging the use of hardwire or optical connections within schools and public libraries. I will let Ken spend a minute on it.

Wells: Schools and public libraries should migrate from RF wireless connections to either hardwired or optical wireless connections within five years of when funding becomes available.

Abrami: Can you spend a second on LiFi?

Wells: yes. There has been adequate research that younger children are susceptible to RF radiation and the alternative to using RF sources would be faster optical systems like LiFi or hardwired connections which don't emit radiation. Lifi is a visible light. There is adequate evidence that living things are quite resistant to visible lights. The speed and security of optical is better than RF based communications. This would be a step up in performance and security.

Abrami: The recommendation is also sensitive to the school districts have spent a lot of money already on WiFi. Understanding that these things have cycles and there is obsolescence. We are suggesting that when funding is available that this be looked at as an alternative to WiFi.

Sherman: Can I just wordsmith one thing? In the last paragraph of the non bolded section, there are words that say: "via say through" I would replace that with: "e.g." and commas. It's a little slangy for a commission report.

Gray: Going back up to the recommendation, I am not so sure that we need to say that they should migrate. Also in the non bolded section it says "strong evidence". There are organizations out there that sell that equipment and would be more than happy to help school districts migrate over. Should they? Shouldn't they? It goes back to your first paragraph, what is an acceptable limit? If you say schools and libraries should be assisted in migrating and you take out the word "strong" and it gets closer to something that I can support.

Sherman: I like it the way it is and if Jim is not going to support it in any event then I would leave it the way it is.

Miller: I would just notate "gigabit" not "giga-byte". It's just one word, gigabit.

Abrami: Ken, are you ok with that?

Wells: Yes, that's good.

Heroux: Mr. Chair, did you ask Carol where she was and if she was alone?

Miller: I am home alone except for the dog and he is on the deck.

Abrami: I will move for recommendation five. Tom?

Sherman: I will second.

Abrami: I am going to call the roll: Tom Sherman (yes), Ken Wells (yes), Kent Chamberlin (yes), Carol Miller (abstain), Denise Ricciardi (yes), Dave Juvet (abstain), Beth Cooley (no), Brandon Garod (abstain), Michelle Roberge (abstain), Paul Heroux (yes), Gary Woods (yes), James Gray (no), Patrick Abami-Chair (yes). There are 7 (yes); 2(no); 4 (abstain). The motion passes.

RECOMMENDATION 6-Establish new protocols for performing signal strength measurements in areas around cell tower radiators to ensure compliance with regulatory radiation thresholds and to evaluate signal characteristics known to be deleterious to human health as has been documented through peer-reviewed research efforts (e.g.,[1]). Those new protocols are to take into account the impulsive nature of high-data-rate radiation that a growing body of evidence shows to have a significantly greater negative impact on human health than does continuous radiation. The measurements should be taken

in regions surrounding the tower that either are occupied or are accessible to the public. Commissioning measurements are to be performed when the site is installed and at regular intervals if required by state statute or municipal ordinance such as those required by the town of Burlington, MA [2]. Measurements should also be collected when changes are made to the tower that might affect its radiation, such as changes in software controlling it. Measurements should be performed under worst-case scenario conditions when the site is transmitting at its highest levels.

It is recognized that theoretical calculations show that existing FCC guidelines will be met by standard cell tower configurations. However, there are cases where the radiation from towers can be focused by buildings, terrain, and antennas, causing signal levels to be considerably higher than would be expected in theoretical calculations unless those effects are taken into account. Further, if measurements are performed using the protocols that are advocated, they will be sensitive to the impulses and summative effects of other radiation sources such as nearby cell towers. The measurements being advocated will require wideband equipment that is typically not used in the averaged signal measurements that are currently used. Two peer-reviewed articles that address the effects of impulsive radiation on organisms are [3] and [4].

[1] Belyaev I., Dean A., Eger H. et al. EUROPAEM EMF Guideline 2016 for the prevention, diagnosis, and treatment of EMF-related health problems and illnesses. *Rev environ Health.* 2016;31(3):363-397. Doi:10.1515/reveh-2016-0011.

[2] Burlington, MA zoning Bylaw Wireless Facilities Section 8.4.6.2 “Annual RF emissions monitoring is required for all sites by an independent RF engineer to be hired with Planning Board approval and at the applicant’s expense. Test results will be submitted to the Town as soon as available, and not later than the close of the calendar year. Annual testing of electromagnetic emission shall be required to ensure continual compliance with the FCC regulations.

[3] B. W. G. (2012). *Bionitiative 2012: A Rationile for Biologically-based Exposure Standards for Low-Intensity Electromagnetic Radiation*

[4]McCarty, D. E., Carrubba, S., Chesson, A. L., Frilot, C., Gonzalez-Toledo, E., & Marino, A. A. (2011). Electromagnetic hypersensitivity: P Evidence for a novel neurological syndrome. *International Journal of Neuroscience,121(12), 670-676*

Abrami: I will let Kent speak to this. It really discusses that there should be something more than the average when we look at signal strength.

Chamberlin: this also has two parts. One is that it says you have to perform measurements on a cell tower. At one point you need to do that at commissioning because there are factors that can cause signals to be greater than what you would expect from simple calculations that the cell tower manufacturers provide. Burlington, Mass has a requirement as a town ordinance saying you have to perform these measurements regularly to make sure you have not exceeded guidelines.

The next part relates to how you perform those measurements. The way that's been done for fifty years is to look at averages. It turns out that it's not just the average power you're exposed to but it has to do with the transient nature of that and the summative effects. The way the measurements are performed now, if you were looking at a particular frequency, you would get a single value. It wouldn't see the contributing effects of nearby transmitters. The way I am proposing it here is that you look at the signals differently. You look at summative, the transient nature, the peak value which as I understand it, are not being looked at right now.

Wells: I am just noticing in this version, the second sentence after the bold section talks about focusing building terrain and antennas, but does not mention beam forming, which I think we discussed in one of the earlier sessions.

Abrami: I think you are right. Where are you?

Wells: The second non bolded sentence. You can put it after building, terrain, beam forming and antenna.

Heroux: Kent, this recommendation is very long. I wonder if somehow it could be a little bit remodeled to make it crisper to understand. All the other recommendations could almost be used in a commercial. Whereas this one, needs some wind to go through.

Abrami: I think you are right. Perhaps, some should be in the discussion part not the bold.

Gray: My objection to this recommendation is that it ought to be a subset of the study that you are requiring in recommendation one. If you found there is a problem, then how do you mitigate that problem?

Sherman: I kind of agree with Jim that this may be the cart before the horse. I don't disagree with this recommendation. I will vote for it but it would be great to have some parenthetical phrase somewhere in there that says depending on results of section one, or something like that.

Abrami: Ok. Why don't we say we are voting on the essence of this? Then we will vote again. I just want a sense of this. Is that ok with everybody?

Wells: You can streamline it by taking the first and last sentence in the bold and relegating the rest to the last paragraph.

Heroux: I would like to mention that this is very critical in the sense that this question is not something that will come out of a new investigation. It has been around for fifty years. The point here is that if you only look at biological effects over a gram and over averages, you blind yourself to reality. This is essentially what this very important recommendation says.

Abrami: I think that's why we have it here actually. I am ok with trimming it down and taking the middle part and moving it down below.

Woods: Just to clarify. We are trying to work this which is fairly complicated. Are we going to have another work session before the next full session?

Abrami: Yes. The work group is going to meet one more time because we have to talk about the rest of the report and get that going. Let's get the essence of a yes or no on this. If it's a no, we won't bother reworking it. We will have another vote specifically on this recommendation at the next full meeting.

Cooley: I will be voting no on this just because the FCC has its regulations in place here and they occupy the field. That's clear in both federal statute and federal regulation. Also, this is seemingly implying that wireless radiation is unsafe. Thank you.

Juvet: Mr. Chair, I would also like to let the commission that I will also be voting no on this. Again, this is making New Hampshire and outlier. This is a regulation that should be handled at the federal level. I think it sends a bad message about New Hampshire being serious about embracing the latest technologies for economic development.

Woods: As far as the consideration for New Hampshire being an outlier, I would like to point out that New Hampshire is the only state that does not have a mandatory safety belt law resulting in the loss of about 27 lives per year because of disuse. We have no trouble being an outlier in that regard. So I think that is perhaps something to consider the argument by itself to be an outlier perhaps should be put in a broader context.

Abrami: We all have our opinions. Ok. I move recommendation 6. This is just the essence, not the final words. We will vote on it one more time.

Chamberlin: I will second it.

Abrami: I am going to call the roll: Tom Sherman (yes), Ken Wells (yes), Kent Chamberlin (yes), Carol Miller (abstain), Denise Ricciardi (yes), Dave Juvet (no), Beth Cooley (no), Brandon Garod (abstain), Michelle Roberge (abstain), Paul Heroux (yes), Gary Woods (yes), James Gray (no), Patrick Abami-Chair (yes). There are 7 (yes); 3(no); 3 (abstain). The motion passes.

RECOMMENDATION 7- Require that any new wireless antennae located on a state or municipal right-of-way or on private property be set back from residences, businesses, and schools. This should be enforceable by the municipality during the permitting process, unless the owners of residences/business or school districts waive this restriction. Given these are local public rights-of-way and under the jurisdiction of a municipality, the Commission feels empowering individuals impacted by these antennae to be within states' rights to legislate such standards. This statute would return personal freedoms back to the individual in being involved with decisions as to non-essential devices that are being placed in front of their property.

Siting restrictions for cell phone towers already in force in the world were intended to ensure the safety of vulnerable populations, like children and those with illnesses. India already prohibits placement of cell phone towers near schools or hospitals, and Canada (Standing Committee on Health), as well as many European countries, are looking into similar restrictions. In California, firemen have been exempted from the forced placement of towers on their stations, because of radiation health concerns.

There are plans to use higher frequencies in the future. These higher frequency transmitters have to take into account:

1. Less signal penetration into structures
2. The atmospheres oxygen and water absorption of radiation
3. The shrinking antenna apertures
4. The noise from multiple extraneous sources

For human users, this means increased power density exposures. In addition, exposures will become more irregular and originate from multiple sources (Multiple-Input-Multiple Output Architecture). As vulnerable individuals are exposed ever day in society to RF-radiation, limits should be universally applied, and set according to the Largest Observed Adverse Effect Distance (LOADE) using the experience from the past and current uses of 2G, 3G, and 4G technology, since there is no epidemiological experience with 5G.

An engineering practice would use a set-back requirement for new base-station cellular towers, including 5G micro-towers. A conservative LOAED should include all observed health effects. From the 18 papers abstracted in Appendix XX, shown in historical order, this set-back for all new cell towers should be 500 meters which translates to 1,640 feet. The actual set-back requirement should be established by the municipality based upon a balance of the science and reasonable accommodation for these antennae.

Abrami: Recommendation seven has to do with setbacks. I will let Paul speak to this one.

Heroux: There has been a lot of evidence in epidemiology that the proximity of cell phone towers enhances cancer effects that happen at the maximum within two years of installation as well as a variety of neurological effects that have been documented and so we believe that to bring densification to New Hampshire represents by itself a risk. Cell phone towers should be distanced from where people live whether they are vulnerable or not.

The non-bold section relays this information and says that there is evidence of health effects until 500 meters. In terms of best practice, this is what should happen.

Gray: This recommendation does not take into consideration any power level that is going out, beam forming or other things. If we are going to do this, it can't be all cell towers have to be .31 miles away. These new 5G are much less power. Unless you start to talk about power density and other measurements in recommendation 6, then this really has no meaning.

Cooley: As I expressed prior, this likely runs afoul of federal law. A state and locality cannot dictate where a wireless network can or cannot be built particularly if it creates holes in coverage and that is a barrier to entry. I will be voting no for that reason. I will also point out that there is a reference to California and that firemen were exempted from "forced" placement of towers. That is actually an incorrect statement. I have the legislative analysis that shows why the California firefighters were exempt from AB 57 many years ago. I would just submit for the commission that that is an incorrect statement. Thank you.

Heroux: 5G is something that is not yet defined and it will have beam forming which although the individual towers consumes less power, it has a higher effective radiated power because of antenna gain. So in the face of a new method of transmission, that is 5G that has yet to be defined by most people who deploy it, we can only rely on the past to assess the health impacts of cellular systems. In other words, we cannot be twenty years in the future to gauge as Senator Gray does suggest the health impacts of 5G. We can only use our experience of the past and this is what this distance is based on.

Sherman: I have to agree with Beth on this one. If we are going to leave this intact and I know it's weakening your recommendation, but I would change the word "require "to "encourage" because I don't think you can do this kind of siting or require it. It's just a non-starter. I know that in Rye when we talk about a new cell tower coming in, which there needs to be and will be, that is a very productive negotiation between the town and Verizon and so I think "encourage" would be a way I could vote for this. Correct me if I am wrong, but I think Beth had it right that this is federal statute and we can't do this. So, it's a non-starter to put a recommendation that we can't do.

Abrami: I don't have a problem with encourage.

Sherman: I also want to make sure that we are accurate where Beth pointed out we were inaccurate. Maybe at the next subcommittee work session, be absolutely confident that you are correct in what you are talking about with California. If it's not clear, I would remove it.

Abrami: Beth, can you send us your documentation on that please and I will share it with the whole group?

Cooley: Absolutely. It's directly from the California legislature.

Juvet: Mr. Chair, in light of changing that first word in the bold from "require" to "encourage", doesn't that make the entire second sentence unnecessary? I don't understand how the municipality will have the ability to enforce this.

Sherman: Dave, I think they can't anyway. I would get rid of the second sentence. I just don't think they have the ability to do this.

Woods: I agree with the comments about what is currently available legalistically. However, I think part of the concept of this report is what we think we would like to see obtained, a sort of wish list if you like. Then the actual application or translation into legislation would take these factors into consideration. I have no trouble with the changes in view of honoring the legal aspect. But by the same token, I don't think we should shy away from stating what we think should be the standard and let that be heard.

Sherman: One way to do that would be to state the goal in your first sentence and then state in your second sentence how you would hope to get there.

Heroux: This could be done by the municipality.

Sherman: Well, as Gary said, you would need to have a statutory change probably at the federal level. So you could encourage. That's what we are doing in my town because we arer working with the industry and it's actually going to be fine. So, one way is to encourage. The other way is to ask for Congress to change the law.

Heroux: I just proposed to say that this could be done by the municipality during the permitting process.

Sherman: I don't think they can do that right now.

Abrami: We will take that last sentence out and move forward with this.

Garod: I think I have to agree with Beth and Senator Sherman. I don't think there is anything wrong with encouraging municipalities to consider these factors when they are negotiating the placement of towers and when they are having a conversation about where it makes the most sense. But I think if you do anything that is seen as encouraging them to require a certain placement, the commission would be encouraging them to do something that is preempted by federal statute. I think the commission should stay away from any type of recommendation that suggests that municipalities have the ability to simply restrict where these towers are placed because I don't think they have the ability to do that.

Wells: Perhaps, when we revisit this in the workgroup, we can see whether this recommendation should be linked to recommendation one which calls for the delegation to look at the federal law.

Sheman: I think we are tight on time. Should we move to recommendation eight and agree that this needs work?

Abrami: Ok. No vote on number seven. The workgroup will work on it and maybe integrate it with another recommendation. The next time the full commission meets, we will vote on it.

RECOMMENDATION 8- Upgrade the educational offerings by the NH Office of Professional Licensure and Certification (OPLC) for Home Inspectors to include RF intensity measurements. Home Inspectors currently operate as private contractors who may be hired by citizens or enterprises to measure such things as radon, to collect water quality samples, or search for mold or insect damage. Home inspectors routinely supply test results to both their clients and government entities.

The majority of the Commission believes the public has the right to discover the RF power intensity related to radio frequencies at a property which they will be purchasing or renting before the transaction is closed. Also, the proprietors of publicly accessible venues may wish to reassure the public about the RF power intensity within their establishments, by posting the data collected by a state-approved inspector. In addition, such testing should be paid for by the party requesting it and the testing itself should be performed by a professional who owns or rents the test equipment and has met the state requirements for training of Home Inspectors regarding RF measurements.

The majority of the Commission proposes that Home Inspectors be offered training by NH OPLC on how to measure on-site peak and 24-hour average RF intensities. Measurements of frequencies and intensities will be performed using low-cost equipment (such as GQ-390 meters). [Description of existing Home Inspector training offered for radon, mold, etc. may be seen at https://oplc.nh.gov/home-inspectors/index.htm]

Wells: This recommendation puts in place training for home inspectors that is offered then by the Office of Professional Licensure and Certification. Just as homeowners can request testing for radon or mold, they should be able to request testing for RF exposure on their property or prospective property and expect that the person doing the measurement has had training on the use of the equipment.

Abrami: the point is, we are not talking about making it mandatory. It deals with training inspectors to be able to do the measurements. So if someone has concern, if they are RF sensitive or whatever and they want they can go to somebody that's trained on how to do the measurements. This is totally different than the original recommendation eight. Several people had concerns with the original recommendation, myself included. If someone bought their home decades ago and cell towers were put up, there is nothing they can do to mitigate that problem. If an inspector found lead paint or a water problem, there are things they can do before the house is sold to mitigate that problem. This addresses that if someone wanted testing done, that inspectors are trained.

Gray: With this one, I am sure that Beth is going to tell me that this assumes that radiation is bad and all that. Again, non-mandatory, a state approved way to license. I don't have a problem with. They should have a reliable place to go to get those measurements from a qualified person might be a better way to go might be better.

Chamberlin: This is mostly on wording. In the second paragraph, the majority of the commission believes the public has the right to discover etc., and it says "at a property that they will be purchasing or renting before the transaction is closed". You know, that could be read as almost being a requirement before the sale, which it isn't. Also, it implies that the time when you could get testing done is when you are buying or selling something. I would like to keep it more general and that any citizen that wants this done, can call upon this service. Can we reword this so it makes it clear that it is voluntary and it is not necessarily tied to buying and selling of properties?

Wells: It should also be an option if you want as part of a building inspection as part of an agreement on something you don't own yet. There is nothing about requirement in there. The seller could say no. I refuse to have it inspected and go away and I will find another buyer.

Heroux: I might have been the one to have suggested this and the actual intention was to avoid bursts of demand as a result of some article and make the requirements for testing more evened out over time. I recognize that it's true, if you are buying or selling something, this might be a variable of interest.

Abrami: We are running out of time. I know a few of you have to go but I would like to vote on this one. Maybe the workgroup can work on the wording to make it clear it's voluntary. Is that okay?

Chamberlin: Yes. That addresses my concern.

Abrami: Then we can come back for another vote. Any workgroup changes will come back to the group for another vote. I move to vote.

Wells: second.

Abrami: I am going to call the roll: Tom Sherman (yes), Ken Wells (yes), Kent Chamberlin (yes), Carol Miller (abstain), Denise Ricciardi (yes), Dave Juvet (abstain), Beth Cooley (abstain), Brandon Garod (abstain), Michelle Roberge (abstain), Paul Heroux (yes), Gary Woods (yes), James Gray (no), Patrick Abami-Chair (yes). There are 7 (yes); 1 (no); 5 (abstain). The motion passes and will be revisited.

RECOMMENDATION 8A- The State of New Hampshire should begin an effort to measure RF intensities within frequency ranges throughout the state, with the aim of developing and refining a continually updated map of RF exposure levels across the state, using data submitted by state-trained Home Inspectors. The data should be collected in such a way as to identify geographic areas of notably high RF exposure, places where RF signal for wireless communication is inadequate (dead spots), and places where RF is unusually low (white spots) sought by people who wish to minimize their RF exposure. One possible use of this data will be buyers/renters of property or the public in general using benchmark values to make comparisons and make their own decisions based on their comfort level with RF exposure. After a while, an extensive New Hampshire RF database will exist to provide useful maps and data for future public health investigations. Appendix XX outlines in more detail the technical aspects of this recommendation.

Wells: So 8A is what we would do with the data that home inspectors come up with. One of the things would be that the State of New Hampshire would begin an effort to collect that data in such a way that we can identify geographic areas of notably high RF exposure and places where RF exposure is unusually low and this would be published in a database or a map. It could be used for future health investigations or for people who are looking for places with lower RF exposure.

Abrami: We are also talking about the state taking this on to actually do some measurements,itself. Am I correct on that Ken?

Wells: Yes. That could be a part of it. We talked about the way that Vermont did it. For the most part, this recommendation talks about a low cost way of assembling the data by collecting the data from licensed home inspectors.

Abrami: I can see that being added to the data. That would probably take a long time to get a real picture. The one thing we agreed on was we didn't want the general public taking their own measurements because there is no control.

Wells: It says here that the state of New Hampshire should begin an effort to measure RF intensities throughout the state. That does not preclude the state from having someone from the proper agency go around and take measurements.

Abrami: The essence is we want the state to look at the mapping of RF radiation and if recommendation 8 goes through, that data would be collected as well. These would likely be part of the same legislation.

Gray: My objection to this goes back to the state having to go through this. We haven't proven that there is a big problem yet. I would suggest that Kent work through the University system, get some grant funding and fund this thing. They can do all the studying and data recording and all the measurements that they want to but I don't believe that the state should be required to put together the organization to go do this. Thank you.

Cooley: I will be opposing this 8A as it tries to undermine safety standards that are set by the federal government with the potential to mislead residents that somehow RF within legal limits, is dangerous. So, I will be voting no. Thank you.

Sherman: Just to respond to Beth's comments. Actually, I don't think that's the case at all. Suppose if we find RF levels within the state that are exceeding federally acceptable levels. I am Chair of the Commission on chronic illness that has been standing since 2014 or 2015, looking at the link between human health and chronic illness. This kind of map is something we've been envisioning on all sorts of things. DES and DHHS are actually looking at this in relation to arsenic and bladder cancer and we've talked about expanding this. So these ideas of maps are not new. I think right now, it's a huge unknown. If the state of New Hampshire were to do this or if somebody were to develop a map, I think it would be very helpful. We may be surprised that we may have various RF exposure that far exceeds federal limits but right now, we don't have any clue what those levels are.

So, I don't think that is correct, Beth. I think that this would be useful information making sure that people are not unwittingly being exposed to levels that are beyond what our federal industry accepted levels.

Abrami: Again, we don't say in this recommendation that we are setting different levels.

Roberge: I would just echo what I have said previously. If this intention is that this recommendation be implemented by a state agency, then funding would be necessary. I don't know if you can build language in there similar to recommendation three.

Abrami: The state of New Hampshire "should fund an effort"…how is that?

Wells: I think this could be done in conjunction with the training of the home inspectors. If it's part of their training to do half a dozen measurements in locations the state is interested in.

Juvet: Mr. Chair, starting out that statement with the state of New Hampshire clearly implies it's the state.

Abrami: "The state of New Hampshire should fund or find resources to support the beginning of an effort to measure RF…"

Wells: I am not comfortable with that. One of the advantages of having the state do it, is that the state does not have a conflict of interest. I can imagine if there were entities that would have a conflict of interest and the data collected may not be believed by everyone.

Abrami: Right. We talked about this last time Michelle. Obviously, this isn't going anywhere unless legislation is passed. And if we want the state to do this, there would have to be funding as part of the legislation. It would have to have budget dollars associated with it. Again, this is more of a statement of what we would like to see happen.

Roberge: understood.

Abrami: I am going to say, just keep it the way it is. Is there any other discussion? I move recommendation 8A.

Wells: second.

Abrami: I am going to call the roll: Tom Sherman (yes), Ken Wells (yes), Kent Chamberlin (yes), Carol Miller (abstain), Denise Ricciardi (yes), Dave Juvet (abstain), Beth Cooley (no), Brandon Garod (abstain), Michelle Roberge (abstain), Paul Heroux (yes), Gary Woods (yes), James Gray (no), Patrick Abami-Chair (yes). There are 7 (yes); 2 (no); 4 (abstain). The motion passes.

RECOMMENDATION 9- Require all new cell phones sold in New Hampshire come equipped with updated software that can stop the phone from radiating when positioned against the body. The Commission has been made aware that cell phones contain proximity sensors that will allow a cell phone to only radiate signals when a certain distance from the body, for example, held in the fingers, or placed on a table. This does not change the functionality of the device, only the way it is used, specifically not held against the head or body. Implementation is a software update in the cell phone, as these phones already have a proximity detector to turn off the screen and soft keys when an obstacle is present. With this change, the screen and the RF circuit are automatically turned off. This removes the problems of brain cancers (glioblastomas and acoustic neuromas) and the issue of SAR limits for the industry. See Appendix XX for more detail references to the science behind this recommendation. Cell phones should come set with this inhibition, with instructions in the manual on how to disable it. There should be a soft button on then unit to easily re-enable the radiation inhibition, for example if the unit is handed to a child. In all cases, it should be easier to enable the restriction than to disable it. Cellular phones marketed specifically for children should stop radiating when positioned against the body under all circumstances. The installation of such proximity sensors is also encouraged in laptops and tablets.

Abrami: Number nine has to do with cell phones and I will let Paul explain it.

Heroux: Essentially, there is in cell phones a system that blanks out the screen when it's close to the head. This was originally intended to prevent the soft keys from being activated and the battery from being spent unnecessarily. This software could also interrupt the radiofrequency radiation so that when you bring it against your head so that half of the radiation that was previously broadcast into your head does not exist. In other words, you could use your cellphone exactly as before but you would need to hold it a certain distance from your head as instructed in most manuals sold with the cell phone. Or you could place it in front of your face or place it on the table for example.

Abrami: So the internals of the cellphone can do this with an app, is that correct?

Heroux: Either an app or a modification in the embedded code that is in the phone.

Cooley: since I had to drop early from our last meeting, I didn't get to speak on this recommendation. We are strongly opposed to this. Not only does science not require any of this. This is not necessary. The FCC has a 50 fold safety factor and there is no safety risk. I would be remiss not to point out Berkeley. The decision from last week in terms of compelled speech and First Amendment issues and I will just leave it at that and I will be voting no on this.

Sherman: I am just concerned that when we carve out New Hampshire as a different market from the rest of the entire world. To me, it's a little concerning. I am wondering if the intent here was to have this software that could be enabled by the user rather than something that would be inflicted on them. In other words, you go into your phone and you say I want this to automatically turn off when it's a certain distance of my body. You have activated that software and that keeps it a choice issue. I think that might be a little more doable. I worry about this one. I understand the intent and agree with the intent. But I wonder if making it enabling rather than mandating might be a better way to go.

Heroux: As it is, it is a choice of the user, you have to realize. Of course if you don't have the software in there to do this, you can't do it. In other words, every individual has the choice to accept this radiation when it's against their head or to reject it. We have discussed this issue of choice before. I believe Rep. Abrami brought it up and it was decided that adults should have the choice to use the phone and irradiate their brain if they wish but that the facility to subtract themselves from this radiation should be provided because it is technically very easy to do. In a sense, it is a negligence of industry not to have provided this before.

Heroux: So, Paul what you are saying is that this would have the software not activated but present so if the consumer chooses to use it.

Heroux: That is entirely right. If I may take off the gloves here…. The first thing that will happen from industry is that when the software is included, they will instruct all their sales force to do a favor to the buyer and say I will undo this for you. That's what I expect would happen because they do not want even this capability to be known. I think this is unfair to users.

Gray: If we continue to debate all of these instead of just accepting comments, we are never going to get out of here. My comment on this one is that on recommendation three, we are already putting out information on a site and using this as a hands free device which most cellphones do.

Abrami: the real essence of this recommendation is that it is possible to do this. I kind of agree with Tom. If it's true that most phones can do this, do we encourage entrepreneurs to come up with apps that allow people to buy and do this on their own? My understanding was that this existed in the phones, sensors. The question becomes would an app be allowed by a third party to be put on a phone to turn it off? There are many apps that go on phones, so I don't know. Do we need the cell phone industry to bless this or not?

Again, we are making a statement here. I would almost say "encourage"

Sherman: How about this wording? "Encourage that all new cell phones sold, come equipped with updated software that allows the user to automatically stop the phone from radiating when positioned against the body.

Abrami: It would be a tough sell in NH now that I think about it. There are some states with different emissions limits than others. The auto industry actually does comply with those different limits. California has different fuel standards.

Sherman: But California has a slightly different market share then New Hampshire.

Abrami: you got that right. We are the rounding error. But we like to be first in stuff though. So, with those two changes, any more discussion? I move recommendation nine.

Sherman: I will second.

Abrami: I am going to call the roll: Tom Sherman (yes), Ken Wells (yes), Kent Chamberlin (yes), Carol Miller (abstain), Denise Ricciardi (yes), Dave Juvet (no), Beth Cooley (no), Brandon Garod (abstain), Michelle Roberge (abstain), Paul Heroux (yes), Gary Woods (yes), James Gray (no), Patrick Abami-Chair (yes). There are 7 (yes); 3 (no); 3 (abstain). The motion passes.

Abrami: I know that Denise has to leave at a quarter after. A couple of hers are coming up here at the end. I know Gary has to leave too. I think what we may do …

Woods: Mr. Chair I have number eleven and I think that should be pretty straight forward if you want to do it that way.

Abrami: I think we will do it that way. We will do one more, number eleven. I will just have to call another meeting. I said a potential of two more meetings so before I lose everybody, can we meet in two weeks? The 8th or the 9th?

Sherman: Why don't we do 10-11:30 on Thursday, October 8th?

Abrami: Ok. Subgroup I will reach out to you

Garod: I am sorry to be the one who jams everything up but I have a prescheduled meeting on the 8th at 11. I will be available for the first hour.

Abrami: We will book 1.5 hours but let's say it's going to be an hour meeting. If we just do the recommendation votes, we should be able to get that done in an hour. Let's just do number eleven.

RECOMMENDATION 11- Further basic science studies are needed in conjunction with the medical community outlining the characteristics of expressed clinical symptoms related to radio frequency radiation exposure. Further studies are just beginning to explore the quantum mechanical mechanisms which are the fundamental basis for understanding the biological changes occurring during the interaction of radio frequency radiation and molecules. These mechanisms can affect cells, tissues and whole organs, as well as accumulate over time.

The majority of the Commission feels the medical community is in the ideal position to clarify the clinical presentation of symptoms precipitated by the exposure to radio frequency radiation consistent with the Americans with Disabilities Act (ADA) which identifies such a disability. The medical community can also help delineate appropriate protections and protocols for affected individuals.

All of these endeavors (basic science, clinical assessment, epidemiological studies) must be completely independent and outside of commercial influence.

Woods: Basically, this just addresses the issue of further studies needed and addresses the issue of transitioning from what are called in the physics world, bulk materials to the actual quantum mechanical effects. We discuss these in a little bit of a peripheral way but have addressed such as proton tunneling and other similar quantum mechanical effects which really represents the way that all radiation interacts with molecular entities. That interaction is a base for cellular activity and as a consequence, also organ and overall systems activity. Those are really needed and they are just now coming on line. I think the bulk studies that have been done in the past, point out that we do need to look at this further. They were inconclusive for a variety of reasons. That's the inherent difficulty with bulk material studies especially when they are as complex as cells and organs. We need to encourage further looking at this.

Secondly, as this comes to the fore, there is a push in the medical community to identify exposure to these frequencies as a clinical entity. The State Medical Society and National Medical Societies are looking at this to try and colleague information in a way that will identify these as a potential designation of a syndrome. Indeed, the ADA already recognizes the exposure as a disability. I think it behooves the medical community to be thoroughly and completely engaged in this process to identify that dimension. So everything from the study, from the quantum mechanical effects which we've addressed to the clinical designation is needed.

Abrami: this is calling for the medical community to work on this. This one really has to do with RF sensitivity more than anything else. Gary is already beginning to reach out to the medical community to start addressing this in a more thorough way.

Woods: This is primarily meant for the readers of this report to identify that in fact there are other things in the works and we need to pay attention to those. The person reading the report will not only understand the other dimensions outlined in the other recommendations but that we as a commission recognize that this is a direction that we need to go and this is a direction that we need to go.

Sherman: I just had one little wordsmith in the first line. Gary would you object to after the word further" basic science and clinical studies are needed" so that it captures the full spectrum of basic science up to the clinical.

Woods: you could put it that way. The second portion of that, the medical community outlined that studies are needed in conjunction with clinical studies.

Sherman: Ok.

Cooley: I will be voting no on this. Take a look at the World Health Organization statement on this. That is why I will be voting no. Thank you.

Abrami: Any more discussion? Ok. I move recommendation eleven.

Heroux: I second.

Abrami: I am going to call the roll: Tom Sherman (yes), Ken Wells (yes), Kent Chamberlin (yes), Carol Miller (abstain), Denise Ricciardi (yes), Dave Juvet (no), Beth Cooley (no), Brandon Garod (abstain), Michelle Roberge (abstain), Paul Heroux (yes), Gary Woods (yes), James Gray (no) because I think it should be a sub of recommendation one, Patrick Abami-Chair (yes). There are 7 (yes); 3 (no); 3 (abstain). The motion passes.

Abrami: thank you all. As far as the Minority Report, Jim and I traded emails back and forth about whether a subcommittee is needed on the Minority Report. Joel doesn't think it's necessary but I know you had some concerns Jim about 91A stuff.

Gray: If you form a group, then I have to follow 91A and publicize the meetings and all those other things. If we don't have a quorum of the group then it can be informal. We can email back and forth and then present it to the group as a recommendation.

Abrami: those who want to sign onto the Minority Report, you can give your suggestions to Jim and correspond back and forth but there can't be meetings.

Gray: right. Forming a group would hinder me from writing the report. As long as I don't have quorum of the whole group or any committee of the group, then we can get together and talk about it because that small group cannot make decisions that are binding on anyone. Everyone should have a copy of what I wrote to begin with. I think Beth would like me to put at least a paragraph in there about the FCC and their requirements and I have no problem doing that. If other people want to communicate with me, just use my legislative email: *james.gray@leg.nh.us*. We will certainly publish it out through Pat to the rest of the group.

Abrami: I am ok with that. Joel's counsel to me was it was ok if you guys interact. I just wanted to make sure that was your understanding Jim.

Thank you everyone. I know some of you had to leave early. You know these commissions we have people from industry, it's very difficult to get unanimous on any of this stuff. That's why we are doing it the way we are doing it with the Minority Report. The legislature has recognized this and I ran into similar things with the Marijuana Commission. There were differences of opinion that could not be reconciled. The resolution that the legislature has is a Minority Report built into the total report so people don't miss it in fairness. So that is where we are at. We will see everybody in a couple of weeks.

V. Next meeting via Zoom: October 8th 10-11:30 am

Meeting Adjourned at 11: 27 am

Text chat during Zoom meeting:

Chat from HB522 5G Commission Meeting, Sept 22, 2020

From Rick Maynard to Everyone: 09:02 AM Morning All.

From Deb Hodgdon to Me: (Privately) 09:04 AM thank you

From Cece Doucette to Me: (Privately) 09:08 AM Morning, Kent. If the Recommendations document has changed from the one you sent me dated 9/17 in the file name, would you mind sending it to me? Thanks.

From Me to Cece Doucette: (Privately) 09:09 AM We will be discussing the version that I sent you.

From Cece Doucette to Me: (Privately) 09:12 AM Supah, thanks!

From Cece Doucette to Me: (Privately) 09:29 AM Rec. 1, non-bold paragraph, first line: (TTA) should be (TCA)

From Cece Doucette to Me: (Privately) 09:42 AM Rec. 2 bold section, line two, in parentheses, (there) should be (their). Also, line 5, after "cell phones" might you consider adding, "and other wireless devices"?

From Helene to Everyone: 09:47 AM We are very concerned about having a cellphone tower being installed in less than 1/4 mile from the front of our home. We are listening to this meeting today so that we can be active in this process to ensure that residents of NH have a seat at the table to ensure that we have representation to protect our health and rights

From Rick Maynard to Everyone: 09:48 AM Thank-you all. Take care, I have to go.

From EH Trust to Everyone: 09:49 AM Published research o cell towers here https://ehtrust.org/cell-towers-and-cell-antennae/compilation-of-researchstudies-on-cell-tower-radiation-and-health/ research on 5G https://ehtrust.org/scientific-research-on-5g-and-health/

From Helene to Everyone: 09:49 AM considering that we are currently in the process of dealing with our Town and a Wireless Tower company that gained approval in a way that we feel was not appropriate. None of the neighbors were included in the meeting and we are being told by the Town committee that we never would have had any say in the tower being approved because of the current laws in our State, regardless of our concerns

From EH Trust to Me: (Privately) 09:51 AM Can I record please . It is a public meeting. I requested to record

From Cece Doucette to Everyone: 09:52 AM Rec. 3, at the end of the bolded section, please consider adding after "pregnant women" the other vulnerable populations, "the elderly and those with existing health compromises."

From Me to EH Trust: (Privately) 09:54 AM I'm not able to grant permission to record during an active meeting. However, verbatim minutes will be posted on our public website.

From EH Trust to Me: (Privately) 09:56 AM Thank you, I thought it was an open meeting so we could From Helene to Everyone: 10:01 AM The biggest concern is that they are allowed to put numerous antennae on top of the towers which can increase the emf emissions greatly. Please consider this.

From Cece Doucette to Everyone: 10:13 AM Do we have long-term studies on Li-Fi? Perhaps we can modify the bold where it says, "optical connections" to "optical connections if proven biologically safe." Rec. 5, second unbold paragraph, please be careful about recommending LEDs, many suffer negative biological effects from them today.

From Helene to Everyone: 10:17 AM Here is a caveat; we have a cell tower going up in less than one mile from 2 schools. What good is converting over to broadband or fiber optic technology (which is not only better, but less risky for security purposes) when there is a cell tower with 10 - 20 antennae located so close and children are exposed 5 days/week for 6-8 hours per day. Health concerns are not only for children, but all people are susceptible to emissions. Many towns are now electing to not install towers due to the findings from many studies and the notable increased health risks

From EH Trust to Everyone: 10:32 AM You can watch a news investigation that shows it was lobbying from firefighters here https://www.youtube.com/watch?v=61h_vuBujw0&feature=emb_title Affidavit of Susan foster https://ecfsapi.fcc.gov/file/7022117660.pdf

From Helene to Everyone: 10:32 AM Should we remind everyone that the FDA has approved numberous medications in the past as SAFE, but they were not. Tobacco and asbestos were considered safe and they were not. We have evidence from other countries that this technology is not safe, yet it is being shoved down our throats and to comment that NH would be an outlier is wrong and uninformed. Thank you Dr. Heroux for pointing that information out. There should be several regulations implemented keeping towers from close proximity to residential homes, schools and businesses. There are OTHER safe options available and people should have the right to say NO to unsafe technology, especially until it is found to be made safer.

From EH Trust to Everyone: 10:35 AM Resources on firefighters here https://ehtrust.org/firefighter-unions-opposing-cell-towers/

antennas on forestations were carved out of the bills Fire stations AB57- Firefighters have gotten an exemption to have cell towers on or adjacent to their facilities. This was codified in California's 2015 legislation AB57 . CA AB57 (2015) Legiscan Text of Bill. " Section 65964.1. (f) Due to the unique duties and infrastructure requirements for the swift and effective deployment of firefighters, this section does not apply to a collocation or siting application for a wireless telecommunications facility where the project is proposed for placement on fire department facilities. " SB649- They also received an exemption in California's SB649 (2018), a bill which was vetoed by GovernorBrown. SB 649 California (2017) Wireless Telecommunications Facilities – 65964.2. "(a) A small cell shall be a permitted use subject only to a permitting process adopted by a city or county pursuant to subdivision (b) if it satisfies the following requirements: ….(3) The small cell is not located on a fire department facility."

From Cece Doucette to Everyone: 10:35 AM You can replace the firefighter passage with: Please note, in 2004 the International Association of Fire Fighters adopted a formal Position on the Health Effects from Radio Frequency/Microwave (RF/MW) Radiation in Fire Department Facilities from Base Stations for Antennas and Towers for the Conduction of Cell Phone Transmissions. They oppose them, "until a study with the highest scientific merit and integrity on health effects of exposure to low-intensity RF/MW radiation is conducted and it is proven that such sitings are not hazardous to the health of our members." They reaffirmed that stance in California's 2017 Senate Bill 649 which would take away municipal home rule to place more wireless infrastructure in our communities, on poles in the public rights of way, at street level every 4 to 12 homes. They included an exemption in the bill: Section 2 "65964.2. (a)...(3) The small cell is not located on a fire department facility." Every citizen should have the same protections.

From EH Trust to Everyone: 10:36 AM The news investigation details the fire fighter position. You can watch it all here https://www.youtube.com/watch?v=61h_vuBujw0&feature=emb_title

From NR to Everyone: 10:38 AM New Hampshire does have the legal right to "require" those setbacks. According to the TCA of 1996 -- 47 U.S.C. § 332(c)(7)(B)(i)(I) is very clear: in only prohibiting discrimination between "providers of functionally equivalent services." "Functionally equivalent services" are defined as those wireless services functionally equivalent to those being provided by the "personal wireless service facilities" for which approval is sought. Therefore, a county zoning ordinance that imposed different and stricter procedural requirements (e.g., conditional use) on wireless service facilities than on facilities used for providing fiber to the home, cable TV, utilities, or other services would not be in violation of the law. Moreover, 47 U.S.C. § 253 does not prohibit the county from imposing stricter procedural requirements on WTFs than on cable or other uses of facilities. Section 253 has three relevant parts. Section 253(a) creates the general rule that "[n]o State or local statute or regulation, or other State or local legal requirement, may prohibit or have the effect of prohibiting the ability of any entity to provide any interstate or intrastate telecommunications service". In turn, subsections (b) and (c) are "savings clauses" that provide safe harbors to protect the ability of states and localities to regulate zoning and construction of wireless facilities:

From NR to Everyone: 10:38 AM (b) State Regulatory Authority

Nothing in this section shall affect the ability of a State to impose, on a competitively neutral basis and consistent with section 254 of this title, requirements necessary to preserve and advance universal service, protect the public safety and welfare, ensure the continued quality of telecommunications services, and safeguard the rights of consumers. (c) State and Local Government Authority Nothing in this section affects the authority of a State or local government to manage the public rights-of-way or to require fair and reasonable compensation from telecommunications providers, on a competitively neutral and nondiscriminatory basis, for use of public rights-of-way on a nondiscriminatory basis, if the compensation required is publicly disclosed by such government. From Helene to Everyone: 10:41 AM Yes, Rep Abrami. Exactly what we are going through right now. From GARY WOODS to Me: (Privately) 10:41 AM will you be able to forward the "chat" to us? From Helene to Everyone: 10:42 AM Cell tower will be erected within the hot zone of our home and we are being told that we have NO rights

From Deb Hodgdon to Me: (Privately) 10:46 AM kent see chat on state rights

From EH Trust to Everyone: 10:49 AM You can see how Switzerland measures RF and posts it fr all to see here https://map.geo.admin.ch/?topic=funksender&lang=en&bgLayer=ch.swisstopo.pixelkartefarbe&layers=ch.bakom.mobil-antennenstandorte-5g,ch.bakom.radio-fernsehsender,ch.bakom.mobilantennenstandorte-gsm,ch.bakom.mobil-antennenstandorte-umts,ch.bakom.mobil-antennenstandortelte&catalogNodes=403,408

From Me to GARY WOODS: (Privately) 10:51 AM Yes, I'll forward the chat after the meeting.

From Cece Doucette to Everyone: 11:03 AM

Most kids don't use cell phones against head, but they do have their cell phones, tablets and laptops on their bodies. Please expand this to all wireless devices, not just cell phones.

From EH Trust to Everyone: 11:05 AM Phones exceed RF limits at body contact My daughter uses the phone to her head. I think it should be for al wireless devices as well. Many lawyers and politicians and coaches use cell phones to their head. and most people carry phones touching their body and in bras

From Cece Doucette to Everyone: 11:17 AM Doctors, nurses and others can be trained January 28-31 at the EMF Medical Conference. There are IDC codes already established and in use today. There is an EMF primer offered October 23-24. Health care providers and the general public are invited to register for both. https://emfconference2021.com/

WHO has reopened their investigation into in 2020 based on recent science showing cancers, reproductive issues and other effects: https://www.who.int/peh-emf/research/rf_ehc_page/en/index1.html

From EH Trust to Everyone: 11:20 AM The Who EMF Project has no transparency as published research shows here https://www.spandidospublications.com/10.3892/ijo.2017.4046 Whereas The Who IARC is independent and scientists are vetted for conflicts of interest Our scientists letter to the EHO about the "factsheets" they post online was never answered https://ehtrust.org/scientists-call-for-transparency-at-the-world-health-organization-emf-project/ The Who refuses to answer these questions

From Cece Doucette to Everyone: 11:22 AM Yes, just like the FCC refuses to answer this Commission's questions.

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS OF EVOLVING 5G TECHNOLOGY

Meeting held:
10/8/20
10:00 am-12:00 pm EST
Via Zoom (https://unh.zoom.us/j/8760768986)
Via telephone-US (1 312 626 6799 (US Toll) ID: 876 076 8986)

In attendance: (13)
Rep. Patrick Abrami-speaker of the house appointee
Rep. Ken Wells- speaker of the house appointee
Kent Chamberlin-UNH-appointed by the chancellor
Denise Ricciardi-public-appointed by the governor
Michele Roberge-DHHS- Commissioner of DHHS appointee
Dr. Paul Heroux- Professor of Toxicology, McGill University- speaker of the house appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee
Senator Tom Sherman-president of the senate appointee
Brandon Garod-AG designee, Asst. AG Consumer Protection
Bethanne Cooley-CTIA , trade association for wireless industry and manufacturers
Carol Miller-NH Business & Economic Affairs Dept
David Juvet-Business and Industry Association

Not present: (0)

Meeting called to order by Rep Abrami at 10:03 am

Abrami: Due to the Covid 19 virus and the Executive order signed by the Governor this public meeting is allowed to be conducted via Zoom. It is open to the public for viewing and was duly posted as a zoom meeting. With that said, if you are not a member of the Commission, can you please turn your cameras off and mute yourselves? That would be much appreciated. In addition the meeting is being recorded as an aid to doing the minutes. All chat room discussions will be included in the minutes.

I. Approval of minutes from 9-22-20:

I have not received any changes to the minutes that I sent out about a week ago. Are there any changes that anyone wants to make? Seeing none, I will say …without objection, we approve the minutes from that meeting.

II: Agency Disclaimer:

I sent out the agency disclaimer that will be in the report. That is there especially for the agencies. I think I heard back from two of you. I can't recall if I heard from all three of you. My sense is that the language is okay with your leadership. I think most of you took it up the pole to your leadership. I think you are all okay with that language. I am looking at Michelle, Carol and Brandon. Yes? Ok. So, we are good there. That language will appear in the report.

III: Vote on Recommendations (6,7,8,10,12,13,14):

Some of these recommendations we voted on but said we would change some of the wording so we are going to go back to them, discuss them and take another vote. We may have to revisit #9 as well. The work group changed some of the wording.

I would like to work backwards so Brandon can at least hear the discussion on the ones we have not discussed before and be involved in that vote. I sent the updated document out. It's the document dated October 5th in the upper right hand corner. We will start with Recommendation #14. Denise,that was yours.

RECOMMENDATION 14- The State of New Hampshire should engage our Federal Delegation to legislate that under the National Environmental Policy Act (NEPA) the FCC do an environmental impact statement as to the effect on New Hampshire and the country as a whole from the expansion of RF wireless technologies. Concern comes from the fact that the FCC is projecting that 140,300 low orbit satellites, 800,000 5G small cell antennae plus many additional macro towers will be required for these networks to function.

The majority of the Commission is concerned that any new large-scale project that will densify antennae networks to this extent truly requires an environmental impact study. The NEPA statute requires that the agency consider environmental concerns in its decision-making process. NH should be provided documentation of such considerations. Until there is Federal action, NH should take the initiative to protect its environment.

Ricciardi: We had discussed doing something about the environmental impact with the expansion of wireless technology. The reason I addressed it is because we have an act: the National Environmental Policy Act (NEPA). That statute requires that the agency consider environmental concerns in their decision making process. New Hampshire should be able to request for documentation to be provided of such considerations for the impacts on our environment. That's why I wanted to use this NEPA to reflect that.

Abrami: Any discussion? I don't see anyone. Ok. Without any discussion, I will move to vote. We will take the votes as we did the other day. Is there a motion to accept the recommendation?

Cooley: Mr. Chair, before we do that. Are you guys getting feedback?

Abrami: Yes. Someone is not muted. Please mute yourselves. Thank you, Beth. I was hearing that as well. The static is gone now.

Ok. I need a motion that we accept the recommendation.

Ricciardi: I make the motion that we accept recommendation #14.

Chamberlin: I second it.

Sherman: Are we going to have discussion on this, Patrick?

Abrami: Yes. I did ask for discussion.

Sherman: I just want to clarify one word and that is "fact" in the second sentence. We have seen the citation that the FCC is projecting 140,300 low orbit satellites. Is that from an FCC publication? I just want to be sure that that is a verified fact and that the FCC has stated that.

Ricciardi: It is a fact that Ajit Pai stated that the FCC estimated 800,000 wireless facilities for 5G. That, I know for sure.

Wells: Yes, the 14,300 is the number I have heard associated with the SpaceX operations. There is a citation for the 800,000 in the chat.

Sherman: I just want to make sure that we have the documentation if someone asks, is that truly a fact? This has come up on other recommendations. If you have the documentation that the FCC has projected that, then I am fine with it the way it is.

Ricciardi: Yes and I am sending it. I am trying to make sure I don't miss anybody.

Gray: The relevance of this…are we saying that the radiation from those satellites are going to cause damage to people, DNA, heating, all of those things? Yes. There may be that many satellites but what relevance does that have to our committee? It's like the thing that you sent out the other day about Van Halen having a metal guitar pick and he attributing that to his cancer and discounting all of the smoking that he did for years and years. A lot of this stuff, although may be interesting, it is just anecdotal. It is not a fact. It is not good science. It is not worthy of being talked about and reported in the minutes of these meetings. Thank you.

Woods: I understand the Senator's comment on the relationship and how this recommendation #14 does not make that direct connection. This is basically an assessment of the degree to which the level of radiation is increasing. The rest of the report relates to the basic science. This does not address basic science and its relationship to cellular or organism impact. But, just a documentation of the prevalence and so in that sense, I think it should remain.

Abrami: The third piece of this was additional macro towers to make the networks function. I would imagine without much stretch of the imagination, there would be more macro towers. I know we got the low orbit satellites from somewhere because originally we had 140,000 and Ken, I think it was you who said, it's 140,300.

Wells: I can look for a link on the satellite numbers.

Heroux: the point of the recommendation is that the FCC is avoiding a NEPA review, while modifying the environment substantially. It doesn't qualify the consequences, it just says that the US formality is that is normally fulfilled, has not been, by the FCC.

Abrami: Ok. While Ken is looking for that, let's hold on the motion and move to #13.

Wells: I found a news article from March of this year that the FCC has approved up to a million small cell antennae for the Starlink network.

Woods: If I could clarify that Ken said antennae but the question was about satellites.

Abrami: Ken you keep looking. We will skip this one for now. Denise, please speak to #13.

RECOMMENDATION 13- The State of New Hampshire should engage agencies with appropriate scientific expertise, including ecological knowledge, to develop RF-Radiation safety limits that will protect the natural environment; trees, plants, birds, insects, and pollinators.

The majority of the Commission understands that current Federal safety limits set twenty-four years ago with the intention of only protecting humans from short term effects, but not protecting flora or fauna from harm. The State of New Hampshire needs to ensure our natural environment and wildlife are protected by effective safety standards. Tree limbs, birds, and pollinators will be closer than humans to 5G cell antennae and associated 4G densified infrastructure. In fact, the wireless radiation from cell antennae could exceed safe limits when leaves of trees and flying birds and, since they may have higher exposure being in direct line of sight of wireless RF beams. When pollinators are impacted so are all forms of vegetation that depend on them for reproduction. Research on this issue is shown in Appendix XX.

Ricciardi: We all discussed that the State of New Hampshire should engage agencies with the appropriate scientific expertise including ecological knowledge to develop RF radiation safety limits that will protect the natural environment: trees, plants, birds, insects and pollinators. I like this recommendation.

Abrami: I prefer that we have a discussion before we move to vote in case there are some slight modifications that we can agree to. I will open this up to discussion.

Heroux: I thought we had agreed to remove the word "environment" and use the word "ecology".

Abrami: Yes. We did. What we agreed to was " including ecological knowledge".

Heroux: I think you should remove environment from there entirely and put: trees,plants, birds, insects and pollinators.

Abrami: get rid of “natural environment” is that what you are suggesting?

Heroux: yes.

Gray: One of the key things you cited is data from twenty three years ago. There is also both FDA and FCC guidance that have been promulgated on this that’s dated in “18,’19 and ’20 where they state that they have reviewed the current science and nothing like that is even mentioned in this recommendation. Again, I think you are giving the opposing argument short shrift on this and not considering all the science that is out there.

Sherman: could I say something? Senator Gray and I and everyone in the legislature, understands that federal limits and regulations may not necessarily reflect the latest science. The most recent example of this is the EPA and their regulations on PFAS, which still is at 70 ppt. No scientist worldwide would say that is adequate protection. So, we actually had a bill that we passed asking the DES through their science and toxicology to go ahead and come up with maximum contaminant levels.

I, for one, always find it a little fascinating for us to say: well let’s just trust the federal government to do the right thing when we know they are not necessarily doing it. If we want to wordsmith the second paragraph, that’s fine but I think there is absolutely zero harm having the scientists that are part of our state already and we have great ones at DHHS and DES to take a look at the science and perhaps come up with their own recommendations for guidelines. Not only is there legislative and statutory precedent for this kind of thing, we have selective trust of the federal government when it comes to these scientific matters. We have generally erred on the side of saying: well, let’s take a look at it ourselves. I would say, let’s vote on this one and move on.

Ricciardi: Thank you, Senator Sherman.

Gray: Again, I am not saying you are not going to put this recommendation in. I am saying that you say the guidance out there is 23 years old, but you don’t mention the documents from ’18,’19 and ’20 that affirm that they have conducted reviews that are of the current data that is out there. Unless you are going to treat both sides fairly, then the report you get at the end has no meaning.

Abrami: If you read on, it says with the intention of only protecting humans from short term effects. Obviously the first studies were done on humans, not birds, plants, insects and pollinators. I am ok taking the 24 years out but as Tom said, even with that, the state doesn’t necessarily trust what the federal government has done.

Sherman: Mr. Chair, I have a fairly straightforward wordsmith that hopefully addresses Jim’s concern. It could say: “the majority of the commission understands that current federal safety limits were made with the intention of only protecting humans from short term effects” They have looked at subsequent science but they are the same so we don’t have to get into that. We can just capture that by saying the intention.

Abrami: right. Thank you for helping with that one. That was my feeling.

Sherman: If there is no further discussion, we should move. We have to keep moving.

Abrami: we are up against a time clock here. That's why it may appear that I am rushing.

Roberge: Just a recommendation. In recommendation #1, we are asking our federal delegation to require the FCC to look at the standards with respect to human health. I am wondering why we wouldn't ask for them to look at the environmental impacts as well. An example of that was in my previous job at DES, that at the EPA looking at the Clean Air Act and standards set by EPA, there is a primary health based standard and a secondary environmental standard on things like sulfur dioxide and nitrogen oxide. I am just suggesting that we add this on for recommendation #13.

Abrami: We had it separate to highlight that only human effects have been considered and I would like to keep it separate.

Cooley: Just a comment and I don't me to belabor the point but this is more so for the minutes. States do not have jurisdiction to set their own RF safety limits. That is the exclusive jurisdiction of the FCC. For that reason, I will be voting no on this recommendation.

Abrami: Again, this is only to have the state study if it so wishes. This would be just like Tom was saying; the state took the initiative to look at PFAS a little more closely. That's what we are doing here. We are trying to add to the knowledge base.

Ricciardi: in 2018 and 2019, statements by the FDA are not about the birds, trees, and bees. If you look at the FDA reports, they are only about tumors not environmental effects. As we said before, these are just recommendations by our commission. Recommendations, do not go against the law as Senator Sherman said, you would put legislation forward. With all due respect to everyone here, there is the minority report. I don't feel that we should be constantly changing the one that the majority feels when there will be a minority report. Thank you.

Gray: Again, Denise has her opinion. The thing is that this report should have the fair and equal treatment of both sides of this issue. In paragraph one, you claim to have a fair and equal treatment of both sides. Yet, on this recommendation before it was modified, you spoke to the 23 years and ignored recent documentation issued by both the FCC and FDA. The FDA as far as I know is not in the business of protecting the environment. I agree with that. But, then we didn't go look at other guidance out there to see if it was relevant. All we are asking for is fair and equal treatment. There are experts that we would like to present but we have not been able to do that because of time considerations and scheduling problems with those experts.

If you are going to just put through recommendations on this issue that I feel are far and above what should be done without looking at both sides of the science, then I might as well sign off this call and resign from the commission because it's not doing me any good and it's not doing the citizens of New Hampshire any good. You guys rail road this thing through. Fine. But we are not protecting the citizens of New Hampshire and not providing the economic opportunities that a good and useful cell phone system will provide them. It's just very frustrating.

Abrami: Again, we lost four months due to the virus. I had a lot more speakers lined up and I kept saying to Beth, come up with more speakers. There is no changing our end date on this.

Sherman: Mr. Chair, I just want to make sure the Jim knows that I hear what you are saying and the way these commissions work is we try to be very respectful to everyone's opinion. We move forward as much as we can together and the minority report is for any additional dissent or altering opinion. But Denise, I think it's very appropriate for us to modify the final recommendations to fit as many people on the commission as possible. I fully support making the change that Jim wanted which was getting rid of the years and the timeline in the comment below. I hope we can move forward and bring this to a vote.

Ricciardi: I appreciate that and I understand. It's just the subcommittee has worked over and over again all these iterations. But I do thank you for your comments.

Abrami: any other questions or comments on this? I would like to take this one to a vote.

Sherman: I am happy to move it to a vote.

Heroux: I second.

Abrami: It's going to be as shown and taking out the "natural environment" in bold and taking out "set 24 years ago" and adding "limits were made with the intention", in its place. We will go over all these changes and do a final vote before we do a vote on the report. I will call the roll:

Tom Sherman: yes

Ken Wells: yes

Kent Chamberlin: yes

Carol Miller: abstain

Denise Ricciardi: yes

David Juvet: No, and I would like to comment. This implies that the state is going to be implementing its own RF radiation safety limits which I think will invite a lawsuit. I can't support it.

Beth Cooley: no

Brandon Garod: abstain

Michelle Roberge: abstain

Paul Heroux: yes

Gary Woods: yes

Jim Gray: no

Pat Abrami: yes

Abrami: The motion passes, 7 yes, 3 no, 3 abstain.

Any information on the numbers for satellites, Ken?

Wells: Elon Musk has approval for 42 thousand but there are other satellite companies like OneWeb but I don't know what the total number is. I would be fine if you want to remove that number of satellites or just talk about the 42 thousand that SpaceEx has been approved for their Starlink project.

Abrami: I remember seeing articles when we first started this that there were two or three companies, I think. If somebody could help me with that, I would appreciate it.

Heroux: You could put that the exact number will be updated by FCC documents. We know it's going to be at least forty three thousand and it may be higher but I don't think that people will vote yes or no on the basis of the exact number of satellites but rather on the impact of all these things.

Abrami: We can vote on the number as written with the intention that we find and have documentation for it and all of these in the appendix and we can modify 140,300 low orbiting satellites before the last meeting.

Sherman: I would recommend the following: I would take the sentence that starts with concern and un-bold it and put it in the discussion. And change the part: concern comes from the FCC projection of numerous low orbit satellites and 5G small cell antennae plus additional macro towers that will be required for these networks to function. You still need documentation in there.

Wells: Citation 53 and 57 talk about FCC license approved.

Heroux: The satellite network is something very fluid. Some of these companies go bankrupt. Essentially, there is a large uncertainty but I think that when the FCC mentions 800 thousand, it is their number and it brings home the impact on the environment because "numerous" could be five. Five is not equal to 800 thousand. When we have a number that originates with the FCC, maybe it shouldn't be in bold because it doesn't refer to a principle but at least it should be in the text underlying, in my opinion.

Gray: Again, the purpose of this commission is to study health and environmental impact. Are we saying that every one of those satellites is affecting health or the environment? No. That's not possible. The FCC has issued further guidance about whether there is a health effect and has said that they have studied the current science out there and current reports that have been done by other people. Not including a reference in this and many of the others to the fact of what the current position of the FCC is, is one sided and not a fair and balanced part of the report. You can say whatever you want but we need to present the facts on both sides, not the facts on one side. Trying to use the number of satellites, the number of antennae, the number of this, the number of that and saying that that is going to affect your health or the environment is purely trying to do fear mongering. Present the facts on both sides.

Abrami: Let's not forget that we wrote to the FCC and the FDA questions that they did not answer. We would love to have had them testify before us as well but that was not going to happen. They would not even answer our questions.

Gray: the guidance is already there on the internet. I went and found it when I was preparing the current minority report.

Ricciardi: It's a captive agency.

Sherman: I would just point out that if you look at the recommendation, it is not drawing any conclusions, Jim. It's asking for further study. I don't think it's necessary that you have to say anything when all you are asking is for further study so I disagree with you on this one. I do agree with Paul that if you want to put a number in there that is a little more dramatic then numerous, you just need to be sure that you have the source of that number documented. I am fine with a number as long as its source is documented.

Woods: I agree that we should move forward with this. This is basically an assessment tool of identifying prevalence. It's probably no different than the technology of putting roads in a hundred or so years ago. We didn't' have roads or bridges and did not have to repair them. But now, we need to assess roads and identify how many bridges we have that need repair. We are now in a different technology, wireless and like roads and bridges we are trying to identify how many we have. We are not saying bridges or roads are bad. We are trying to do an assessment of the prevalence of these items so that when we look at whether they need attention or not, we will have some idea. Again, it's like trying to assess how many bridges we have not whether they are good, bad or indifferent.

Wells: From a physics point of view, the number of antennas is relevant because if you have tens of thousands of satellites and hundreds of thousands of small cell antennas and they are all emitting energy, the energy density is increased by a factor of the number of antennas.

Abrami: Tom's suggested language moving it from the bold section to the explanation portion. Why don't we do that and between now and the next meeting, if we can verify hard numbers we can put them in the report. Is there any other discussion? Kent made motion to move the recommendation. Denise seconded it. I will call the roll:

Sherman: no vote (not on screen)

Wells: yes

Chamberlin: yes

Miller: abstain

Juvet: no

Cooley: no

Garod: abstain

Roberge: abstain

Heroux: yes

Wells: yes

Gray: no

Abrami: yes

I don't see Tom on the screen, so I will not count him. 6- yes, 3 -no, 3 -abstain. Motion passes.

RECOMMENDATION 12- Recommend the use of exposure warning signs to be posted in commercial and public buildings. In addition, encourage commercial and public buildings, especially healthcare facilities, to establish RF-radiation free zones where employees and visitors can seek refuge from the effects of wireless RF emissions.

Many NH citizens are sensitive to electromagnetic radiation emitted from devices used in the delivery of in-building cellular, and fixed wireless services. A majority of the Commission suggests owners of commercial and public buildings, especially healthcare facilities, voluntarily place signage at entrances concerning RF-levels and RF-free zones within these structures so those entering the building are aware.

Miller: It's a simple recommendation for exposure signs to be posted in commercial and public buildings especially in healthcare facilities. This is also to establish RF radiation free zones where employees and visitors can seek refuge from the effects of the emissions. It's a pretty simple recommendation. Some folks are doing it already. I can say that dentist's office tell you to shut your cell phones because it does disturb the equipment. There it is and ready for discussion.

Gray: Are we going to include the report from the World Health Organization that says exposure to this low level of radiation is not a factor and has not been scientifically tied to any syndrome? Is that going to be included at all?

Miller: I don't know. If you think that would balance off this recommendation and would like it in the appendix, I have no problem with that at all. Regardless of whether it's based in science or not, there are many citizens that are sensitive to it. It's as simple as that, for me anyway.

Gray: Again, I am just trying to be fair. There are people out there who say they are sensitive to it but there is no scientific tie in double blind studies that confirm that these people are actually suffering effects of the radiation.

Heroux: and these people don't believe that.

Miller: Right and it's just a recommendation. It's not required. We can add some NH citizens are sensitive…. Regardless of the study and add the appendix note with that. However, you think the justification for the bolded statement addresses both sides. You could put after the words: fixed wireless services…. even though not substantiated through the World Health Organization Report.

Abrami: The lead in to all these recommendations is we are following the Precautionary Principle. All of these would need NH legislative approval. The work group thought this was a reasonable recommendation to make, understanding that it's a high lift to get it through the legislature and the Governor to sign. We can add a line or two but Jim, you have the minority report. I know what you are going to say about this one. You already told us.

Juvet: Just a question for people more knowledgeable about this than me. What exactly is involved with businesses establishing RF free zones? What do they have to do in order to create that?

Miller: We had some examples where hospitals have rooms available for folks that were bothered by the electromagnetic radiation. It's not just from antennas. It comes from computers and a variety of places. I have experienced a customer coming into my business going, "whoa, I can feel everything in here". That was one of hundreds that come in.

Juvet: I am just asking for clarification. You could use hospitals as an example. What did they have to do to create that RF free zone?

Wells: From the physics point of view, you build a Faraday Cage. It's a lightweight metal lined box. It could be similar to a screened porch with metal screening or aluminum foil. Repaper the wall with aluminum foil and you are good.

Heroux: What you can do is survey the environment for the place where the fields are lowest and post signs that you don't want active sources that are controlled by individuals and you may do this at a very low cost. As Ken mentioned, you could also actively try to shield if you have some sources that are very powerful that you want to get rid of in that location.

Abrami: We have somebody who is RF sensitive who says, my oral surgeon was very happy to move me to a lower RF room and make sure no one had devices in the room.

Sherman: I think there is an easy fix on the sentence but I just want to caution Jim or others about citing any traditional or organized medical site like WHO or otherwise… that because they say it isn't so, that it isn't so. I am old enough to have been and I know others will recognize this but when I was growing up in Madison, people who had fibromyalgia syndrome or symptoms or irritable bowel symptoms were actually told by doctors, it's all in your head and come to find out, it's not. Studies were inadequate. They missed the boat. Eventually, when we got the studies together, we recognized not only that the symptoms real and reflected a true syndrome, but now they are mainstream diagnoses. The fact that RF sensitivity is not fully recognized nationally or internationally, doesn't mean a thing to me.

What I would say is "many NH citizens report sensitivity to electromagnetic radiation" and leave it at that. That's the reality. I suspect this will turn out to be a real well-documented syndrome eventually.

The science is so much in its infancy right now. I would be very cautious about saying it doesn't exist. I suspect that it does and we don't have the studies yet to prove it.

Abrami: Our recommendation #11 directs the medical community to start looking at this more rigorously. I am ok with that change.

Gray: It still does not recognize that there have been scientific experiments conducted by the WHO that was supposedly double blind and all the great things we are supposed to do when we do one of these studies that said they cannot, and not to be insensitive to people who are suffering, but they couldn't attribute it to electromagnetic radiation.

Sherman: I would just respond to that Jim, no physician in their right mind would depend upon a single study to say that something does or does not exist or that a treatment does or does not work. Would you agree with that, Gary?

Woods: Absolutely, we have seen as Tom has outlined time and again over the course of hundreds of years, theories have been thrown out on a regular basis for a variety of reasons. This is just one more in that long term step. We went through this with tobacco and we are doing the same thing again. In the chat there are some references for the WHO organization the Jim refers to. The people in the chat seem to be more familiar with it than I. There are two portions of the WHO organization. Some are associated with industry and some are not. It has been pointed out, as we have pointed out in this commission, one of the WHO organization provided the conclusion that radio frequency radiation was indeed a Class II carcinogen. So to say that a WHO organization says there are no effects, would not be inclusive of all the WHO organization findings.

Gray: Saying that it is a carcinogen, it doesn't take into consideration what the level of that radiation is. The FCC's recommendations are 50 times less than what has been demonstrated in various studies. To say that it's a carcinogen, yes at certain levels it is. When we treat cancer and have multiple doses of radiation going into a patient, we do it at different aspects so the tissue in between is not affected. To make that statement without some kind of a radiation limit, doesn't bode well for me.

Sherman: Mr. Chair, can we move the question?

Abrami: Are there any other comments? Ok, let's move the question. The only change is in the descriptor, "many NH citizens report sensitivity". Tom, are you making the motion?

Sherman: yes.

Abrami: second?

Heroux: yes.

I will call the roll:

Sherman: yes

Wells: yes

Chamberlin: yes

Miller: abstain

Ricciardi: yes

Juvet: abstain. I appreciate that this is a recommendation and not a mandate. On the other hand, I am uncomfortable with sentences like “many NH citizens”. I don’t know what “many” means in the context of the overall state population so I am on both sides of this one.

Cooley: abstain.

Garod: Brandon had to leave. He is gone.

Roberge: abstain.

Heroux: yes

Woods: yes

Gray: no

Abrami: yes

7- yes, 1-no,4- abstain. Motion passes.

We are going to go to #10.

RECOMMENDATION 10- Promote and adopt a statewide position that would strongly encourage moving forward with the deployment of fiber optic cable connectivity, internal wired connections, and optical wireless to serve all commercial and public properties statewide.

The majority of the Commission believes that fiber optic transmission is the infrastructure of the future. When compared, RF wireless transmission lacks fiber optic characteristics: speed, security, signal reliability and biological effects on humans and the environment.

The State should encourage partnerships between towns to make this happen and encourage our Federal Delegation to support grant money to assist with such deployments when it comes to funding fiber optic cable deployment especially in rural locations.

Abrami: This is really a shout out to fiber optic connectivity.

Miller: It is simply adopting a statewide position, not a body but a position that strongly encourages moving forward with deployment of fiber optic connectivity, internal wired connections and optical wireless to serve commercial and public properties statewide. That would just mean hard wired connections or optical wireless as opposed to Wifi. Open for discussion.

Heroux: I am very in favor of this. I think in the modern world, having fast access to the internet is a human right nowadays. This should be done in the most technologically advanced way, which is optical fiber. There is both a technological aspect to this and a human aspect. I think this is very important.

Juvet: just a quick comment. I am actually prepared to vote for this recommendation because the BIA believes in an “all of the above” approach for technology and communication. My question is in the text, when you talk about comparisons with RF wireless transmissions, we are only mentioning things that don’t compare well with fiber optics. I am wondering if there are any advantages to wireless and if there are, shouldn’t that also be mentioned?

Abrami: The advantage would be mobility.

Miller: Well, not only mobility but cost. Being able to distribute wireless connections is a lot cheaper than hardwiring connections.

Wells: The recommendation talks about fiber optic cable and in other recommendations, we talk about wireless optical transmission. The major advantage RF has is its not tethered. It is possible to do optical without being tethered. But that’s not built into this recommendation but appears elsewhere.

Abrami: Well, yes it is in here.

Wells: oh yes. Now I see it. You are right.

Heroux: Lifi (optical wireless) has advantages of privacy over radio frequency or microwave (Wifi) which is very leaky from the privacy point of view.

Cooley: I just want to note for the record that I will be voting no on this. We see this as discriminatory and it doesn’t take into account the realities of geography, topography and economic realities that may limit the ability to provide fiber. By removing one type of technology altogether like wireless, you could be exacerbating the digital divide and removing options for consumers to connect. Thank you.

Sherman: I just found one tiny point. I feel like the grammar police here but in the sentence with “biologic effects in the human environment, doesn’t make sense to me. The way I would say that is, ”RF wireless transmission lacks fiber optic characteristics including speed, security and signal reliability while avoiding potential biologic effects on humans and the environment.

Abrami: Yes, you are right. I agree with you.

Gray: I have less of a problem with this recommendation with that change but it still assumes there is an effect on humans and the environment. We are picking one technology over another that I am not sure I am comfortable with.

Sherman: I would just add Jim, you are not picking it, but the majority of the commission feels this way.

Gray: and as Senator Sherman knows, the people who elected me elected me to voice my opinion and speak strongly in their defense.

Abrami: we respect that Jim.

Woods: This doesn't say anything about the biological being good or bad. It just says avoids it. Because when you have radiation in the environment, there will be an effect on humans. It's like measuring the bridges. We are just being cognizant that in fact, this is an exposure.

Juvet: Just a request from the commission. In my reading of this, the promotion of fiber is not meant to exclude the development of Wifi but Beth makes a good point. Is there some way in the recommendation that we could add the words, "where practical"? This would recognize that a lot of areas of this state, we recognize the benefits of that but it's just not a practical option.

Abrami: I have no problem with that.

Juvet: I would insert "where practical" and delete, "to serve all commercial and public properties statewide".

Wells: I just want to note, is it practical to put electricity I commercial and public properties? You are talking about exactly the same type of installation for fiber optic.

Abrami: I think the practical consideration David was talking about was cost.

Wells: I am thinking of the Rural Electrification Act. You know it's surely more expensive to supply service in low density areas, yet broadband is as necessary these days as electricity and running water. I don't see that adding "where practical" in here is a necessary or a desirable qualifier.

Miller: Even though I will abstain from the vote on this and have written this, I think the idea behind this… as far as cell service and all of that, everything has its place. This particular recommendation really starts to get at the infrastructure of the future which regardless of mobile technology and everything else is where New Hampshire needs to go. However you decide to wordsmith it, I would not like to see the essence of that recommendation be diluted by it. That's my thought even though I will be abstaining.

Heroux: I agree with Carol and I would like to point out that in some recommendations we talk about the majority of the commission. We start the recommendation this way. I wonder if this wording is appropriate. Why is it in some recommendations and not others when we will probably report how many people voted for it and how many voted against? I don't see any recommendation in this report that will be unanimous.

Sherman: I am just reflecting. As Ken was saying, maybe rather than using "where practical", and say "wherever possible" captures what Carol was saying. It also captures the idea that if you can get electric in there, you can get fiber optic in there. Even the top of Cannon Mountain has it. If you are on top of Mount Washington and all you have is cell service and there is no electric and you are living on kerosene lamps, then maybe it's not possible. Practical can mean if it is $10 more to put in fiber optic, maybe it's not practical because you already have cell. I think putting in "possible" captures the spirit of what Carol was saying and also captures what Ken was saying. I am just putting it out there.

Abrami: I guess the one I have to ask is Dave.

Juvet: I would prefer practical. The senator says possible and what if it's ten thousand dollars more? Anything is possible if you want to devote enough financial resources to it.

Miller: I wanted to go back and respond to Paul's comment about the majority of the commission. I think we coined that phrase because of Senator Gray and the fact that we don't have 100% consensus on a lot of these recommendations. It's nothing more than that.

Abrami: we have three options. Either don't change it; possible; or practical.

Juvet: Mr. Chair maybe I can make it easier on the commission and perhaps we should just be voting on the original wording because I think it's going to get difficult if we are trying to find out which wordsmithing we are more comfortable with. I am not sure it will change people's votes, ultimately. I would like to withdraw my recommendation and we can just vote on the original wording.

Abrami: Ok. Thank you for that. What we are changing is, "while avoiding potential effects".

Wells: I would like to move that.

Woods: second.

We are voting on recommendation #10.

Sherman: yes

Wells: yes

Chamberlin: yes

Miller: abstain

Ricciardi: yes

Juvet: no

Cooley: no

Garod: absent

Roberge: abstain.

Heroux: yes

Woods: yes

Gray: no

Abrami: yes

7- yes, 3-no, 2- abstain. Motion passes.

Juvet: Mr. Chair, I do need to drop off the zoom meeting now because I am leading one that starts in about two minutes. Thanks everyone for all their work on this but I do need to leave at this point.

Abrami: Before you go, we are thinking of a meeting on Tuesday, the 27th one o'clock for at least two hours.

Juvet: I am available on the 27th.

Abrami: Can anyone not make that? I will check with Brandon.

Ok moving backwards now to #8.

RECOMMENDATION 8- Upgrade the educational offerings by the NH Office of Professional Licensure and Certification (OPLC) for Home Inspectors to include RF intensity measurements.

Home Inspectors currently operate as private contractors who may be hired by citizens or enterprises to measure such things as radon, to collect water quality samples, or search for mold or insect damage. Home inspectors routinely supply test results to both their clients and government entities.

The majority of the Commission believes the public has the right to discover, on a voluntary basis, the RF power intensity related to radio frequencies at a property which they will be purchasing or renting before the transaction is closed. Also, the proprietors of publicly accessible venues may wish to reassure the public about the RF power intensity within their establishments, by posting the data collected by a state-approved inspector. In addition, such testing should be paid for by the party requesting it and the testing itself should be performed by a professional who owns or rents the test equipment and has met the state requirements for training of Home Inspectors regarding RF measurements.

The majority of the Commission proposes that Home Inspectors be offered training by NH OPLC on how to measure on-site peak and 24-hour average RF intensities. Measurements of frequencies and intensities will be performed using low-cost equipment (such as GQ-390 meters). [Description of existing Home Inspector training offered for radon, mold, etc. may be seen at https://oplc.nh.gov/home-inspectors/index.htm]

Cooley: Mr. Chair, my notes say that language was supposed to be inserted making this voluntary.

Gray: My objection to this one is that we are putting it on the Office of Professional Licensure and Certification to go and do something. I don't think we need the State of New Hampshire to do that at all.

Abrami: Beth, we did add that if you go to the second paragraph…"on a voluntary basis".

Gray : if it's a voluntary program then OPLC shouldn't have to do that, take some advocacy group and develop the thing and get certified through the advocacy group. I don't think it needs to be a function of the state.

Sherman: Mr. Chair, I move that we adopt this recommendation as written.

Ricciardi: I second it.

Abrami: Ok. Let's go to the vote:

Sherman: yes

Wells: yes

Chamberlin: yes

Miller: abstain

Ricciardi: yes

Juvet: absent

Cooley: abstain

Garod: absent

Roberge: abstain.

Heroux: yes

Woods: yes

Gray: no

Abrami: yes

7- yes, 1-no, 3- abstain. Motion passes.

RECOMMENDATION 7- Require that any new wireless antennae located on a state or municipal right-of-way or on private property be set back from residences, businesses, and schools. This should be enforceable by the municipality during the permitting process, unless the owners of residences/business or school districts waive this restriction.

Local public rights-of-way are under the jurisdiction of municipalities, and the Commission feels that municipalities should uphold the rights of individuals impacted by antennae. The Commission also supports the right property owners to manage decisions on non-essential devices being placed in front of their property.

The Commission believes that it is important to prioritize citizen safety, particularly as 5G is an upgrade, rather than the provision of wireless service to unserved areas. Additional rationale for this recommendation shown in Appendix XX.

Abrami: #7 was rewritten after objections by Beth on the California firefighters. That was in the write up.

You sent us all the California Senate amendments. They say that "due to the unique duties and infrastructure requirements for swift and effective deployment of firefighters, those provisions do not apply to co- location or siting application for telecommunication facility where the project is proposed for placement of fire department facilities." This is my read on this, they are carving out the fire stations and the reason that they give is totally different from all the background history that says health effects.

They said it had to do with them interfering with their duties, not that it's health effects. They basically said having towers on top of the building is going to interfere with the swift and effective deployment of firefighters. To me, that's a sleight of hand what they are saying here. They are trying to skirt the federal law with this. To me, it's a wink and a nod. Is that the way you read this, Beth?

Cooley: You can just read the statute itself. You can imply intention or read into it all you want but the statute itself says it's got the FCC language in there that you know that states and localities cannot consider RF emissions or the alleged health effect as a reason to deny a facility. You have to read the statute as is. You can rely on innuendo or fake news coverage all you want but that's really all I have to say.

Abrami: What I don't understand is how does the cell tower on the roof impact the duties for swift and effective deployment of firefighters? I don't understand the logic.

Cooley: you have to read the statute in conjunction with the fact they are honoring federal law,

Abrami: That's the only way they can honor federal law. They are not going to say what the real issue was. The real reason was fire fighters fought hard because of health effects. We don't have the time digging into the logic of California legislature on this other than to get around the federal law and appease the firefighters. I would ask that question.

Ricciardi: If you want, I can send you documents on how they lobbied on health effects.

Abrami: we know there are documents on health effects but this is the only way they could skirt federal law. If the FCC really wanted to take this on, they could. How does a cell tower on your roof impact the swift deployment of firefighters?

Cooley: Mr. Chair, I don't think it changes the essence of the recommendation. I will be voting no and you guys all know that. Your setback requirements are unlawful and essentially a prohibition of service. Even if you conceded the California topic, which I am not, you read the statute as it's written. You still have the underlying recommendation which is incredibly problematic.

Gray: The bottom line of this is that there is a federal preemption. Whether or not there is a California law to do something, it doesn't matter. There is a federal prohibition against us doing that. That's the bottom line and this recommendation should not be in the report.

Abrami: California proves that you can do a carve-around. That's what I am seeing here. They have carved out a certain set of people. That's the way I view it.

Sherman: I just want to move to accept the recommendation as written.

Chamberlin: I will second it.

Sherman: yes

Wells: yes

Chamberlin: yes

Miller: abstain

Ricciardi: yes

Juvet: absent

Cooley: no

Garod: absent

Roberge: abstain

Heroux: yes

Woods: yes

Gray: no

Abrami: yes

7- yes, 2-no, 2- abstain. Motion passes.

Abrami: Ok. We took number six and split it into 6A and 6B.

RECOMMENDATION 6A- Signal strength measurements must be collected at all wireless facilities as part of the commissioning process and as mandated by state or municipal ordinances. Measurements are also to be collected when changes are made to the system that might affect its radiation, such as changes in the software controlling it. Signal strength is to be assessed under worst-case conditions in regions surrounding the tower that either are occupied or are accessible to the public, and the results of the data collection effort is to be made available to the public via a website. In the event that the measured power for a wireless facility exceeds radiation thresholds, the municipality is to be empowered is to be immediately have the facility taken off line. The measurements are to be carried out by an independent contractor and the cost of the measurements will be borne by the site installer.

It is recognized that theoretical calculations show that existing FCC guidelines will be met by standard cell tower configurations. However, there are cases where the radiation from towers can be focused by buildings, terrain, and beamforming antennas, causing signal levels to be considerably higher than would be expected in theoretical calculations unless those effects are taken into account. Collecting field measurements provide the only valid approach for determining whether exposure guidelines have been met. It is to be noted that some municipalities (e.g., the town of Burlington, MA [1]) have ordinances requiring measurements at cell towers.

Federal Law and NH law grant to municipalities the power in enact zoning rules regulating the placement of personal wireless service facilities within the geographic boundaries of the municipalities. Municipalities should be proactive in this area and through the exercise of zoning power establish where, how, and a process for compliance with existing FCC guidelines for signal strength in the surrounding coverage area. Municipalities should establish a hierarchy of siting values and compliance acknowledgements so that the siting most favored by the municipality is the easiest siting for the wireless applicant to obtain and conversely the siting which is least desirable should be the most difficult siting for the applicant to obtain. The zoning ordinance should lay out the compliance requirement as part of the zoning approval.

[1] Burlington, MA zoning Bylaw Wireless Facilities Section 8.4.6.2 "Annual RF emissions monitoring is required for all sites by an independent RF engineer to be hired with Planning Board approval and at the applicant's expense. Test results will be submitted to the Town as soon as available, and not later than the close of the calendar year. Annual testing of electromagnetic emission shall be required to ensure continual compliance with the FCC regulations.

Chamberlin: We split this into two separate recommendations. The change made to 6A was to add that municipalities can take the antenna off line if it exceeds thresholds. It's one thing to take measurements but what do you do about it if it's an issue? It also mentions that these measurements will be taken by an independent contractor with the cost to be borne by the site installers. This only addresses requirements that measurements be performed on the facility. We might want to discuss that first because there is a part that Carol put in also talking about the control of the facility by the municipality.

This part was added by Carol.

Federal Law and NH law grant to municipalities the power in enact zoning rules regulating the placement of personal wireless service facilities within the geographic boundaries of the municipalities. Municipalities should be proactive in this area and through the exercise of zoning power establish where, how, and a process for compliance with existing FCC guidelines for signal strength in the surrounding coverage area. Municipalities should establish a hierarchy of siting values and compliance acknowledgements so that the siting most favored by the municipality is the easiest siting for the wireless applicant to obtain and conversely the siting which is least desirable should be the most difficult siting for the applicant to obtain. The zoning ordinance should lay out the compliance requirement as part of the zoning approval.

Miller: This language comes from some presentations and attorney recommendations for towns. It simply says that federal law and NH law grant to municipalities the power to enact zoning rules regulating the placement of personal wireless service facilities within the geographic boundaries of their municipalities. The municipalities should be proactive in this area. Through the exercise of zoning power establish where and how and a process for compliance with existing guidelines for signal strength in the surrounding coverage area. They can establish a hierarchy of siting values and compliance acknowledgements so that the siting most favored by the municipalities is easiest siting for the wireless applicant to obtain. Conversely, deciding which is least desirable should be the most difficult siting for the applicant to obtain. The zoning ordinance should lay out those compliance requirements as part of that zoning approval. It's just legalese legal speak for what the municipalities can indeed control within their realm. Is there any discussion about that? It comes from Donahue, Tucker and Ciandella which does a lot of work for municipalities across the state with regard to cable franchises and wireless siting and all of the above.

Cooley: That new language is concerning to me because it's a clear outline of how to put up obstacles for deployment. So a municipality is saying we want this site here over this one but the municipality has no idea where coverage is needed or where there are coverage holes. That language is quite concerning to me.

Gray: the problem I have with this one is you start off by talking about signal strength and being able to shut down a site. If the facility is operating within the FCC goals, I don't think you have the ability to do anything after that site has been established. And then we moved to this paragraph which talks about siting the thing. That's very concerning. I can't think of powers here in the city of Rochester that have gone through the planning and zoning process that haven't gotten a favorable decision because of the strength of the law giving the FCC certain responsibilities.

Abrami: It assumes that the limits are above the FCC guidelines.

Heroux: Cultural acceptability of these installations and social acceptability to the people who use them is very important and critical in my opinion.

Abrami: I don't see anything wrong with us saying the municipality can measure whether sites are within federal guidelines. If they are not, we are saying action can be taken by the municipality. That's all it is saying.

Ricciardi: I just want to remind everyone that we are here to make recommendations based on what we have learned over the course of all of these months and that is what we are doing. We wrote long questions to the FCC, FDA, EPA. We did not get answers. They did not want to present. So we are using from the presenters, from the science and from what we read, to make recommendations to help residents in the state of New Hampshire. That's our job of this commission. This is just a recommendation based on our findings. It's not a law.

Abrami: my concern is that right now, we put three or four cell towers near each other, how do we know, who is the policeman on this? Maybe Beth knows this answer. Is the industry out there taking measurements making sure they are within federal limits?

Cooley: I don't have a clear picture on that so I don't want to say publicly. I have heard different things from different members of mine but I can look into that. I can follow up.

Gray: I wanted to comment on Denise's comment about the questions that were sent to the FCC. Many of the issues she raised are already available on the FCC and FDA website. For a commission member to send a letter off that did not even come from the whole commission in an approved list of questions to the FCC doesn't meet the common sense test in this instance. That information is available. Maybe they did not respond to Denise's letter…ok? Is the information that Denise asked for available on their website? Yes. I went in and found it. We are not citing a lot of that information anywhere in our report.

Ricciardi: "We" gave specific questions that are not answered on the website. They did not answer them and those are the answers to the question we were truly seeking to find.

Abrami: I did review them before she sent them out and we shared them with everyone. We can go round and round on this one. Let's bring it to a vote. I need a motion.

Heroux: yes.

Wells: second.

Abrami: Ok. We are voting on 6A.

Sherman: yes but I have five minutes and then I have to leave at noon.

Wells: yes

Chamberlin: yes

Miller: abstain

Ricciardi: yes

Juvet: absent

Cooley: no for the hierarchy siting language and I also need to leave at noon.

Garod: absent

Roberge: abstain.

Heroux: yes

Woods: yes

Gray: no

Abrami: yes

7- yes, 2-no, 2- abstain. Motion passes.

Abrami: let's try to do 6B. Were there any changes to this one?

Chamberlin: the only change that was made addresses taking new measurements that takes into account the impulsive nature of radiation and the summative effects. What was asked for in the last meeting of this group was that we take some of the references and put them in the appendix and that's all that we really did on this one. I also mentioned that the development of those funding protocols should be funded by the appropriate federal agency like NIH, FCC etc. We are in the process of creating more references that support the statement that it's impulsive radiation more than continuous radiation that has the deleterious effect on humans. That's the change and is in compliance with what was asked in our previous meeting.

Gray: again the FCC I believe in the spring of 2019 addresses a lot of these topics in there. They reviewed the science and found these effects are not true. You don't have any of that information in this report that is anti to the opinion of the majority of the group.

Abrami: if no more discussion, I would like to get a motion on this one and vote before the two leave.

Chamberlin: So moved.

Heroux: Second.

Sherman: yes

Wells: yes

Chamberlin: yes

Miller: abstain

Ricciardi: yes

Juvet: absent

Cooley: no because of the alleged assumption of negative health effects.

Garod: absent

Roberge: abstain.

Heroux: yes

Woods: yes

Gray: no

Abrami: yes

7- yes, 2-no, 2- abstain. Motion passes.

Abrami: I think that's it. I am going to have to pull this all together. I will rely on Joel to help me pull pieces from one place to another and I will get it to you as soon as I can. I asked the work group to pull together the appendices that go with these recommendations. The work group will meet once before the final meeting and possibly reorder these in some logical way without losing the numbering.

Jim: as soon as I know the order, I will tell you and give you a map.

Gray: It doesn't appear we will have time if you aren't meeting until the 27^{th}. We only have a few days to do the minority report.

Abrami: I was assuming you would be working on the minority report in parallel based on the recommendations.

Gray: we have been trying to do that but every time we get changes getting it back through the people on the minority report is becoming a problem. Again, we will do our best.

Abrami: ok. The date is November 1st. If we need a little wiggle room we might be able to get it. Just because we are meeting on that date does not mean we won't have the report out to everybody before that date. Ok Jim? A lot of this is going to fall on me and Joel to get it pulled together. I will try to get it to you a week ahead of that date so you can see what it looks like before then.

Gray: and I will do my best to get the thing to you as soon as I can.

Abrami: I know Jim. We are all under pressure having to campaign at the same time.

Workgroup next meeting: Monday, the 12^{th} 10am-12 pm. Kent, will you set that up and the other one as well?

Chamberlin: yes.

Abrami: ok very good. Thank you.

IV. Next meeting via Zoom: October 27th 1-3pm

Meeting Adjourned at 12:03 pm

Chat from HB522 Commission October 8, 2020 Meeting

From EH Trust to Everyone: 10:15 AM

800,000. We'll need an estimated 800,000 new cell sites by 2025.
https://docs.fcc.gov/public/attachments/DOC-354323A1.pdf

REMARKS OF FCC CHAIRMAN AJIT PAI
WHITE HOUSE 5G SUMMIT
WASHINGTON, DC
SEPTEMBER 28, 2018
Research showing impacts to trees sent to fcc here Testimony of Albert M. Manville, II, Ph.D., C.W. B., and Principal, Wildlife and Habitat Conservation Solutions, LLC, on Behalf of Friends of Amazon Creek, Before the City of Eugene City Planning Department in Opposition to AT&T/Crossfire's Application for a "Stealth" Cellular Communications Tower in the Upper Amazon Creek Corridor / Testimony-of-Albert-M.-Manville-for-Amazon-Creek.pdf Testimony of Albert M. Manville, II, Ph.D., C.W. B., and Principal, Wildlife and Habitat Conservation Solutions, LLC, on Behalf of Friends of Amazon Creek, Before the City of Eugene City Planning Department in Opposition to AT&T/Crossfire's Application for a "Stealth" Cellular Communications Tower in the Upper Amazon Creek Corridor / Testimony-of-Albert-M.-Manville-for-Amazon-Creek.pdf

From EH Trust to Everyone: 10:20 AM

https://ecfsapi.fcc.gov/file/10718080685516/Testimony-of-Albert-M.-Manville-for-Amazon-Creek.pdf
Trees https://ecfsapi.fcc.gov/file/1001669617135/Trees-in-Bamberg-and-Hallstadt-Documentation-2006-2016.pdf

more on trees damaged https://ecfsapi.fcc.gov/file/1001669617135/RF-Radiation%20injures%20trees%202016.pdf

Published study A review of the ecological effects of radiofrequency electromagnetic fields / A review of the ecological effects of radiofrequency electromagnetic fields (RF-EMF)
https://ecfsapi.fcc.gov/file/7520939746.pdf

Published study Impacts of radio-frequency electromagnetic field (RF-EMF) from cell phone towers and wireless devices on biosystem
and ecosystem – a review
https://ecfsapi.fcc.gov/file/7520943486.pdf
Impacts to insects from higher frequencies that are to be used in 5G. Here is a paper
https://ecfsapi.fcc.gov/file/1210030663890/Exposure%20of%20Insects%20to%20RadioFrequency%20Electromagnetic%20Fields%20from%202%20to%20120GHz%205g%20.pdf

From Cece Doucette to Everyone: 10:21 AM

Rec 13: Line 5, need to insert the word "were" between the words "limits" and "set".

From EH Trust to Everyone: 10:26 AM

The FDA info does not include ANY review of impacts birds or bees
in fact the FDA only looked at tumors and their "literature review" was only on tumors, not bees, not trees, not birds
See the details on the FDA here https://ehtrust.org/expert-physicians-surgeons-and-scientists-call-for-fda-to-retract-biased-anonymous-report-of-cancer-impacts-of-cell-phones/

These documents by the FDA have nothing to do with trees or birds or wildlife.
No, the EPA was defunded in 1996 AND never looked at environment
The letter I sent you from the EPA shows thats pollinators and trees and plants have NEVER been looked at

From Ken Wells to Everyone: 10:28 AM

"Starlink " wiki cites reports of FCC approvals for up to 42,000 Starlink satellite antennas:
https://en.wikipedia.org/wiki/Starlink

From EH Trust to Everyone: 10:29 AM

Statement from Dr. Albert Manville on the FDA Report on Cell Phone Radiation
https://ehtrust.org/press-statement-from-dr-albert-manville-on-the-fda-report-on-cell-phone-radiation-2/

From Cece Doucette to Everyone: 10:30 AM

The FCC is being sued for not addressing the scientific literature submitted to them showing biological affects: The Environmental Health Trust and a coalition of other commentators in 2020 also filed a court appeal challenging the FCC's order terminating its evaluation of the adequacy of FCC RF radiation limits.
https://ehtrust.org/action-alert-lawsuit-against-the-fcc/

Robert F. Kennedy, Jr.'s Children's Health Defense is also suing the FCC for negligence:

https://childrenshealthdefense.org/news/robert-f-kennedy-jr-s-childrens-health-defense-submitted-historic-case. Additionally, Dr. Jeffrey Shuren of the FDA has serious conflicts of interest, his wife is a partner in a law firm that represents the wireless industry: https://www.5gcrisis.com/shuren-petition

From EH Trust to Everyone: 10:40 AM

The EPA letter that is on your record shows there is no standard for the environment. See it here the EPA letter https://ehtrust.org/epa-birds-bees-trees-5g-wireless-effects/

Environmental Health Trust is suing the FCC . Read the brief here https://ehtrust.org/eht-takes-the-fcc-to-court/

Please be sure to read the NRDC brief that showcases the lack of review regarding environmental impacts here https://ehtrust.org/wp-content/uploads/20-1025-NRDC-amicus-brief.pdf

This Amicus brief also has the letter from the EPA that says What US agency has reviewed the research on damage to trees from cell phone radiation?   If so, when was it issued and send a link to the review. Note this study showing damage from long term exposure to cell antennas. EPA Response: The EPA does not have a funded mandate for radiofrequency matters, and we are not aware of any EPA reviews that have been conducted on this topic. We do not know if any other US agencies have reviewed it. Published research can be found here https://ehtrust.org/environmental-effects-of-wireless-radiation-and-electromagetic-fields/

From Cece Doucette to Everyone: 10:41 AM

Senator Gray and others, you may wish to review the Mobile Communications and Health study commissioned in 2000 by T-Mobil, the German parent company of T-Mobile. It concluded there are many non-thermal biological effects well below public radiation exposure limit levels. They recommended specific precautionary measures should have been taken, but they were not and the industry continued to market hazardous products: https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnx1bmRlcnN0YW5kaW5nZW1mc3xneDo3MTE4NThkYmY3NmUzMzc0

From EH Trust to Everyone: 10:43 AM

Theodora Scarato of EHT asked “What US agency has reviewed the research on impacts to birds and bees?   If so, when and send a link to the review. I will note the latest research showing possible impacts to bees from higher frequencies to be used in 5G.” July 8, 2020, Lee Ann B. Veal Director, Radiation Protection Division Office of Radiation and Indoor Air, Environmental Protection Agency of the United States of America responded “EPA Response: The EPA does not have a funded mandate for radiofrequency matters, and we are not aware of any EPA reviews that have been conducted on this topic. We do not know if any other US agencies have reviewed it.” Link to letter here https://ehtrust.org/epa-birds-bees-trees-5g-wireless-effects/

Statement by Wildlife Biologist Alfonso Balmori, BSc on the FDA Review of Cell Phone Radiation and Cancer
The FDA review omits an evaluation of the science on wireless radiation impacts to trees and wildlife. Electromagnetic radiation is a form of environmental pollution which may hurt wildlife. I am providing examples of my published research below as examples of this scientific evidence. Read the letter with studies at https://ehtrust.org/26684-2/

From EH Trust to Everyone: 10:47 AM

The FCC has NOT studied the issue. In fact they are using the lack of response by agencies to "prove' there are not effects.

From Jen White to Everyone: 10:47 AM

I second the comment above!!

From Cece Doucette to Everyone: 10:48 AM

Senator Gray and others, please read Harvard Law School's Center for Ethics report, "Captured Agency: How the FCC is Dominated by the Industries it Presumably Regulates." It likens FCC and industry approach to the tobacco industry tactics: https://ethics.harvard.edu/news/new-e-books-edmond-j-safra-research-lab

From EH Trust to Everyone: 10:53 AM

Research shows that the levels of RF will be increased with 5G infrastructure 4G densification . As an example of how rapidly RF is increasing from wireless antennas, a 2014 published study looked at RF in three European cities and found in just one year (between April 2011 and March 2012) that the total RF-EMF exposure levels in all outdoor areas in combination increased by 57.1% in Basel by 20.1% in Ghent and by 38.2% in Brussels (Urbinello 2014). "Exposure increase was most consistently observed in outdoor areas due to emissions from mobile phone base stations."
https://www.sciencedirect.com/science/article/pii/S0013935114002254

2018 study published in Annals of Telecommunications found increased RF-EMF exposure from small cell LTE networks in two urban cities in France and the Netherlands. Researchers measured the RF-EMF from LTE (Long-Term Evolution) MC (macro cells meaning large cell towers) and SC networks (low-powered small cell base stations) and found that the small cell networks increased the radio emissions from base stations (called downlink) by a factor of 7–46 while decreasing the radio emissions from user equipment exposure (called) by a factor of 5–17. So while the devices themselves could emit less radiation, the cell antennas will increase the levels from cell antennas (Mazloum et al., 2019). This study shows the increased exposures would be involuntary. We can turn our phones off, but we cannot turn off the antennas in the neighborhood. https://link.springer.com/article/10.1007%2Fs12243-018-0680-1

From EH Trust to Everyone: 10:54 AM

An Australian study published in the Journal of Exposure Science & Environmental Epidemiology also found that children in kindergartens with nearby antenna installations had nearly three-and-a-half times higher RF exposures than children with installations further away by more than 300 meters (Bhatt et al., 2016). https://www.ncbi.nlm.nih.gov/pubmed/27759027

From Cece Doucette to Everyone: 10:57 AM

Rec. 12: Can we include other essential services? These have been well defined for COVID-19, and the public should be able to access those services too.
Senator Gray and others, the WHO determined RF is a Group 2B Possible Human Carcinogen in 2011. Now that the animal studies have been completed and show cancerous tumors and DNA damage, the WHO has re-opened its investigation in 2020: https://www.who.int/peh-emf/research/rf_ehc_page/en/index1.html

From EH Trust to Everyone: 10:58 AM

Research shows low level RF is tied to harm such as promoting tumors. And more

From Cece Doucette to Everyone: 10:58 AM

Please also note there are two WHO groups for EMFs, one is populated with those with industry ties, the other has independent scientists: https://ehtrust.org/scientists-call-for-transparency-at-the-world-health-organization-emf-project/

From EH Trust to Everyone: 11:00 AM

The science shows it IS substantiated
https://www.researchgate.net/publication/305689940_EUROPAEM_EMF_Guideline_2016_for_the_prevention_diagnosis_and_treatment_of_EMF-related_health_problems_and_illnesses

https://www.sciencedirect.com/science/article/abs/pii/S0013935120303388?via%3Dihub

Electromagnetic hypersensitivity (EHS, microwave syndrome) – Review of mechanisms
Peterborough, Canada
The City has an information sheet to help organizations accommodate individuals who have electromagnetic hypersensitivity. They recommend – among other things:
Temporarily disable City owned WAP devices.
Turn off or minimize fluorescent and LED.
Notify attendees to set mobile phones to airplane mode. https://ehtrust.org/wp-content/uploads/EHS-Tip-Sheet-Peterborough-5-8-2018.pdf

From Brandon.H.Garod to Everyone: 11:00 AM

I apologize but I have to leave for another meeting starting at 11:00

From Deb Hodgdon to Everyone: 11:00 AM

my oral surgeon was very happy to move me to a low rf room and make sure no one had devices in the room.

From EH Trust to Everyone: 11:03 AM

International
France: 13 Plaintiffs Win: The Tribunal de Grand Instance of Bordeaux ordered in favor of 13 of the 206 plaintiffs who had initiated a lawsuit against the installation of the electric meter created by Enedis.
https://www.femmeactuelle.fr/sante/news-sante/compteur-linky-la-justice-donne-raison-a-13-plaignants-electrosensibles-2077743

The word "unsubstantiated" should not be used.
Plus The WhO site being referenced is industry loyal and that is well documented in published research https://www.spandidos-publications.com/10.3892/ijo.2017.4046

Actually it IS recognized and has been in several ada cases

From Jen White to Everyone: 11:03 AM

Both myself and 10 year old son are RF sensitive. It's very real and not to be discredited. Thank you. - Thank you Tom for saying that, much appreciated!

From EH Trust to Everyone: 11:04 AM

Austrian Medical Association
The Austrian Medical Association has developed a guideline for differential diagnosis and treatment of health problems associated with outdoor and indoor electrosmog.
Guidelines of the Austrian Medical Association for the diagnosis and treatment of EMF related health problems and illnesses (EMF syndrome) https://ehtrust.org/wp-content/uploads/The-Austrian-Medical-Association-Guidelines-for-Diagnosis-and-Treatment-of-EMF-related-Health-Problems.pdf

Exposure to Nonionizing Radiation ICD 10 Medical Codes for Exposure to nonionizing radiation – ICD-10-CM W90
"The ICD-10 code is the standard diagnostic tool for epidemiology, health management & clinical purposes. It is used for medical code lookups by physicians, nurses, researchers, health information managers, medical billing coders, health information technology workers, insurers & patient organizations to classify diseases and other health problems recorded on many types of health records, including death certificates. ICD 10 codes are also used by medical billers & payers for reimbursement purposes."
Medicare Accepted ICD-10 codes under W90 for Exposure to other nonionizing radiation. These codes can be used for all HIPAA-covered transactions.

From Cece Doucette to Everyone: 11:04 AM

The public is welcome to join health care practitioners for the continuing medical education-accredited EMF Medical Conference in January where you will learn the science. We do have the studies already to prove wireless is harmful: https://emfconference2021.com/

From EH Trust to Everyone: 11:05 AM

2014:US Resident Provided Accomodations in Housing Case Regarding "Smart" Water Meters: Mechanical Meter For Resident PLUS Neighbors
Not only was a resident provided a mechanical meter after filing in court and coming to an agreement with the water authority; but in addition the neighbors of three adjacent properties also were provided free opt outs for the switch to mechanical meters.
That is correct- this switch AWAY from water meters was made with NO charges- NO FEES. The legal filing says that the Fair Housing Act prohibits discrimination based on disability.
Click here to see redacted HUD water meter agreement. https://ehtrust.org/wp-content/uploads/HUD-meter-settlement-Redacted.pdf

2014; Los Angeles Unified School District Accommodated a Teacher Who Fell Ill After Wireless Installation.
On September 18, 2014, LAUSD, the second largest public school district in the US, officially accommodated teacher Ms. Anura Lawson by approving her request to have the Wi-Fi turned off in her classroom during the 2014-2015 school year and alternatively approving a reassignment to a different school site where Wi-Fi has yet to be installed.
Watch the video of her testimony to the LAUSD School District Here. Read her letter of accommodation here. https://ehtrust.org/wp-content/uploads/LA-Teacher-Accomodation.pdf

From EH Trust to Everyone: 11:06 AM

We, physicians, acting in accordance with the Hippocratic Oath, we, scientists, acting in the name of scientific truth, we all, medical doctors and researchers working in different countries worldwide, hereby state in full independence of judgment,
that a high and growing number of persons are suffering from EHS and MCS worldwide; that EHS and MCS affect women, men and children;
that on the basis of the presently available peer-reviewed scientific evidence of adverse health effects of electromagnetic fields (EMFs) and various chemicals, and on the basis of clinical and biological investigations of patients, EHS is associated with exposure to EMFs and MCS with chemical exposure…"
Excerpt from the 2015 Brussels International Scientific Declaration on Electromagnetic Hypersensitivity and Multiple Chemical Sensitivity. Download http://www.ehs-mcs.org/fichiers/1441982143_Statement_EN_DEFINITIF.pdf

Magda Havas PhD at the National Institute of Environmental Health Sciences
"Electrosmog, the missing link as it relates to cancer, reproductive problems and electrohypersensitivity." https://www.youtube.com/watch?v=fqMCjEs9oxE&feature=emb_logo

From EH Trust to Everyone: 11:09 AM

The Who EMF project was started by industry funddscientist.
See EHT and others letter to The WHO EMF Project . They refuse to answer our letter and we have asked numerous times about that factsheet on The Who site . https://ehtrust.org/scientists-call-for-transparency-at-the-world-health-organization-emf-project/

There is no 50 times safety margin. This is a false statement because research on FCC record shows it. Read it here https://ecfsapi.fcc.gov/file/7520958286.pdf

From Cece Doucette to Everyone: 11:09 AM

The FCC limits are only based on heat exposure. The peer-reviewed non-industry funded independent science shows there is significant harm at the non-thermal level. Please see the Bioinitiative Color Charts for a summary of the science and findings of biological effects: https://bioinitiative.org/rf-color-charts/

From EH Trust to Everyone: 11:11 AM

The 50 times margin was based on a study of rodents with a thermometer in their rectum and it has been well disproved by science. Plus it is only about heating effects so it has nothing to do with cancer. https://ecfsapi.fcc.gov/file/7520958286.pdf

In fact for carcinogens the safety limit can be up to 10,000 times the level that cancer was found
So even if there was a 50 times safety margin- it is not adequate protection.

From Cece Doucette to Everyone: 11:11 AM

Rec. 10: Can we expand this to bring hard-wired to residential premises too?

From Jen White to Everyone: 11:14 AM

https://www.emfanalysis.com/fiber-optics-increasing-electrical-sensitivity/ - Will low EMI fiber optics be explored or discussed at some point?

From Cece Doucette to Everyone: 11:15 AM

Reliability is a factor too, in emergencies from storms, fires, etc., cell antennas often go down which leaves the public vulnerable to not being able to call for emergency services.

From Jen White to Everyone: 11:17 AM

We have a wired internet system that is not fiber optic. This is preferred and residents should have a choice, especially RF sensitive people such as myself.

From EH Trust to Everyone: 11:20 AM

There are no protections at the federal level to stop companies from using fiber for wireless purposes. Remember that if fiber optic is laid on a road, then a company can use it for their small cell. There should be federal protections in place to stop this.

Wireless companies like fiber because then they can attach wireless antennas.
It should be wired to and through the premises. Please see this study on how to hardwire in buildings https://www.sciencedirect.com/science/article/pii/S0360132319305347

From EH Trust to Everyone: 11:31 AM

Please read about how wired technology uses more energy consumption compared to wired. https://ehtrust.org/science/reports-on-power-consumption-and-increasing-energy-use-of-wireless-systems-and-digital-ecosystem/

The California Association of Realtors' Property Sellers Questionnaire specifically "cell towers" listed on the disclosure form for sellers of real estate. The seller must note "neighborhood noise, nuisance or other problems from.. " and includes cell towers and high voltage transmission lines on the long list problems. Click here to see the California Association of Realtors' Property Sellers Questionnaire (p. 3-4 under K. Neighborhood) https://ehtrust.org/wp-content/uploads/Real-Estate-Seller-Property-Questionaire-reduced-12-17-1.pdf

From Paul Bloede to Everyone: 11:32 AM

I show a vote was taken on both 8 and on 8A, at the 9/22 meeting. Both were approved, with slightly different tallies. 8 was voted in with 7 yes, 1 no, and 5 abstain.

From EH Trust to Everyone: 11:33 AM

2014 Survey by the National Institute for Science, Law and Public Policy (NISLAPP) in Washington, D.C., "Neighborhood Cell Towers & Antennas—Do They Impact a Property's Desirability?"
Home buyers and renters are less interested in properties located near cell towers and antennas, as well as in properties where a cell tower or group of antennas are placed on top of or attached to a building. 94% said a nearby cell tower or group of antennas would negatively impact interest in a property or the price they would be willing to pay for it.
Read the Press Release: Survey by the National Institute for Science, Law & Public Policy https://electromagnetichealth.org/electromagnetic-health-blog/survey-property-desirability/

Best Best and Krieger Letter to Ms. Marlene H. Dortch, Secretary Federal Communications Commission September 19, 2018 "RE" Smart Communities and Special Districts Coalition – Ex Parte Submission: Accelerating Wireless Broadband Deployment by Removing Barriers to Infrastructure Investment, WT Docket No. 17-79; Accelerating Wireline Broadband Deployment by Removing Barriers to Infrastructure Investment, WC Docket No. 17-84" "A good example lies in the Commission's discussion of undergrounding.62 The Commission at once appears to recognize that communities spend millions of dollars on undergrounding projects, and that allowing poles to go up in areas where poles have been take down has significant impacts on aesthetics (not to mention property values)."

From EH Trust to Everyone: 11:34 AM

https://www.montgomerycountymd.gov/cable/Resources/Files/Towers/cellTowerInfo/Ex%20Parte-Smart%20Communities%20and%20Special%20Districst%2009-19-18-c2%20(1).pdf

"Appraiser: Cell Tower Will Affect Property Values" New Jersey Patch on T Mobile Cell Tower
"Properties that are approximately close to the tower will suffer substantial degradation to their value based on the nature of the unusual feature in the residential neighborhood." https://patch.com/new-jersey/bridgewater/appraiser-t-mobile-cell-tower-will-affect-property-values

From Deb Hodgdon to Everyone: 11:34 AM

I know a home inspector who is very interested in being trained and licensed to do that

From EH Trust to Everyone: 11:37 AM

ConsumerWatch: 5G Cellphone Towers Signal Renewed Concerns Over Impacts on Health
In this news report below- California investigative reporter Julie Watts interviews firefighters and California officials on the SB649 exemption for firefighters. It is very clear this is about health effects as the firefighters state it

From Deb Hodgdon to Everyone: 11:37 AM

sounds like it interferes because you can't think quickly and efficiently

From EH Trust to Everyone: 11:39 AM

Read it here https://sanfrancisco.cbslocal.com/2018/01/25/consumerwatch-5g-cellphone-towers-signal-renewed-concerns-over-impacts-on-health/

you can simply say that the firefighters lobbied because of health effects
Which is documented in numerous documents
The CBS story say So, following lobbying by firefighters, assemblyman Quirk and his co-author exempted fire stations from their bill, making them one place cell companies couldn't put a tower."
read it here https://sanfrancisco.cbslocal.com/2018/01/25/consumerwatch-5g-cellphone-towers-signal-renewed-concerns-over-impacts-on-health/

you could quote the CNS report https://sanfrancisco.cbslocal.com/2018/01/25/consumerwatch-5g-cellphone-towers-signal-renewed-concerns-over-impacts-on-health/

From Cece Doucette to Everyone: 11:39 AM

Rec 7: There is a private property owner in Pittsfield, MA who just opted for a cell tower on the edge of the property, which abuts a neighborhood of eights streets. Only three of the proposed 46 antennas have been turned on, and children and adults are already experiencing headaches, insomnia, cognitive impairment, and one little girl described it as, "Mommy, I feel all buzzy inside." The public needs to be protected from all cell antennas regardless of whose property they are on. The epidemiological studies show similar biological effects within 1,500 or so feet from a cell antenna: https://sites.google.com/site/understandingemfs/cell-towers

From Deb Hodgdon to Everyone: 11:40 AM

yes pat.

From EH Trust to Everyone: 11:42 AM

““This is the first piece of legislation that anyone is aware of where somebody got an exemption because they were concerned about health. Did they tell you at all about the study?” we asked the assemblyman.

Quirk’s response: “All I know is that when the firefighters ask, I do what they ask me to do.” https://sanfrancisco.cbslocal.com/2018/01/25/consumerwatch-5g-cellphone-towers-signal-renewed-concerns-over-impacts-on-health/

This is a study- although a few years old- details why restricting cell towers from schools is a human rights issue https://ecfsapi.fcc.gov/file/1070795887708/Roda%26Perry_EnvSci%26Policy_.pdf

From EH Trust to Everyone: 11:54 AM

The FCC is not actively taking measurements.
In fact a Wall Street Journal shows many sites exceed FCC limits
https://www.wsj.com/articles/cellphone-boom-spurs-antenna-safety-worries-1412293055 One in 10 sites violates the rules, according to six engineers who examined more than 5,000 sites during safety audits for carriers and local municipalities, underscoring a safety lapse in the network that makes cellphones hum, at a time when the health effects of antennas are being debated world-wide.
No, the FDAdoes not say anything about bees and trees

From Cece Doucette to Everyone: 11:54 AM

6A: Minor typo on the bold line, "...be empowered is to be immediately..." remove the words "is" and "be".

From EH Trust to Everyone: 11:59 AM

If you go to the website by the FDA
you will see that in fact they have not looked at all the data
The FDa did not look at impacts to sperm or impacts to brain damage. That is all on the record
https://ehtrust.org/scientistsletter-calling-for-a-retraction-to-the-fda-report-on-cell-phone-radiation-and-cancer/

From Jen White to Everyone: 11:59 AM

If 5G moves forward in NH, Will there be any RF "safe zones" in residential areas where RF sensitive residents live? If we have a 5G repeater outside of our home.....that is literally a sick sentence for my 10 year old son!

From EH Trust to Everyone: 12:03 PM

For the record https://www.sciencedirect.com/science/article/pii/S2542519618302213?via%3Dihub Ronald N. Kostoff, Paul Heroux, Michael Aschner, Aristides Tsatsakis, Adverse health effects of 5G mobile networking technology under real-life conditions, Toxicology Letters, Volume 323, 2020, Pages 35-40, https://www.sciencedirect.com/science/article/abs/pii/S037842742030028X

Thermal and non-thermal health effects of low intensity non-ionizing radiation: An international perspective, Environmental Pollution, Volume 242, Part A, 2018, Pages 643-658, ISSN 0269-7491, https://doi.org/10.1016/j.envpol.2018.07.019 . https://www.ncbi.nlm.nih.gov/pubmed/30025338

NH COMMISSION TO STUDY THE ENVIRONMENTAL AND HEALTH EFFECTS OF EVOLVING 5G TECHNOLOGY

<u>Meeting held:</u>
10/27/20
1:00 -1:47pm EST
Via Zoom (https://unh.zoom.us/j/8760768986)

Via telephone-US (1 312 626 6799 (US Toll) ID: 876 076 8986)

<u>In attendance: (13)</u>
Rep. Patrick Abrami-speaker of the house appointee
Rep. Ken Wells- speaker of the house appointee
Kent Chamberlin, Phd.-UNH-appointed by the chancellor
Denise Ricciardi-public-appointed by the governor
Michele Roberge-DHHS- Commissioner of DHHS appointee
Paul Heroux,Phd.- Professor of Toxicology, McGill University- speaker of the house appointee
Rep. Gary Woods-speaker of the house appointee
Senator Jim Gray-president of the senate appointee
Senator Tom Sherman-president of the senate appointee
Brandon Garod,Esq.-AG designee, Asst. AG Consumer Protection
Bethanne Cooley-CTIA , trade association for wireless industry and manufacturers
Carol Miller-NH Business & Economic Affairs Dept.
David Juvet-Business and Industry Association

<u>Not present: (0)</u>

Meeting called to order by Rep Abrami at 1:03 am

Abrami: Due to the Covid 19 virus and the Executive order signed by the Governor this public meeting is allowed to be conducted via Zoom. It is open to the public for viewing and was duly posted as a zoom meeting. With that said, if you are not a member of the Commission, can you please turn your cameras off and mute yourselves? That would be much appreciated. In addition the meeting is being recorded as an aid to doing the minutes. All chat room discussions will be included in the minutes.

<u>I. Approval of minutes from 10-8-20</u>

Let's start with the minutes from the October 8th meeting. I have not received any changes to the minutes that I sent out about a week ago. Are there any changes that anyone wants to make? Seeing none, I will say …without objection, we approve the minutes from that meeting.

II: Agreed to Recommendation changes

Sherman: Pat, I think you need to do the “right to know” script and a call of the roll, don’t you? Maybe it’s different for the House than the Senate.

Abrami: I am doing it with what I just read. The last meeting we voted on many of the recommendations in the report and I want to go through to show you. Kent, can you pull up Page 9? I am not going to be able to see you all as Kent will be sharing his screen. So members just jump in if you have something to say.

Fourth line from the bottom, “principle” was spelled incorrectly and was corrected.

Recommendation #1 is the old 1. We agreed after the bold where you see Telecommunication Act, to delete “TTA”.

Recommendation #2 is the old 3. We changed “attachment” to “appendix”. “There is” in the last line was taken out as it made no sense.

Recommendation #3 is the old 4.The word “harm” was taken out three lines from the bottom as that made no sense.

Recommendation #4 is the #5, the next to the last paragraph: five lines up: is required for “data”.

Recommendation #5 is the old 6A. In the bold where it says, the municipality is… “to be” was deleted. “in “ was changed to “to”.

Recommendation 6 is the old 6B: should show “as having” instead of “to have” significant impact. Joel, please change that.

Recommendation 7 is the old 7. The “of” was inserted between right and property.

Recommendation 8 is the old 8.

Recommendation 9 is the old 8A.

Recommendation 10 is the old 9. “detailed” replaced detail.

Recommendation 11 is the old 10,

Recommendation 12 is the old 11,

Recommendation 13 is the old 12.

Recommendation 14 is the old 13.

Recommendation 15 is the old 14.

Those are the changes. Does anybody recall anything differently about any of these changes?

III: Report walk through

Abrami: Kent, can you put the report back up? On this first page, Beth contacted me. We have Beth as representing cell phone/wireless technology industry. We are going to put CTIA, representing the wireless industry. Is that okay with you Beth?

Cooley: That's fine. Thank you.

Abrami: The next page is the disclaimer that all three agencies were okay with.

Miller: Before we move on, my title is incorrect as well. I am not representing the High Tech Council. That no longer exists. It's the Tech Alliance but I am not representing them either. I am from the New Hampshire Dept. of Business and Economic Affairs.

Abrami: Any others on title changes? Ok. Next we have the Table of Contents. We have a bit of introductory discussion then a summary of observations and the recommendations that we went over. We have chosen to insert the Minority Report in the report. We will get to the Minority Report in a while. Then we have the Appendices and the Minutes, which are extensive. They are basically a total recording of what happened in our meetings. As far as the introduction, I talk about the Commission responsibilities and my view that it's an evolving role as we learned about the different technologies and how 5G works with 4G and 3G. Our discussions evolved over time. Basically, it became all things RF radiation. We talked about the various meetings that we had and who the main presenters were and our big hiatus for four months. Then we have Questions posed by HB522. Then we have a section on Summary and Observations. We actually got the reference to the 800,000 small cell towers from the CTIA website.

IV:Discussion

Abrami: Any discussion?

Sherman: Pat, I just want to thank people both on the Majority and the Minority side for all the work they put in. I think everybody in spite of their differences of opinion or their different interpretations of the science. I think everybody has approached this with incredible fairness and collegiality. Thank you for leading it and for all the work that everybody has done.

Abrami: I was going to say when we got to the Minority Report, Jim I think you did a great job on it. To me, it makes the report even better having both sides represented in the report. The majority of the members yielded to the precautionary principle because there are still a lot of unanswered questions. Is there any other discussion?

V: Report Vote

Let's vote on the majority report: Yes, No or Abstain.

Sherman: yes

Wells: yes

Chamberlin: yes

Miller: abstain

Ricciardi: yes

Juvet: no

Cooley: no

Garod: abstain

Roberge: abstain

Heroux: yes

Woods: yes

Gray: no

Abrami: yes

7-yes, 3-no, 3-abstain. This will be considered the Majority Report.

VI. Minority Report:

Abrami: Jim, we have to have a lead in. For example, Jim Gray and the others who want to sign on have to let us know who they are. Jim do you want to go through this?

Gray: I am not going to go through a lot. One of the reasons that we got the report to you twenty four hours before this meeting is so that you could look at it. It's the same things that I have been talking about in the various meetings. The FCC and the FDA have on their websites a plethora of information about the safety of 5G and 4G and 3G as they are used for the cell phone industry. The first page starts off as a quick summary about the 50x safety factor that's in there and the rest. There are a lot of references in there because we were trying to say that we are not making these things up. There is stuff that is available on the FCC and the FDA websites. I can't remember if we left the WHO in there or not at the end. Things tend to get a little confused right now with campaigning and everything else. You have had a little time to review it. If anyone has questions, they can forward them to me. What I would do rather than having anyone on this zoom meeting say they support or don't support. It would certainly be fine with me if someone wanted to notify you as the chair at some other point. I think I will leave it at that.

Abrami: Any questions for Jim?

Juvet: no questions, Mr. Chair. I think you said those who want to sign onto the Minority Report that they need to let you know. I wish to be signed on to the Minority Report.

Cooley: As would CTIA as well.

Abrami: Ok. Fine. So you don't have objection at the beginning to say the three of you are the Minority members? Is that ok?

Gray: either at the beginning or at the end.

Abrami: I am going to yield to Joel.

Anderson: I think it is just as well to put it at the beginning. People will know upfront who the Minority Report is from.

Gray: It can be as simple as, the undersigned not being able to agree with the majority, offer the following report and then list the three names. Does that work for everyone?

Abrami: yes.

Anderson: Can it be instead that you endorse the report? Because you won't actually be signing it.

Abrami: House Commissions don't require signatures.

Juvet: Whatever the appropriate wording is, I am good with.

Abrami: Joel, after we do it, we can share it with the three Minority members.

Ricciardi: is it acceptable to read my comments?

Abrami: yes. It's appropriate.

Ricciardi: I genuinely appreciate everybody's point of view.

First, on foot note two, it addresses only thermal effects but if you see appendix D of the Majority Report there is science showing harmful effects at the non-thermal level. I just wanted to draw attention to that. In the Minority Report, it cites the IEEE papers but the IEEE does not have medical or biological expertise. However even the IEEE has acknowledged harm at the non-thermal level in two papers which I have sent to you. In 2016 IEEE acknowledged biological effects of non-ionizing microwaves in the IEEE Power and Electronics magazine article. I wanted to also mention that the Minority Report makes several references to the American Cancer Society but fails to provide links to the sources. Furthermore, the American Cancer Society in 2016 called the NTP study a paradigm shifting of good science. The public should also note that the American Cancer Society reports a sharp rise in colon and rectal cancer among young adults at the very locations where many carry their cell phones. In footnotes 11 and 12, the World Health Organization citations are out of date. In 2020, the WHO reopened its investigation into the biological effects. Additionally, there are two groups at the WHO that report on EMFs. One is represented by the industry. The other is represented by independent scientists with credentials appropriate to weigh in on the biological effects. In footnotes 18 and 19, the Minority Report indicated the rate of brain tumors in humans as being flat for the last twenty years. This is not true. Cancer registries are typically five years behind and while overall cancer cases are not rising as they once did. The following show dramatic growth where cell phones and wireless devices are used or stored on the body or cell tower emissions. The incidence of glioblastoma is the deadliest type of brain tumor and I have links to all of this that I have mentioned which I am going to forward to you. The last thing I want to say is that industry tends to focus on the cancer rates as cancer takes the longest time to develop during which time the industry can continue to promote toxic products. Other diseases are developing more rapidly as shown in the Majority Report,in Appendix D, including infertility, neurological harm and especially to children. With regard to the section on 5G mm waves, the IEEE is referenced yet again. These are industry engineers who do not have the biological expertise. I just wanted that for the record.

Abrami: Ok. It will be in the minutes.

Heroux: Essentially, one thing I regret is I am addressing primarily the people of the Minority Report, is that there was not more discussion between us. What I mean by this is technical discussion in looking at the actual issues. I know that probably most of the people of the Minority Report felt very solid in their opinions relying on legislation that was passed and I can understand that. In spite of our differences, I do respect your opinion because this is your opinion. One last comment is that we were not provided the material that would have led to this discussion. Perhaps the people who were in the Majority Report could assemble more energy to present. In fact, the same amount of enthusiasm was not apparent on the other side. I would like to remind the Commission that on January 10th meeting, there were promises by the CTIA to provide us with reports that support the positive health impacts of cellphone deployment. These reports did not materialize. Essentially, I think that the lopsidedness that is quoted in the Minority Report is more a result of energy and initiative in providing evidence. Thank you.

Abrami: Ok. Any other comments at this point?

<u>VII: Minutes of this Meeting:</u>

Abrami: Let's talk about the minutes of this meeting. They will be in the report. Deb Hodgdon is going to work very hard and we will get the minutes out to everybody. We will not have a meeting to approve them. If you see something you think is incorrect, please email me. We want to get this report in by November 1st with the minutes of this meeting included. Is that okay with everybody? Ok. Thank you.

VIII: Submission Process

Abrami: I talked to Jim about this. I think he is okay with us putting the Minority Report in the same style type as the rest of the report. There will be a letter of transmittal. The report goes to the Governor, the Speaker and the Senate President. There is a letter of transmittal that the House staff will put together. There are no signatures on it just the letter of transmittal that goes on top of the report and it's sent out. This report will be posted online on the Commission's website. We added that website to the report so if anybody wanted to see the additional information or papers we posted there, things like that will be available for the public. It's all about the minutes. No pressure Deb. If I stop talking, we can get the minutes done sooner right?

IX. Commission Farewells

Abrami: First I want to say, it's been a pleasure working with all of you. We had a great group. There were a lot of scientific minds in the room, legal, business. We didn't agree on everything as Tom said but I think we all got along very well. I want to specifically point out Kent Chamberlin for coming to the rescue. When we couldn't get bandwidth from the state to continue this Commission, he volunteered. Or I asked him to volunteer! UNH's zoom capacity was great as well as setting up all those meetings and being behind the scenes making the meetings go smoothly.

I want to thank Joel Anderson for his support behind the scenes. It was a lot of work especially when it came to the report and I think I hinted at this when I sent something out. There was one night he worked until ten o'clock at night to get the report ironed out. He proofed a lot of the report and found links that were outdated or not working and corrected those. Thank you, Joel for going beyond the call of duty.

And of course I want to point out Deb Hodgdon who has been doing our minutes since the beginning. These minutes are more like a court transcription. I know she spends a lot of time going through and preparing those.

I also want to thank the audience. I know we never formally opened it to the public which I had promised. That has to do with the fact that we closed down for four months. We missed five meetings. We were just cramped for time or we would have opened this up more to the public. But with zoom, we were able to open it up to more than just ten or so people that would gather at the onsite meetings at the statehouse. We have people from all over participating. Their comments in the zoom chat were captured and added to the minutes.

I thank you all again. Does anybody want to make any closing comments?

Ricciardi: I just want to say that it was an honor to work with all of you. It really was and I am so proud of the work that we have all done. So, thank you.

Heroux: To me, this commission is extremely memorable. I would like to congratulate the Chair on bringing this difficult boat to port. I want to ensure all of you, especially those of the Minority Report that you can contact me at any point in the future and you will have my full cooperation if you need my help. Thank you.

Cooley: Will we be notified when the letter of transmittal is sent? Will the Commission know?

Abrami: We will make sure everyone gets notified. It will be out there electronically and we will let you know where to go to find it.

Cooley: Thank you.

Abrami: Stay well. We are formally adjourned (1:47 pm)

Chat from HB522 5G Commission Meeting, October 27, 2020

From Beth Cooley to Me: (Privately) 01:23 PM

Should Herman's video be shown? just curious. I've directed my members to turn their videos off

From Theodora Scarato to Everyone: 01:27 PM

The World Health Organization EMF Project The World Health Organization EMF Project says "There is no consensus."

Dr. Emilie van Deventer, Head of the World Health Organization's EMF Project was quoted in The Daily Princetonian, "The data is gray. It's not black and white...There is no consensus, it's true."

"Furthermore, as I see it, the WHO EMF Project was not only hijacked by the ICNIRP but, from the inception, it was set up as a front for the ICNIRP agenda of unifying exposure standards to RF-EMF, " stated Dariuz Leszczynski PHD (a member of the EMF working group of the WHO/IARC who stated in 2020," ICNIRP is a private club. Its new members are selected by the current members where the prerequisite of selection is the very close similarity of opinions on non-ionizing radiation health effects. There are no published criteria for the selection of new members. Nobody checks whether the selected experts are sufficiently good experts."
https://betweenrockandhardplace.wordpress.com/2020/09/08/leszczynski-there-is-something-utterly-wrong-with-the-icnirp-membership/

From Theodora Scarato to Everyone: 01:27 PM

Fact: There is no 50 times safety margin. The FCC is ignoring the science and promoting the myth of the 50 times safety factor despite being informed that it is not based on scientific fact.
Scientific data refutes the claim. The FCC says this factor is based on studies that show behavioral disruptions to animals at 4 w/kg. However the EPA found thermal harm at 1 W/kg. The EPA stated in 2020 that the last time the agency did a research review was in 1984 as detailed in the 1984 EPA Report The Biological Effects of Electromagnetic Fields. The EPA 1984 Report concludes with the summary that

“It has been concluded from this review that biological effects occur at SAR up to about 1 W/kg some of them may be significant under certain environmental conditions.” Therefore the level of harm of 4W/kg used by IEEE and adopted by FCC is inaccurate. See the 1984 EPA report, Comments of Pong Research Corporation, Environmental Working Group and Environmental Health Trust.
https://ehtrust.org/epa-1984-report-biological-effects-of-emfs/

From Theodora Scarato to Everyone: 01:28 PM

Furthermore, the Environmental Protection Agency typically uses safety factors in the 100s or 1000s range for noncancer endpoints and for carcinogens, a threshold or nonthreshold approach is used (National Research Council (US) Committee on Improving Risk Analysis Approaches Used by the U.S. EPA).
https://www.ncbi.nlm.nih.gov/books/NBK214619/

Of key importance, even if there were a slim safety factor, the level chosen is about heating harm only. It is thermally based and has nothing to do with biological harm from non thermal exposures that can occur at far far lower RF exposures.
Furthermore these limits were not based on protecting trees, birds, insects or the natural environment. Thus, flora and fauna are entirely unprotected.
The EPA 1984 Report concludes with the summary that “It has been concluded from this review that biological effects occur at SAR up to about 1 W/kg some of them may be significant under certain environmental conditions.” Therefore the level of harm of 4W/kg used by IEEE and adopted by FCC is inaccurate.

From Theodora Scarato to Everyone: 01:30 PM

There is no 50 times safety factor as a fact of science. The FCC is ignoring this science - ignoring the EPA Ignoring facts
Despite the fact that the WHO EMF Project website seems to imply the research shows no harm, such statements are unsubstantiated and are based on a house of cards. The fact is the WHO EMF Project has yet to do a full evaluation of the recent research and the last monograph was in 1993. This is stated on their website quite clearly “The World Health Organization is undertaking a health risk assessment of radiofrequency electromagnetic fields, to be published as a monograph in the Environmental Health Criteria Series. This publication will..update the monograph on radiofrequency fields (1993).”
https://www.who.int/peh-emf/research/rf_ehc_page/en/
Do not confuse the World Health Organization EMF Project with the The World Health Organization International Agency for the Research on Cancer.

These are two separate entities. Unlike the WHO EMF Project (started by a scientist found to be funneling industry money though a university), the WHO International Agency for Research on Cancer (WHO/IARC) which is vetted for conflicts of interest and for whom scientists cannot be financially connected to Telecom.

From Theodora Scarato to Everyone: 01:34 PM

In 2011, the WHO/IARC classified RF as a Class 2 B "possible" human carcinogen based primarily on evidence from human studies that long-term users of mobile phones held to the head resulted in an elevated risk of developing brain cancer. One major reason that the IARC rating was not at "probable" or "known" was the lack of clear evidence from animal studies for exposure leading to cancer.
https://www.iarc.fr/wp-content/uploads/2018/07/pr208_E.pdf
In 2019, the advisory group of the International Agency for Research on Cancer (IARC) of the World Health Organization released new recommendations to reassess as a "high priority" the cancer risks of radiofrequency (RF) radiation between 2020–2024. The recommendations were published in The Lancet Oncology on April 18, 2019.
https://www.thelancet.com/journals/lanonc/article/PIIS1470-2045(19)30246-3/fulltext
CDC shows tumors increasing in children. Read it here https://ehtrust.org/cdc-finds-brain-liver-and-thyroid-cancers-increasing-among-us-children-2001-2014/

From Theodora Scarato to Everyone: 01:35 PM

http://aspho.org/uploads/meetings/2018annualmeeting/Abstracts_for_Website.pdf
Centers for Disease Control and Prevention, Atlanta, Georgia, United States
link: http://aspho.org/uploads/meetings/2018annualmeeting/Abstracts_for_Website.pdf
"increased for non-Hodgkin lymphomas (except Burkitt lymphoma), central nervous system neoplasms, renal tumors , hepatic tumors , and thyroid carcinomas…"
http://aspho.org/uploads/meetings/2018annualmeeting/Abstracts_for_Website.pdf
From EHT- Recently a reporter told EHT that this data seemed to be in contradiction to information posted on the National Cancer Institute (NCI) website. The reporter asked how EHT could be stating that CDC says brain cancers are rising in pediatrics when the reporter went online and found information stating "the brain cancer rates were stable." He sent this link.
So we wrote the CDC scientist and the CDC scientist responded to EHT that that the NCI link sent by the reporter refers to statistics that represent only 13.4% of the US population, whereas the new CDC report uses the USCS database representing 98% of the US population.

From Theodora Scarato to Everyone: 01:37 PM

The European Scientific Committee on Health, Environmental, and Emerging Risks' "Potential effects on wildlife of increases in electromagnetic radiation statement identified emerging issues (including 5G, E-cigarette, and chronic diseases.) The Committee prioritized 5G impact as "high" noting the lack of adequate research and citing studies documenting harmful effects such as Pall 2018, Di Ciaula 2018 and Russell 2018. The report concluded "the lack of clear evidence to inform the development of exposure guidelines to 5G technology leaves open the possibility of unintended biological consequences."
https://ec.europa.eu/health/sites/health/files/scientific_committees/scheer/docs/scheer_s_002.pdf
The 2020 Executive Summary of the Health Council of the Netherlands said clearly that there is no information on mm-waves and human health:"…There has been almost no research into the effects of exposure to frequencies around 26 GHz…"And they recommended against using higher frequencies stating "…The committee recommends not using the 26 GHz frequency band for 5G for as long as the potential health risks have not been investigated…"

From Theodora Scarato to Everyone: 01:37 PM

https://www.healthcouncil.nl/documents/advisory-reports/2020/09/02/5g-and-health

From Cece Doucette to Everyone: 01:39 PM

When will the report be posted?

From Theodora Scarato to Everyone: 01:39 PM

Numerous governments also educate their citizens with recommendations to reduce cell phone radiation, especially to the heads of children. Governments with policy and/or recommendations by health authorities include Belgium, Switzerland, French Polynesia, Finland, Ireland, Germany, Greece, Israel, Turkey, Singapore, France, United Kingdom, Russia, Denmark, India, Australia, Austria, Cyprus, Canada, Italy, Korea and Croatia. In 2011 the Parliamentary Assembly of the Council of Europe issued Resolution 1815: "The Potential Dangers of Electromagnetic Fields and Their Effect on the Environment." A call to European governments to "take all reasonable measures" to reduce exposure to electromagnetic fields "particularly the exposure to children and young people who seem to be most at risk from head tumours" and numerous municipalities have issued resolutions to follow Resolution 1815. https://ehtrust.org/policy/international-policy-actions-on-wireless/

From Cece Doucette to Everyone: 01:43 PM

Sincere gratitude to all for your dedication in seeking the truth and laying the path to transition to safe, sustainable, fiscally responsible technology.

From Theodora Scarato to Everyone: 01:44 PM

Thanks beyond words for your incredible effort in putting forward scientific facts in a transparent fashion.

Radiation Analysis in a Gradual 5G Network Deployment Strategy

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***Abstract*—In a world where many overlapping 2G, 3G, and 4G electromagnetic radiation sources already exist, concerns regarding the potential increase in these radiation levels following the roll-out of 5G networks are growing. The deployment of 5G is expected to increase power density levels drastically, given the limitations of mmWave communications that impose a notably higher number of base stations to cover a given area of interest. In this paper, we propose a gradual deployment strategy of a 5G network for a small area in downtown Austin, Texas, using the already existing 4G LTE sites of the area. The radiated power density of the proposed 5G network is then analyzed according to several electromagnetic field (EMF) exposure limits and compared to the radiation levels of the same area where only the LTE network is present. Simulation results for the selected area demonstrate the significant increase in radiation levels resulting from the addition of 5G cell towers.**

***Index Terms*—5G, Network Planning, Radiation Analysis**

I. Introduction

The notably large bandwidth available in the millimeter-wave (mmWave) band and the potential multi-gigabit-per-second (Gbps) data rates that can be achieved for future communication services have made mmWave communications a key part of Fifth Generation (5G) mobile networks. Despite the promising advantages of millimeter wave communications in terms of improved quality of service requirements, its usage for the 5G wireless standards comes at significant costs. First, working with such high frequencies will reduce coverage ranges of base transceiver stations (BTS). For proper coverage of an area, a densification of 5G BTSs is required to achieve the same coverage provided for this same area by today's 4G BTSs. Also, high propagation loss and increased signal blockage occurs, motivating the introduction of multi-antenna approaches such as Massive MIMO [1], [2].

This potential addition of a large number of transmitters gives rise to another problem that needs to be considered, which is the increase in radiation levels in the rolled-out 5G network. Although these transmissions are non-ionizing radiations, they cause thermal heating at the eyes and skin level. Extensive heating for long periods of time is when adverse health effects may occur. These health concerns have stimulated interest in the biological safety of mmWave transmissions. In this respect, several exposure limits have been specified in standards and regulations developed by commissions and organizations that many governments will rely on when future 5G networks are deployed. However, these regulations have contradicting limits, many of which have remained the same before the year 2000. Therefore, designing a 5G network with radiation levels that complies with all the safety limits is a difficult task given the current regulations.

Despite the ongoing standardization of 5G technology, several works in the literature have presented 5G network deployment studies. The cost and coverage implications of deploying a 5G network in Britain has been presented in [3] where it was shown that full coverage had exponentially rising costs due to network densification. Additional 5G network designs for different cities were presented in [4]–[6] without any consideration for the constraints of electromagnetic radiations or the implications of the environment in mmWave propagation. Network design has been studied under such radiation constraints in [7], [8] but for 4G networks. Power density assessment of 5G cellular nodes in an indoor environment has been presented in [9] where results showed that the peak power density remained below the specified threshold and can thus be deemed safe for the general public. However, not all of the guidelines and exposure limits were considered in this work and the simulation did not represent a real-world scenario.

To the best of our knowledge, no work has provided a thorough analysis of the deployment of 5G networks in terms of its impact on the increase in radiation levels. Existing work in the literature has either focused on the cost (e.g., [3]) or radiation levels for older standards (e.g., [7]). To this end, this paper presents a mmWave-based 5G network deployment strategy given pre-existing LTE nodes in a small geographical area in Austin, Texas. We then approximate the power density levels that would be experienced in such outdoor environments and analyze their variations and compliance with the specified exposure limits for different transmission powers and transmit antenna gains. We also compare this radiated power density in the deployed 5G network to the power density levels of the same area when only the pre-existing LTE BTSs are present.

The rest of this paper is organized as follows: Section II presents the 5G simulation environment considered in this work. The proposed deployment strategy of the 5G network in a small area in downtown Austin, Texas is presented in Section III. Radiation analysis of the deployed network is performed in Section IV. Concluding remarks follow in Section V.

II. 5G Environment Setup

A. Pathloss Model

The close-in free space reference distance (CI) path loss model [10] is considered. It is defined by the following equation:

$$PL^{CI}(f,d)[\text{dB}] = FSPL(f,1m) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma^{CI} \tag{1}$$

where the free space path loss (FSPL) for a frequency of operation f is given by:

$$FSPL(f,1m) = 20\log_{10}\left(\frac{4\pi f}{c}\right) \tag{2}$$

The CI path loss model can be rewritten as:

$$PL^{CI}(f,d)[\text{dB}] = 20\log_{10}\left(\frac{4\pi f}{c}\right) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma^{CI} \tag{3}$$

where:

- n: is the single model parameter or the path loss exponent
- d_0**:** is the reference distance taken as 1 meter
- d: is the distance in meters between the BTS and the mobile station
- X_σ^{CI}: a zero mean Gaussian random variable with standard deviation σ in dB. It represents large scale channel fluctuations due to shadow fading (SF). The standard deviation of this random variable is given by:

$$\begin{aligned}\sigma^{CI} &= \sqrt{\sum X_\sigma^{CI^2}/N} \\ &= \sqrt{(PL^{CI} - FSPL - n10\log_{10}(d))/N}\end{aligned} \tag{4}$$

where N represents the number of measured path loss data points

The values for parameters n and SF vary from one scenario to another. Table I presents the values of these model parameters in different environmental setups, which have been obtained by ray tracing and measurements in [11].

TABLE I: CI Model parameters for different environments [12]

Scenario	CI Model Parameters
UMa-LOS	n = 2.0, SF = 4.1 dB
UMa-NLOS	n = 3.0, SF = 6.8 dB
UMi-S.C.-LOS	n = 1.98, SF = 3.1 dB
UMi-S.C.-NLOS	n = 3.19, SF = 8.2 dB
UMi-O.S.-LOS	n = 1.85, SF = 4.2 dB
UMi-O.S.-NLOS	n = 2.89, SF = 7.1 dB

UMa: denotes Urban Macrocell (Tx Heights > 25 m), **UMi:** denotes Urban Microcell (Tx Heights < 25 m), **LOS:** denotes line-of-sight, **NLOS:** denotes no line-of-sight, **S.C.:** denotes Street Canyon, **O.C.:** denotes Open Square

B. mmWave Specific Attenuation Factors

In mmWave propagation, attenuation due to atmospheric and weather conditions constitutes an important factor to consider [13]. Specifically, we will consider oxygen attenuation $O(d)$ and rain attenuation $R(d)$, which are both dependant on the separation distance d. Oxygen attenuation has been observed to be equal 16dB/km in [14], and hence can be obtained by the following:

$$O(d)[\text{dB}] = \frac{16d}{1000} = 0.016d \tag{5}$$

The rain attenuation factor depends on the climate of the zone under study. The International Telecommunication Union (ITU) have segmented these zones and provide measurements for the rain rates of each zone [15]. Based on these measurements and considering that the area under study in this paper will be in Austin, Texas, the rain attenuation rate will be taken to be 3.5 dB/Km. This loss can then be obtained using:

$$R(d)[\text{dB}] = \frac{3.5d}{1000} = 0.0035d \tag{6}$$

C. Link Budget Estimation

The link budget equation upon which the cell radius will be estimated can now be defined as:

$$P_{Rx}[\text{dBm}] = EIRP[\text{dBm}] - PL^{CI} - O(d) - R(d) + G_{Rx} \tag{7}$$

where P_{Rx} is the power received by the mobile station, G_{Rx} is the antenna gain in dBi of the mobile station, and the effective isotropic radiated power (EIRP) is given by:

$$EIRP[\text{dBm}] = P_{Tx} + G_{Tx} - L_{Tx} \tag{8}$$

where P_{Tx} is the transmission power in dBm of the BTS, G_{Tx} is the transmitting antenna gain in dBi, and L_{Tx} is the cable loss in dB due to possible antenna mismatch. Table II lists the values chosen for each parameter of the link budget equation.

TABLE II: Simulation Parameters

Parameter	Value
Frequency f	28 GHz
Max EIRP	43 dBm
Antenna Gain G_{Tx}	24 dBi
Transmission Power P_{Tx}	19 dBm
Receiver Antenna Gain G_{Rx}	0 dBi
Cable Losses L_{Tx}	0 dB

D. Identifying Cell Ranges

By using the link budget equation in (7) and considering the simulation parameters given in Table II, the separation distance can be found for several receiver sensitivities. The calculated distance constitutes the cell range for a given BTS that satisfies the received power requirement. These calculations are summarized in Table III. A main observation is that the resulting cell ranges become significantly smaller when the receiver sensitivity is higher. Cell ranges that are too small (below 10 meters) are not considered since such small ranges are not desirable for real deployment.

III. Network Deployment

We now consider a small geographical area in downtown Austin, Texas, to deploy the 5G network. A diagrammatic view of our proposed strategy is shown in Fig. 1. The selected area is shown in Fig. 2(a) and delimited in red on the map of Fig. 2(b). This area already contains several locations where LTE sites are already built and which will be the starting points of the gradual 5G network deployment strategy. The initial LTE cell tower locations are obtained from an online cell tower database (www.opencellid.org). We consider a worst case scenario where no line-of-sight components are available.

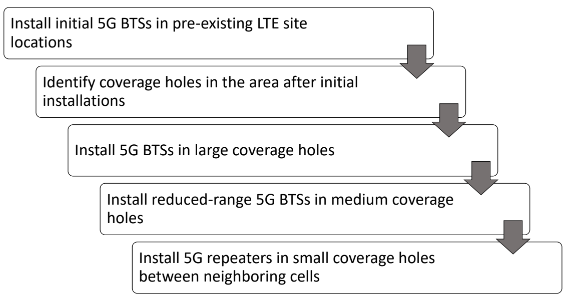

Fig. 1: Gradual Deployment Strategy

(a)

(b)

Fig. 2: Geographical area of interest in Austin, Texas (a) Satellite View (b) Map View

Fig. 3: Coverage of initial 5G BTSs built at the locations of pre-existing LTE cell towers

The first step of deployment starts by building 5G BTSs in the areas where LTE BTSs already exist, a technique known as co-siting. The main aim of co-siting is to reduce capital expenditures (CapEx) required to erect the 5G sites and minimize the operational expenditures (OpEx) needed to sustain their operation. UMa-NLOS towers will be placed in these locations. The receiver sensitivity is considered to be -78 dBm which, according to Table III, sets the cell range of each UMa to be 53 meters. The coverage of the initial BTSs installed is shown in Fig. 3, after slightly changing the location of the BTS within the same area it is built on, which may be any building rooftop, to lessen interference and provide better coverage. It can be noticed that these initial cells do not provide coverage to the whole area due to the small cell range of each BTS. Theoretically, this range can be increased but would demand the EIRP to be increased above the allowed limit of 43 dBm, by increasing the transmission power and selecting a higher-gain massive MIMO antenna configuration

The next step is the identification of coverage holes, as shown in Fig. 4. Large coverage holes are can be noticed, where several UMa towers can be distributed to provide good coverage. Smaller coverage hole are also be identified. Some of these holes are very small areas between neighboring cells where 5G repeaters, such as the one described in [16], can be placed to cover these small holes. Other small holes are not small enough to be fixed merely by the placement of a repeater, and are neither too big to place a BTS with a cell range of 53 meters. In such locations, reduced-range towers can be placed to provide coverage. The coverage range for these towers can be shrinked by reducing transmission power and choosing smaller MIMO antennas. We calculate the cell range for the reduced-range BTS towers to be approximately 30 meters and estimate the coverage of the 5G repeater to be 15 meters. The final design of the deployed 5G network is shown in Fig. 5. It can be observed that the deployment of a 5G network in an area as small as the one presented requires a densification of cell towers and signal repeaters, which in turn will cause much more radiation.

TABLE III: Calculated Cell Ranges for Several Receiver Sensitivities in Various Environments

Receiver Sensitivity	Cell Range (meters) for EIRP = 43 dBm					
	UMa-LOS	UMa-NLOS	UMi-S.C.-LOS	UMi-S.C.-NLOS	UMi-O.S.-LOS	UMi-O.S.-NLOS
-78 dBm	302	53	334	38.5	385	60
-70 dBm	165	29.7	186	22.3	216	33
-65 dBm	105.5	22	120	15.7	139	22.5
-60 dBm	65	14.1	74.5	11	85	15.3
-55 dBm	38.5	×	44.5	×	55	×
-50 dBm	22.6	×	26	×	27	×
-47 dBm	16.2	×	18.6	×	20	×

Fig. 4: Coverage holes identified after initial BTS installations

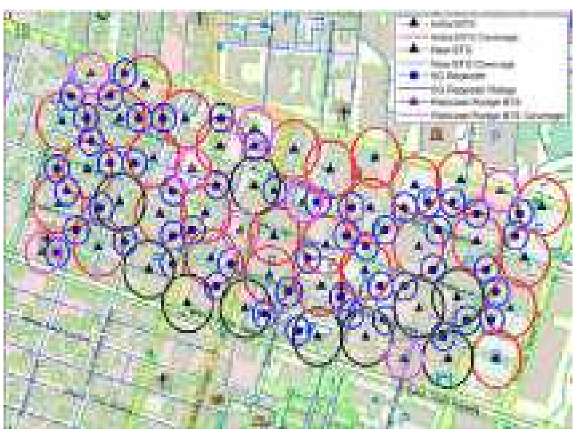

Fig. 5: Deployed 5G Network

IV. Radiation Analysis

A. Exposure Limits

Although mmWave radiation is non-ionizing, the absorption of mmWave energy in the human body causes heating to the skin and eyes. This has caused serious concerns in terms of potential health risks that might come along with the introduction of 5G networks [17]. For this reason, before introducing mmWave devices into the market, they need to comply to several exposure limits that have been specified in several standards and specifications. The specific absorption rate (SAR) has often been used as the metric to determine exposure compliance. The SAR measures the amount of energy absorbed by the human body while using a mobile phone. However, at high frequencies, this absorption is restricted to the skin level and thus it would be difficult to use the SAR as a measure for exposure limits at mmWave frequencies. The power density (P_D) measured in W/m^2 has been the preferred metric in the mmWave domain.

For the frequency range of 2 to 300 GHz, the IEEE C95.1-2019 standard [18] specifies a limit power density value of 10 W/m^2 in restricted environment and 50 W/m^2 in unrestricted environments. These correspond to an averaging time of 30 minutes. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) 2020 guidelines for limiting exposure to electromagnetic fields [19] specify the general public exposure limit at 10 W/m^2 for frequencies between 2 and 300 GHz with the averaging time being 30 minutes. Similar limits are specified by the Federal Communications Commission (FCC) in [20] where a restriction of 10 W/m^2 for the general public has been set. In contrast, the institute for building biology and sustainability (IBN) in Germany have specified the exposure limit to be less than 0.1 $\mu W/m^2$ in their 2015 Standard of Building Biology Measurement Technique (SBM-2015) [21], which is a million-fold lower than what is specified by the aforementioned guidelines. This suggests that negative health effects can occur at levels much lower than 10 W/m^2. Finally, the Chinese ministry of health [22] have set the power density exposure limit to 0.1 W/m^2.

TABLE IV: General Public Power Density Restrictions for the Frequency Range of 2 to 300 GHz

	IEEE C95.1-2019	ICNIRP	FCC	China	SBM-2015
P_D Limit (W/m^2)	10	10	10	0.1	10^{-6}

B. Power Density Assessment

The power density P_D radiated by a transmit antenna can be expressed at a far-field distance d using the following:

$$P_D = \frac{G_{Tx} P_{Tx}}{4\pi d^2} \tag{9}$$

The far-field distance is defined as the Fraunhofer distance expressed by:

$$d_{far-field} = \frac{2D^2}{\lambda} \tag{10}$$

where D is the largest dimension of the antenna and λ is the wavelength that corresponds to a frequency of operation. For distances less than the far-field distance, the power density cannot be computed using (9) and there would be a need to resort to numerical modeling methods such as the finite element method or finite-difference time domain.

C. Results

Fig. 6 shows the value of the power density for several choices of transmission power and transmit antenna gain in the distance range of 1 to 5 meters. For the proposed 5G network, we considered a transmission power of 19 dBm and a transmit antenna gain of 24 dBi. This corresponds to a value of 1.59 W/m^2 at 1 meters which drops to 0.06 W/m^2 at 5 meters. These values comply with the limits set by IEEE, ICNIRP, and FCC, since they are much lower than 10 W/m^2, but do not comply with SBM-2015 and Chinese Ministry of Health regulations. Fig. 7 shows the variations of the power density over the range of 20 to 50 meters. At 50 meters, which is at proximity of the cell edge, the power density drops further to $6.35 \times 10^{-4} W/m^2$ which is still much higher than the limit of the SBM-2015 guidelines. As shown in both Fig. 6 and Fig. 7, increasing the transmission power or choosing an antenna with a higher gain leads to an increase in the radiated power density. To comply with the limit set by China, the total EIRP needs to be dropped to achieve a power density below 0.1 W/m^2 which comes at the expense of a reduced cell range (below 50 meters). This makes it more difficult to plan cost-efficient 5G networks.

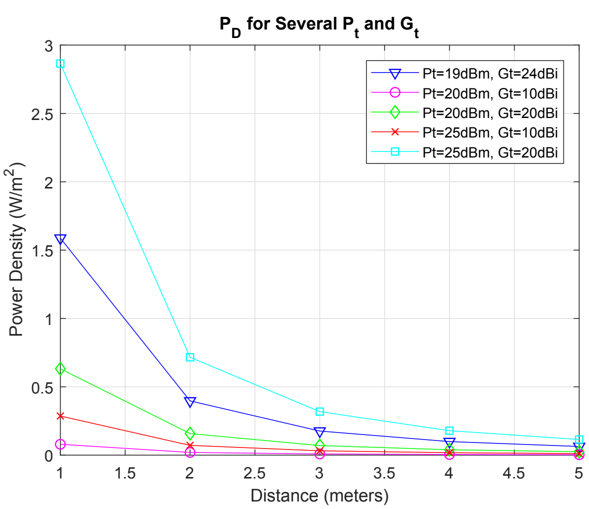

Fig. 6: Power Densities for Several Transmission Powers and Antenna Gains for the range of 1 to 5 meters

Cumulative Distribution Function (CDF) plots for the power density levels experienced in both the pre-existing LTE network and the newly deployed 5G network are shown in Fig. 8. The additional radiations imposed by the 5G network significantly increase the probability of being exposed to power density levels of more than 0.5 W/m^2 and that could reach up to the range of 2 to 2.5 W/m^2, while such power density levels were not experienced in the pre-existing LTE network. This is why the CDF of the power density in the pre-exisitng LTE network reaches the limiting factor of 1 for a power density around 0.65 W/m^2

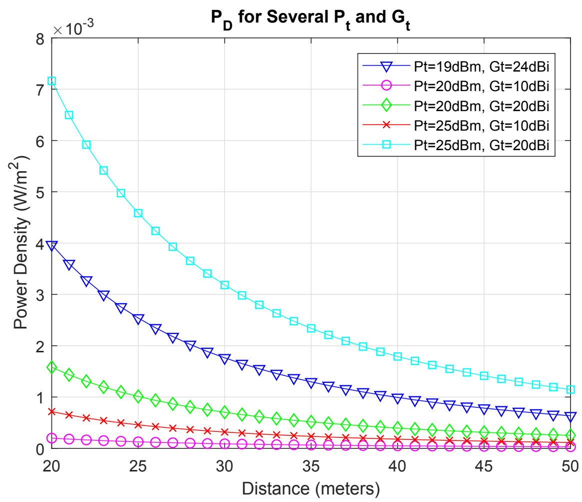

Fig. 7: Power Densities for Several Transmission Powers and Antenna Gains for the range of 20 to 50 meters

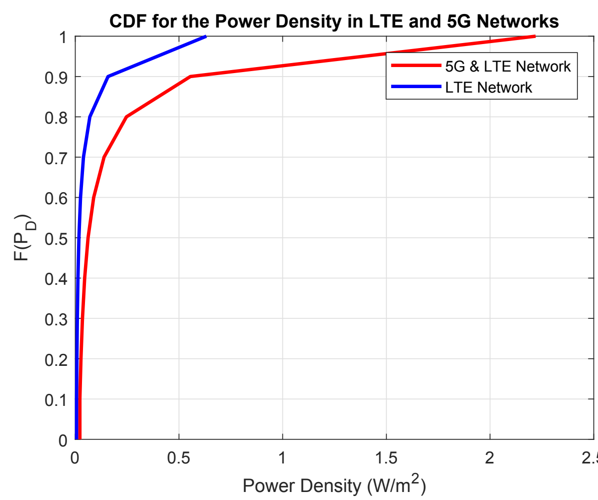

Fig. 8: CDF for the power densities levels for both pre-existing LTE and deployed 5G network

Fig. 9 shows a heat-map representing the radiated power by the LTE BTSs in the area under study before deploying the 5G network, where a simplified path loss model [23] is considered for an urban macrocell. In Fig. 10, a similar heat-map is shown after the deployment of the 5G network. The remarkable increase in radiation levels after integrating 5G infrastructure with the original LTE network can be easily observed through the predominance of the red color in the heat map.

The presented results clearly show that the potential radiation levels that will be reached upon the roll out of 5G networks do not comply with all of the aforementioned exposure limits. This suggests that 5G mobile networks can not yet be classified as safe for the public, and demands serious considerations before using mmWave communications for 5G networks, given the potential harms it could afflict on the public. This paves the way to the consideration of hybrid transmission techniques including traditional electromagnetic waves, free-space optics and visible light communication

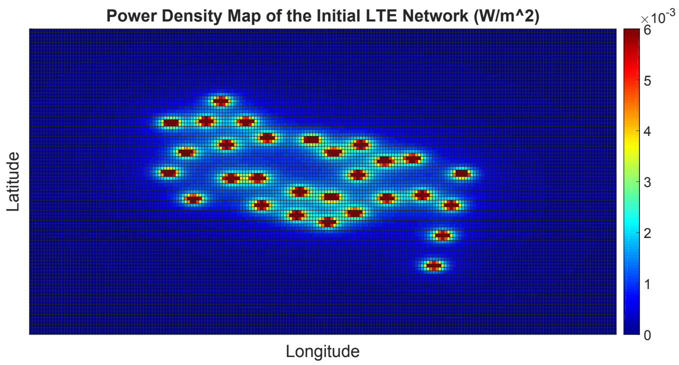

Fig. 9: Power Density Map of the Initial LTE Network

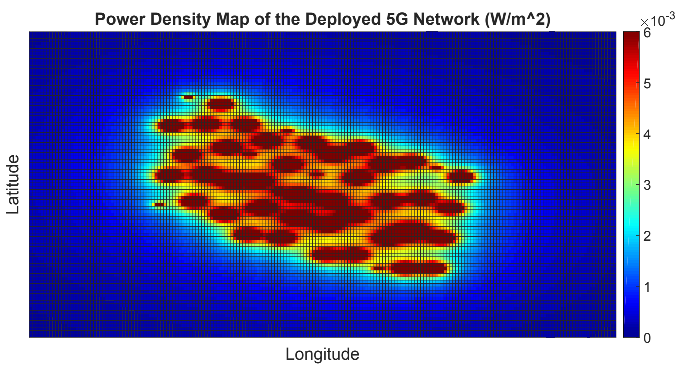

Fig. 10: Power Density Map of the Deployed 5G Network

V. Conclusion

This paper presented an analysis of the radiation levels in a deployed 5G network in an urban outdoor environment. Under the constraints of exposure limits, several challenges face the design and planning of such radiation aware 5G networks. Cell ranges need to be reduced to comply with the maximum allowed radiated power, requiring the densification of small cells in small areas and making it more costly to deploy these radiation-aware 5G networks. Although in this work we considered the maximum allowed EIRP prior to network deployment, results showed power density levels that do not satisfy all the exposure limits set by several sources. In this regard, a positive impact can be imposed by radiation-aware 5G networks on several levels. On a governmental level, the exposure limits for the power density need to be revised using today's data and approaches to bridge the gap between the thresholds specified by the different institutes and commissions. On a technological and scientific level, the radiation exposure constraint can open the door for innovative 5G solutions targeted to limit the health risks and economic barriers associated with this problem. This work can be extended by developing an analytical framework to efficiently rank and rate different cell allocation alternatives to minimize the potential radiations given a carefully chosen list of key performance indicators.

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Health impact of 5G

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Scientific Foresight Unit (STOA)

PE 690.012 – July 2021

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Health impact of 5G

Current state of knowledge of 5G-related carcinogenic and reproductive/developmental hazards as they emerge from epidemiological studies and in vivo experimental studies

The upcoming deployment of 5G mobile networks will allow for significantly faster mobile broadband speeds and increasingly extensive mobile data usage. Technical innovations include a different transmission system (MIMO: use of multiple-input and multiple-output antennas), directional signal transmission or reception (beamforming), and the use of other frequency ranges. At the same time, a change is expected in the exposure to electromagnetic fields (EMF) of humans and the environment. In addition to those used to date, the 5G pioneer bands identified at EU level have frequencies of 700 MHz, 3.6 GHz (3.4 to 3.8 GHz) and 26 GHz (24.25 to 27.5 GHz). The first two frequencies (FR1) are similar to those used for 2G to 4G technologies and have been investigated in both epidemiological and experimental studies for different end points (including carcinogenicity and reproductive/developmental effects), while 26 GHz (FR2) and higher frequencies have not been adequately studied for the same end points.

The International Agency for Research on Cancer (IARC) classified radiofrequency (RF) EMF as 'possibly carcinogenic to humans' (Group 2B) and recently recommended RF exposure for re-evaluation 'with high priority' (IARC, 2019). Since 2011 a great number of studies have been performed, both epidemiological and experimental. The present review addresses the current knowledge regarding both carcinogenic and reproductive/developmental hazards of RF as exploited by 5G. There are various *in vivo* experimental and epidemiological studies on RF at a lower frequency range (450 to 6000 MHz), which also includes the frequencies used in previous generations' broadband cellular networks, but very few (and inadequate) on the higher frequency range (24 to 100 GHz, centimetre/MMW).

The review shows: 1) 5G lower frequencies (700 and 3 600 MHz): a) limited evidence of carcinogenicity in epidemiological studies; b) sufficient evidence of carcinogenicity in experimental bioassays; c) sufficient evidence of reproductive/developmental adverse effects in humans; d) sufficient evidence of reproductive/developmental adverse effects in experimental animals; 2) 5G higher frequencies (24.25-27.5 GHz): the systematic review found no adequate studies either in humans or in experimental animals.

Conclusions: 1) cancer: FR1 (450 to 6 000 MHz): EMF are probably carcinogenic for humans, in particular related to gliomas and acoustic neuromas; FR2 (24 to 100 GHz): no adequate studies were performed on the higher frequencies; 2) reproductive developmental effects: FR1 (450 to 6 000 MHz): these frequencies clearly affect male fertility and possibly female fertility too. They may have possible adverse effects on the development of embryos, foetuses and newborns; FR2 (24 to 100 GHz): no adequate studies were performed on non-thermal effects of the higher frequencies.

AUTHOR

This study has been written by Dr Fiorella Belpoggi, BSC, PhD, International Academy of Toxicologic Pathology Fellow (IATPF), Ramazzini Institute, Bologna (Italy), at the request of the Panel for the Future of Science and Technology (STOA) and managed by the Scientific Foresight Unit, within the Directorate-General for Parliamentary Research Services (EPRS) of the Secretariat of the European Parliament.

The scoping review search was performed by Dr Daria Sgargi, PhD, Master in Biostatistics, and Dr Andrea Vornoli, PhD in Cancer Research, Ramazzini Institute, Bologna.

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Executive summary

1. Background

Recent decades have seen an unparalleled development of technologies known as information and communications technologies (ICT), which include wireless communication used for mobile telephones and, for example, Wi-Fi using radiofrequency (RF) electromagnetic fields (EMF).

The first generation of handheld mobile phones was available in the late 1980s. Subsequently, the second (2G), third (3G) and fourth (4G, long-term evolution = LTE) generations dramatically increased their penetration rates in society, so that today in Europe there are more devices than inhabitants. In addition, Wi-Fi and other forms of wireless data transfer have become ubiquitous and are globally available. Nevertheless, there are new inequalities in terms of access to high-speed internet (even within high-income countries) and control by authoritarian regimes shows risks for democracy and European values.

The introduction of the next generation of RF, 5G, has begun on mobile networks. 5G is not a wholly new technology, but an evolution of already existing G1 to G4 technologies. 5G networks will work within several different frequency bands, the lower frequencies of which are being proposed for the first phase of 5G networks. Several of these frequencies have been or are currently being used for earlier mobile communication generations. There are also plans to use much higher radio frequencies at later stages of the 5G technology evolution. The new bands are well above the ultra high frequency (UHF) range, having wavelengths in the centimetre (3–30 GHz) or millimetre ranges (MMW) at 30-300 GHz. These latter bands have traditionally been used for radar and microwave links and very few have been studied for their impact on human health.

2. Methodology

This review of the currently available scientific evidence focuses on both the carcinogenic and the reproductive/developmental effects of RF from mobile phone telecommunications systems using 2G-5G networks, based on both in vivo animal studies and human epidemiological studies. The studies evaluated have been divided into two groups:

1) studies evaluating health effects due to RF at the lower frequency range (FR) (FR1: 450 to 6 000 MHz), which also includes the frequencies used in the existing 2-4 generations of the broadband cellular network. The current evidence from 2G-4G studies is the best evidence currently available. The studies were evaluated using *narrative* methods;

2) studies evaluating health effects due to RF at the higher FR (FR2: 24 to 100 GHz - MMW). The higher frequencies are new, not previously used for mobile communication and specific to the new 5G technology, which has particular physical characteristics and interactions with biological matter (lower penetration, higher energy, etc.): they were considered separately using a scoping review method.

Narrative review (FR1) will be distinguished from scoping review (FR2), but the selection and assessment criteria indicated for scoping reviews were adopted for both searches and for including/excluding studies on the cancer and reproductive/developmental biological end points.

In finally assessing the results of both epidemiological and experimental study, and of cancer and reproductive/developmental outcomes, consideration was given to the parameters indicated in the IARC Monograph Preamble (2019), tailored to the needs of the present report, and valid for both end points (i.e. cancer and reproductive/developmental effects):

Sufficient evidence: a causal association between exposure to RF-EMF and the specific adverse effect has been established. That is, a positive association has been observed in the body of evidence on exposure to the agent and the specific adverse effect in studies in which chance, bias, and confounding factors were ruled out with reasonable confidence.

Limited evidence: a causal interpretation of the positive association observed in the body of evidence on exposure to RF-EMF and the specific adverse effect is credible, but chance, bias, or confounding factors cannot be ruled out with reasonable confidence.

No evidence: there are no data available or evidence, suggesting lack of adverse effects (to be specified).

The overall evaluation for both cancer and reproductive/developmental effects was obtained by the integration of the human/animal evidence as follows:

Evidence in humans	Evidence in experimental animals	Evaluation based on strength of evidence
Sufficient	Not necessary	Clear association between exposure and the adverse effect
Limited	Sufficient	Probable association between exposure and the adverse effect
Limited	Less than sufficient	Possible association between exposure and the adverse effect
Inadequate	Inadequate or limited	Not classifiable

3. Exposure assessment

The question of exposure assessment with the introduction of 5G is complicated, above all concerning the monitoring of the continuous changes in activity of both base stations (BS) and user equipment (UE) related to MIMO (multiple input, multiple output) technology. Furthermore, the technical approach to exposure assessment in the future scenario, relating to 1G, 2G, 3G, 4G and 5G concurrent emissions, is still being formulated and is hence uncertain.

4. Non-thermal effects

The harmful effects of non-thermal biological interaction of RF-EMF with human and animal tissues have not been included in the determination of the ICNIRP 2020 guidelines (ICNIRP 2020a), despite the huge amount of available scientific publications demonstrating the harmfulness or potential harmfulness of those effects. Athermal bioresponses exist, and indeed some frequencies are being used for therapeutic purposes in a number of branches of medicine. Any drug, as we well know, even the most beneficial, may also entail some adverse effects. So, thermal as well as non-thermal effects of RF-EMF have to be considered in risk assessment.

5. State of the art of the research on RF-EMF

The introduction of wireless communication devices that operate in the RF region of the electromagnetic spectrum (450 to 6 000 MHz, lower frequencies) has triggered a considerable number of studies focusing on health concerns. These studies encompass studies on humans (epidemiological), on animals (rodent experimental studies), and on in-vitro cellular systems.

5G networks will increase the number of wireless devices, necessitating a lot more infrastructure, so as to allow for a higher mobile data volume per geographic area. Moreover, it is necessary to build up increased network density, as the higher frequencies required for 5G (24 to 100 GHz, MMW) have shorter ranges. The studies available on these frequencies are few in number and of mixed quality.

This raises thee questions as to whether these higher frequencies would have health and environmental effects different from those at lower ferquencies. Worldwide, assessments of RF safety have been performed at different levels, with the publication of scientific and policy papers.

With regard to cancer, the IARC 2011 analyis of the literature reviewed up to 2011 (Baan, 2011), published in 2013, and cited throughout as IARC (2013), defined RF-EMF in the frequency range from 30 kHz to 300 GHz as 'possibly carcinogenic' to humans, based on 'limited evidence of carcinogenicity' in human and in experimental animals. The studies available in 2011 examined RF in the range we here call FR1, that is from 450 to 6 000 MHZ. The FR2 frequencies (24 to 100 GHz) lie in the MMW range.

The IARC 2011 analysis evaluated RF-EMF. While there were no studies on 5G, some studies on high frequency occupational radar and microwave exposures were included.

The new MMW frequencies (FR2: 24 to 100 GHz) will be added to the lower frequencies already in use including in part by 5G. It follows that, for 5G in the range 450 to 6 000 MHz (FR1) there are many studies, many collected in the IARC Monograph in relation to cancer, while for 26 GHz and other MMW frequencies in general there is little literature exploring the possible adverse effects on health. The simple reason for this is that hitherto these frequencies have never been used for mass communication and hence there were few suitable populations exposed to these frequencies to study; there are likewise very few adequate studies on non-thermal effects on laboratory animals.

6. Results of the present review

Using PubMed and the EMF Portal database, and applying the scoping review methodology to our research, we found 950 papers on the carcinogenicity of RF-EMF in humans, and 911 papers on experimental rodent studies, totalling 1 861 studies. Regarding reproductive/developmental studies, we found 2 834 papers for epidemiology and 5 052 studies for experimental rodent studies, totalling 7 886 studies. From the present review of the literature and the considerations reported above, we come to the following conclusions:

6.1 Cancer in humans

FR1 (450 to 6 000 MHz): there is limited evidence for carcinogenicity of RF radiation in humans. Updating the results of the overall 2011 evaluation to 2020, positive associations have again been observed between exposure to radiofrequency radiation from wireless phones and both glioma (tumour of the brain) and acoustic neuroma, but the human evidence is still limited.

FR2 (24 to 100 GHz): no adequate studies were performed on the effects of the higher frequencies.

6.2 Cancer in experimental animals

FR1 (450 to 6 000 MHz): there is sufficient evidence in experimental animals of the carcinogenicity of RF radiation. New studies following the 2011 IARC evaluation showed a positive association between RF-EMF and tumours of the brain and Schwann cells of the peripheral nervous system, the same type of tumours also observed in epidemiological studies.

FR2 (24 to 100 GHz): no adequate studies were performed on the higher frequencies.

6.3 Reproductive/developmental effects in humans

FR1 (450 to 6 000 MHz): there is sufficient evidence of adverse effects on the fertility of men. There is limited evidence of adverse effects on fertility in women. There is limited evidence of developmental effects in offspring of mothers who were heavy users of mobile phones during pregnancy.

FR2 (24 to 100 GHz): no adequate studies were performed on the higher frequencies.

6.4 Reproductive/developmental effects in experimental animals

FR1 (450 to 6000 MHz): there is sufficient evidence of adverse effects on male rat and mouse fertility. There is limited evidence of adverse effects on female mouse fertility. There is limited evidence of adverse effects on the development in offspring of rats and mice exposed during embryo life.

FR2 (24 to 100 GHz): no adequate studies on non-thermal effects were performed on the higher frequencies.

7. Overall evaluation

7.1 Cancer

FR1 (450 to 6 000 MHz): these FR1 frequencies are probably carcinogenic to humans.

FR2 (24 to 100 GHz): no adequate studies were performed on the higher frequencies.

7.2 Reproductive/developmental effects

FR1 (450 to 6000 MHz): these frequencies clearly affect male fertility. They possibly affect female fertility. They possibly have adverse effects on the development of embryos, foetuses and newborns.

FR2 (24 to 100 GHz): no adequate studies were performed on non-thermal effects of the higher frequencies.

8. Policy options

8.1 Opting for novel technology for mobile phones that enables RF-EMF exposures to be reduced

The sources of RF emissions that seem at present to pose the greatest threat are mobile phones. Though transmitting installations (radiobase masts) are perceived by some people as providing the greatest risk, actually the greatest burden of exposure in humans generally derives from their own mobile phones, and epidemiological studies have observed a statistically significant increase in brain tumours and Schwann cell tumours of the peripheral nerves, mainly among heavy cell-phone users.

Accordingly, action is needed to ensure that safer and safer telephone devices are manufactured, emitting low energy and if possible only working when at a certain distance from the body. The cable earpiece solves much of the problem but is inconvenient and hence puts users off; on the other hand, it is not always possible to use speakerphone mode. The option of lowering RF-EMF exposure as much as possible in connection with telephones still applies whatever the frequencies being used, from 1G to 5G. Countries such as the US and Canada, which enforced stricter mobile phone SAR limits than in Europe, were still able to build efficient 1G,2G, 3G, 4G communications

(Madjar, 2016). Since 5G aims to be more energy-efficient than the previous technologies, adopting stricter limits in the EU for mobile phone devices would be at once a sustainable and a precautionary approach.

8.2 Revising exposure limits for the public and the environment in order to reduce RF-EMF exposure from cell towers

Recently, EU policies (European Commission, 2019) have promoted the sustainability of a new economic and social development model that uses new technologies to constantly monitor the planet's state of health, including climate change, the energy transition, agro-ecology and the preservation of biodiversity. Using the lowest frequencies of 5G and adopting precautionary exposure limits such as those used in Italy, Switzerland, China, and Russia among others, which are significantly lower than those recommended by ICNIRP, could help achieve these EU sustainability objectives.

8.3 Adopting measures to incentivise the reduction of RF-EMF exposure

Much of the remarkable performance of the new wireless lower frequency 5G technology can also be achieved by using optic-fibre cables and by adopting engineering and technical measures to reduce exposure from 1-4G systems (Keiser, 2003; CommTech Talks, 2015; Zlatanov, 2017). This would minimise exposure, wherever connections are needed in fixed sites. For example, optic fibre cables could be used to connect schools, libraries, workplaces, houses, public buildings, and all new buildings etc., and public gathering places could be 'no RF-EMF' areas (along the lines of no-smoking areas) so as to avoid the passive exposure of people not using a mobile phone or long-range transmission technology, thus protecting many vulnerable elderly or immune-compromised people, children, and those who are electro-sensitive.

8.4 Promoting multidisciplinary scientific research to assess the long-term health effects of 5G and to find an adequate method of monitoring exposure to 5G

The literature contains no adequate studies that would rule out the risk that tumours and adverse effects on reproduction and development may occur upon exposure to 5G MMW, or to exclude the possibility of some synergistic interactions between 5G and other frequencies that are already being used. This makes the introduction of 5G fraught with uncertainty concerning both health issues and forecasting and or monitoring the actual exposure of the population: these gaps in knowledge justify the call for a moratorium on MMW of 5G, pending completion of adequate research.

In light of these uncertainties, one policy option is to promote multidisciplinary team research into various factors concerning exposure assessment and also into the biological effects of 5G MMW at frequencies between 6 and 300 GHz, both on humans and on the flora and fauna of the environment, e.g. non-human vertebrates, plants, fungi, and invertebrates.

MMW will only be brought in with the final 5G protocol, i.e. not until three to five years' time. Given this time frame, one option is to study their effects before exposing the whole world population and environment.

Implementing MMW 5G technology without further preventive studies would mean conducting an 'experiment' on the human population in complete uncertainty as to the consequences. To restrict our scope to Europe, this could occur within a field like that of chemistry, currently governed by REACH (EC, 1907/2006).

REACH aims to improve the protection of human health and the environment through better and earlier identification of the intrinsic properties of chemical substances. EU REACH regulates the registration, evaluation, authorisation, and restriction of chemicals. It also aims to enhance the innovation and competitiveness of the EU chemicals industry. EU REACH is based on the principle of 'no data, no market', placing responsibility on industry to provide safety information on substances.

Manufacturers and importers are required to gather information on the properties of their chemical substances, which will allow their safe handling, and to register the information in a central database in the European Chemicals Agency (ECHA). One policy option can be to apply the same approach to all types of technological innovation.

The results of these studies could form the basis for developing evidence-based policies regarding RF-EMF exposure of human and non-human organisms to 5G MMW frequencies. Further studies are needed to better and independently explore the health effects of RF-EMF in general and of MMW in particular.

8.5 Promoting information campaigns on 5G

There is a lack of information on the potential harms of RF-EMF. The information gap creates scope for deniers as well as alarmists, giving rise to social and political tension in many EU countries. Public information campaigns should therefore be a priority.

Information campaigns should be carried out at all levels, beginning with schools. People should be informed of the potential health risks, but also the opportunities for digital development, what infrastructural alternatives exist for 5G transmission, the safety measures (exposure limits) taken by the EU and Member States, and the correct use of mobile phones. Only with sound and accurate information can we win back citizen trust and reach a shared agreement over a technological choice which, if properly managed, can bring great social and economic benefits.

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1G , 2G, 3G, 4G, 5G	First-fifth generation of telecommunication
2-ME	2-methoxyethanol
3β HSD	3β-Hydroxysteroid dehydrogenase
17 β HSD	17β-Hydroxysteroid dehydrogenases
3GPP	3rd Generation Partnership Project
ABCD	Amsterdam-born children and their development study
AKR/J	mouse strain
ANSES	French Agency for Food, Environmental and Occupational Health and Safety
AOR	covariate-adjusted odds ratio
APD	annual power density
AR	acrosome reaction
ASP	annual summarised power
AUDIPOG	assessment of neonatal growth (score expressed as a percentile)
B6C3F1/N	mouse strain
BALB/c	mouse strain
BAX	Bcl-2-associated X
BCL-2	B-cell lymphoma 2
BCL-XL	B-cell lymphoma-extra large
BLL	blood lead level
BMI	body mass index
BS	base stations
C3H/HeA	transgenic mouse
C57BL/6	mouse strain
CANULI	From the danish 'cancer og social ulighed' (cancer and socal inequality), cohort study
CAT	catalase
CEFALO	multicentre case-control study
CERENAT	multicentre case-control study
CDF	cumulative distribution function
CDMA	code division multiple access
CGRP	calcitonin gene-related peptide
CI	confidence interval
CNS	central nervous system
CRP	C-reactive protein
CW	continuous wave
DECT	digital enhanced cordless telecommunications

DFI	DNA fragmentation index
DNA	neoxyribonucleic acid
DNBC	Danish national birth cohort
ECHA	European Chemicals Agency
EARTH	Environment and Reproductive Health Study
EMF	electromagnetic field
ENU	N-ethyl-N-nitrosourea
EPM	elevated-plus maze
EPRS	European Parliamentary Research Service
Erα	estrogen receptor alpha
Erβ	estrogen receptor beta
EU	European Union
Eμ-Piml	transgenic mouse
F	female
FCC	Federal Communications Commission
FOEN	Federal Office for the Environment
FOMA	freedom of mobile multimedia access
FR1	lower frequency band (450 MHz- 6 GHz)
FR2	higher frequency band (24 - 100 GHz)
FST	forced swimming test
GA	gallic acid
GADD45	growth arrest and DNA damage 45
GBD	global burden of diseases, injuries and risk factors
GD	gestational day
GERoNiMO	generalised EMF research using novel methods
GFAP	glia fibrilliary acidic protein
GHz	giga hertz
GIS	geographical information systems
GSH	glutathione
GSH-Px	glutathione peroxidase
GSM	global systems for mobile communications
GR	γ-radiation
H2O2	hydrogen peroxide
HSP70 (or 25, or 32): 70 (or 25, or 32)	kilodalton heat shock proteins
IARC	International Agency for Research on Cancer
IATPF	International Academy of Toxicologic Pathology Fellow
ICNIRP	International Commission on Non-Ionizing Radiation Protection

ICR	mouse strain
ICT	information and communications technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEMFA	International EMF Alliance
IL-6 (or 10, or 32)	interleukine-6 (or 10, or32)
ILO	International Labour Organization
INMA	Spanish Environment and Childhood Project
INTERPHONE	a set of international case-control studies
INTEROCC	international case-control study
IoT	internet of things
ISTISAN	Italian National Institute of Health (Istituto Superiore di Sanità) report
IRR	incidence rate ratio
ITA	Austrian Institute fur Technickfolken
IT'IS	Foundation for Research on Information Technologies in Society
JECS	Japan Environment and Children Study
kHz	kilohertz
LH	luteinising hormone
LTE	long-term evolution
M	male
MARHCS	Male Reproductive Health in Chongqing College students cohort study
MDA	malondialdehyde
MDI	mental development index
MEL	melatonin
MHz	megahertz
MIMO	multiple-input and multiple-output antennas
MMP2 (or 14)	matrix metallopeptidase 2 (or 14)
MMW(s)	millimeter wave(s)
MoBa	prospective population-based pregnancy cohort study
MOCEH	Korean Mothers and Children's Environmental Health Study
MOE	moringa extract
MPBS	mobile phone base stations
MW	millimeter waves
MWM	Morris water maze
NéHaVi	cohort study
NIR	non-ionising radiation
NMRI	mouse strain

NO	nitric oxide
NOS	nitric oxide synthase
NTP	national toxicology programme
NTP TR	national toxicology programme technical report
OECD	Organisation for Economic Co-operation and Development
OFT	open field test
OR	odd ratio
OSI	oxidative stress index
PARP	poly (ADP-ribose) polymerase
P21	cyclin-dependent kinase inhibitor 1
P450scc	cholesterol side-chain cleavage enzyme
P53	tumour protein P53
PCNA	proliferating cell nuclear antigen
PD	power density
PDI	psychomotor development index
PECO	population, exposure, comparator and outcome
PEM	personal exposure meter
PGE2	prostaglandin E2
PND	postnatal day
PRISMA-ScR	preferred reporting items for systematic reviews and meta-analyses extension for scoping reviews
REACH	registration, evaluation, authorisation and restriction of chemicals
RF	radiofrequency
RFR	radiofrequency radiation
RF-EMF	radiofrequency electromagnetic field
RL	reference level
ROS	reactive oxygen species
RR	relative risk
RWTH	Rheinisch-Westfälische Technische Hochschule Aachen
SAR	specific absorption rate
SCENIHR	European Commission Scientific Committee on Emerging and Newly Identified Health Risks
SCHEER	Scientific Committee on Health, Environmental and Emerging Risks
SDQ	strengths and difficulties questionnaire
SEM	source-exposure matrix
SF1	splicing factor 1
SOD	superoxide dismutase
SPOCK3	PARC (osteonectin), cwcv and kazal-like domains proteoglycan 3

SSM	Swedish Radiation Safety Authority
SR	scoping review
StAR	steroidogenic acute regulatory protein
STOA	European Parliament's Panel for the Future of Science and Technology
TAC	total antioxidant capacity
TETRA	terrestrial trunked radio
TSC	total sperm count
TST	tail suspension test
UE	user equipment
UHF	ultra-high frequencies
UMTS	universal mobile telecommunications system
UK	United Kingdom
V/m	volt/meter
VEGF	vascular endothelial growth factor
W/kg	watt/kilogram
WHO	World Health Organization

1. Introduction

1.1 Background

Recent decades have experienced an unparalleled development of technologies known as Information and Communications Technology (ICT), which include wireless communication used for mobile telephones and, for example, Wi-Fi using electromagnetic fields (EMF). The first generation of handheld mobile phones were available in the late 1980s. Subsequently, the second (2G), third (3G), and fourth (4G, Long-Term Evolution = LTE) generations dramatically increased their penetration rates in society, so that today there are more devices than inhabitants in Europe. In addition, Wi-Fi and other forms of wireless data transfer have become ubiquitous, and are globally available. At present we are starting to introduce the next generation of RF, 5G, on mobile networks. 5G is not new technology, but an evolution of already existing G1 to G4 technologies.

1.2 The exposure scenario

1.2.1 Present scenario of exposure

The different exposure situations that may occur with the intensive deployment of telecommunications was well described in Monograph 102 of the International Agency for Research on Cancer (IARC, 2013). Monograph 102 is concerned with non ionising radiation in the RF range of the electromagnetic spectrum, i.e. between 30kHz and 300 GHz, thus including the frequencies relevant to the present review.

The corresponding wavelengths (the distance between successive peaks of RF waves) range from 10 Km to 1mm, respectively. EMF generated by RF sources couple with the human body, which results in induced electric and magnetic fields and associated currents inside body tissues (IARC, 2013). Human exposures to radiofrequency electromagnetic fields (RF-EMF) can occur from use of personal devices (e.g. mobile telephones, cordless phones, Bluetooth, and amateur radios), from occupational sources (e.g. high-frequency dielectric and induction heaters, and high-powered pulsed radars), and from environmental sources such as mobile-phone base stations, broadcasting antennas, and medical applications.

For workers, most exposure to RF-EMF comes from near-field sources, whereas the general population receives the highest exposure from transmitters close to the body, such as handheld devices like mobile telephones. Exposure to high-power sources at work might involve higher cumulative RF energy deposited in the body than exposure to mobile phones, but the local energy deposited in the brain is generally lower.

Typical exposures ofthe brain from rooftop or tower-mounted mobile-phone base stations and from TV and radio stations are several orders of magnitude lower than those from global systems for mobile communications (GSM) handsets. The average exposure from use of digital enhanced cordless telecommunications (DECT) phones is around five times lower than that measured for GSM phones, and third-generation (3G) phones emit, on average, about 100 times less RF energy than GSM phones, when signals are strong. Similarly, the average output power of Bluetoothwireless hands-free kits is estimated to be around 100 times lower than that of mobile phones.

EMFs generated by RF sources couple with the body, resulting in induced electric and magnetic fields and associated currents inside tissues. The most important factors that determine such induced fields are the distance of the source from the body and the output power level (IARC, 2013). The near field and far field are regions of the EMF around an object, such as a transmitting antenna, or the result of radiation scattering off an object. Non-radiative near-field behaviours dominate close to the antenna or scattering object (mobile phone), while electromagnetic radiation far-field behaviours dominate at greater distances (BC Center for Disease Control, 2013).

Additionally, the efficiency of coupling, and resulting field distribution inside the body, strongly depends on the frequency, polarisation, and direction of wave incidence on the body, and anatomical features of the exposed person, including height, bodymass index, posture, and dielectric properties of the tissues. Induced fields within the body are highly non-uniform,varying over several orders of magnitude, with local hotspots. Holding a mobile phone to the ear to make a voice call can result in high specific RF energy absorption-rate (Specific Absorption Rate = SAR) values in the brain, depending on the design and position of the phone and its antenna in relation to the head, how the phone is held, the anatomy of the head, and the quality of the link between the base station and phone. When used by children, the average RF energy deposition is two times higher in the brain and up to ten times higher in the bone marrow of the skull, compared with mobile phone use by adults. Use of hands-free kits lowers exposure to the brain to below 10% of the exposure from use at the ear, but it might increase exposure to other parts of the body (IARC, 2013).

1.2.2 The 5G scenario of exposure

Figure 1 – History of mobile technology

With the upcoming deployment of 5G mobile networks, significantly faster mobile broadband speeds and increasingly extensive mobile data usage will be ensured. Technical innovations include a different transmission system (MIMO: multiple-input and multiple-output antennas), directional signal transmission or reception (beamforming), and the use of other frequency ranges. This is made possible by the use of additional higher frequency bands (millimetre waves = MMW). 5G is intended to be the intersection of communications, from virtual reality to autonomous vehicles to the industrial internet and smart cities. In addition, 5G is considered the basic technology for the Internet of Things (IoT), where machines communicate with machines. At the same time, a change is expected in the exposure to EMF of humans and the environment (Figures 1 and 2).

Figure 2 – 3G vs 4G vs 5G

	3G	4G	5G
Deployment	2004-05	2006-10	2020
Bandwidth	2mbps	200mbps	>1gbps
Latency	100-500 milliseconds	20-30 milliseconds	<10 milliseconds
Average Speed	144 kbps	25 mbps	200-400 mbps

The 5G networks will work within several different frequency bands, of which the lower frequencies are being proposed for the first phase of 5G networks. Several of these frequencies (principally below 1 GHz - Ultra-High Frequencies, UHF) have been or are currently being used for earlier mobile communication generations. Furthermore, much higher RF are also planned to be used at later stages of the evolution of the technology.

The operating frequencies at low and mid bands can overlap with the current 4G band at 6 GHz or below. The biological effects of RF radiations at these lower-frequency bands are thus likely to be comparable to 2G, 3G or 4G. However, the scenarios of high band 5G, especially for 24 GHz to 60 GHz in the MMW region for high-capacity, short-range wireless data communications, are relatively recent new arrivals, and pose considerable challenge to health-risk assessment (Lin, 2020). These latter bands have traditionally been used for radar and microwave links (Simkò and Mattsonn, 2019) and very few have been studied for their impact on human health.

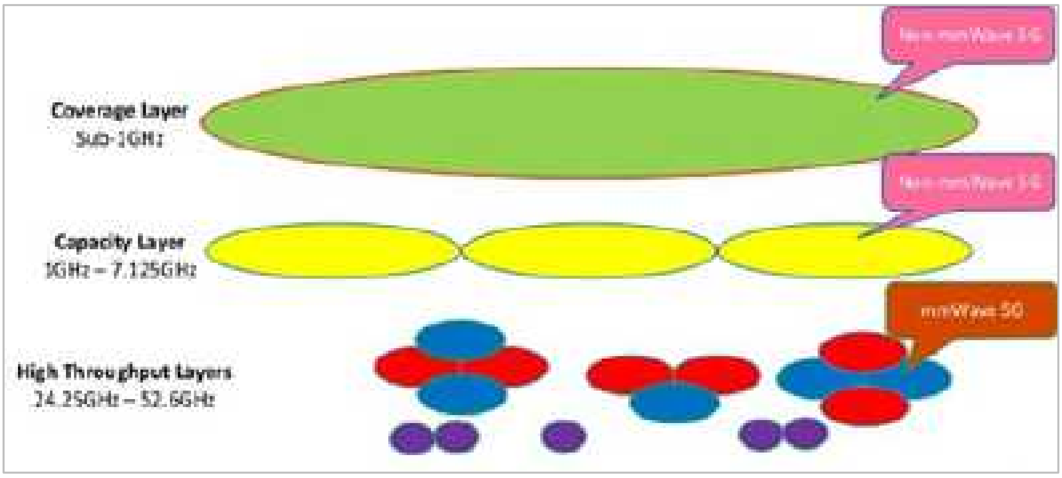
1.2.3 5G: beam forming and MIMO

The recent increase in cell-phone traffic over the microwave frequency band has shifted attention towards the broad MMW spectrum, which has hitherto been under-used. Up until 4G technology, cellular communication used frequencies below 3GHz and the idea that higher frequencies (greater than 3 GHz) incur more attenuation by physical obstacles tended to make the lesser frequencies seem more reliable. However, intelligent beamforming is improving the coverage and cutting interference to a minimum. The technique of dynamic radio masts employing beamforming, combined with multi-user MIMO (MU-MIMO), forms the basis of 5G NR (New Radio); working together they will enable over 1,000 more devices per square metre to be supported than with 4G, sending many more users ultra-fast data with high precision and low latency.

MIMO was originally developed for Single-User (SU-MIMO) applications so as to improve the efficiency of LTE (4G) networks. It was soon realised that such technology could be extended to Multi-User applications with a view to reducing or avoiding the problem of interference within a cell. This led to a series of solutions known as MU-MIMO (David and Viswanath, 2005). On the other hand, implementation of these inevitably raised queries as to the health impact. The European Parliament tackled the issue in a 2019 document concerning the state of advancement of 5G distribution in Europe, the US and Asia:

"Significant concern is emerging over the possible impact on health and safety arising from potentially much higher exposure to radiofrequency electromagnetic radiation arising from 5G. Increased exposure may result not only from the use of much higher frequencies in 5G but also from the potential for the aggregation of different signals, their dynamic nature, and the complex interference effects that may result, especially in dense urban areas. The 5G radio emission fields are quite different to those of previous generations because of their complex beamformed transmissions in both directions – from base station to handset and for the return. Although fields are highly focused by beams, they vary rapidly with time and movement and so are unpredictable, as the signal levels and patterns interact as a closed loop system. This has yet to be mapped reliably for real situations, outside the laboratory" (Blackman and Forge, 2019).

Figure 3 – 5G needs different frequency bands



Source: Qualcomm, 2020

5G will use a broad range of radio spectra (Fig.4). They divide into three distinct levels according to user need:

- the "*coverage layer*", with frequencies lower than 1GHz, provides broad outdoor coverage and deep indoor coverage. It basically consists of a frequency band used by digital television that performs well in penetrating obstacles. This system does not use beamforming, and in terms of management is similar to Radio Base Stations (RBS) using 4G technology, though possibly applying a corrective factor (peak power reduction coefficient) which takes account of the mean power used by the transmitting system;

- the "*coverage and capacity layer*", between 1GHz and 6GHz, is one of the major novelties of 5G. It uses the Massive – MIMO system to ensure an optimum compromise between coverage and capacity, i.e. the speed of data transfer per unit of frequency. It includes the band C spectrum, around 3.5 GHz. This non-millimetre frequency band operates in beamforming mode so as to concentrate most of the radiated power upon the target terminal;

- the "*super data layer*", from 6GHz up to MMW frequencies of 30 GHz and over, offers the breadth of band and data speeds required by the top-performing International Telecommunication Union Radiocommunication Sector (ITU-R) of the International Mobile Telecommunications (IMT)-2020 standard. This frequency band also uses the beamforming technique.

The main frequency bands for 5G standards taken up globally5G technology will not just be geared to communication among people, but also to interconnected automated systems (Internet of Things) using electromagnetic waves on a frequency belonging to the band 26.5-27.5 GHz. The frequency of such electromagnetic waves is so high that they are unable to penetrate buildings or get past obstacles. So 'solving' that difficulty calls for installation of many small cells of sizes ranging from about 10 metres (indoor) to several hundred metres (outdoor) - greatly inferior in range to the macro-cells of previous technologies which may extend for several kilometres. In Europe, the general picture might be summarised as reported in Fig. 4, 5 and 6 (Source: Qualcomm, 2020).

Figure 4 – 5G spectrum status by dashboard and auctions in Europe

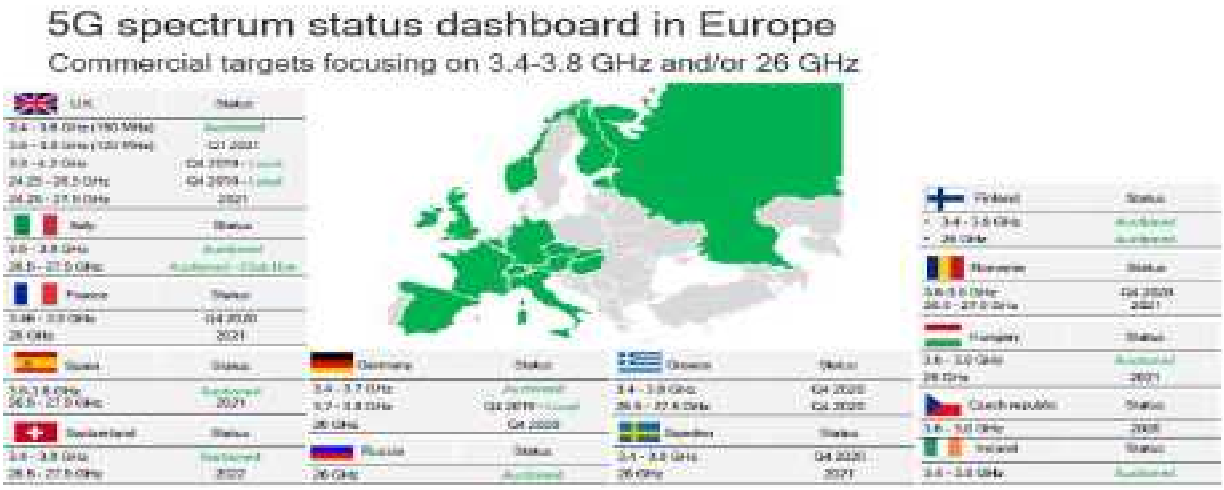


Figure 5 – 5G spectrum status by auctions in Europe (FR1: 700 MHz)

Figure 6 – 5G spectrum status by auctions in Europe (FR1: 3.4 -3.8 GHz)

Nasim and Kim (2017) simulates the possible exposure scenario to RF after 5G deployment using beamforming technology. The authors consider that at MMW frequencies, at which future mobile telecommunications systems will most likely operate, two changes that are likely to occur may increase concern as to the exposure of human users to RF fields. First, larger numbers of transmitters will operate. More base stations (BSs) will be deployed due to proliferation of small cells (Rappaport et al., 2013; Agiwal, 2016; Al-Saadeh, 2017) and mobile devices accordingly. This will increase the likelihood of human exposure to RF fields. Second, narrower beams will be used as a solution for the higher attenuation in higher frequency bands (Shakib, 2016; Zhang et al., 2017; Akdeniz et al., 2014). Very small wavelengths of MMW signals combined with advances in RF circuits enable very large numbers of miniaturised antennas. These multiple antenna systems can be used to form very high gains. The authors declare that their paper is motivated by the fact that previous works have not sufficiently addressed such a potential increase in risk. In their conclusions, the authors state*:*
"This paper has highlighted the significance of human RF exposure issue in downlink of a cellular communications system. This paper measured the exposure level in terms of PD and SAR, and compared them to those calculated in Release 9 as a representative of the current mobile communications technology. Unlike previous works that studied uplinks only, this paper has found that the downlinks of a 5G also yield significantly higher levels of PD and SAR compared to Release 9 [the present scenario of exposure]. Our results emphasized that the increase stems from two technical changes that will likely occur in 5G: (i)more access points (APs) due to deployment of smaller cells and (ii) morehighly concentrated RF energy per downlink RF beam due to use of larger phased arrays. As such, unlike prior work, this paper claims that RF fields generated in downlinks of 5G can also be dangerous inspite of far-field propagation. Therefore, the authors call for design of cellular communications and networking schemes that forcean AP to avoid generation of RF fields if pointed at a human user at an angle yielding a dangerous level of PD and SAR. To this end, the paper identifies as a future work developing the idea of techniques that reduce human exposure to RF fields in 5G downlinks" (Imtiaz and Seungmo, 2017).

It is noteworthy that this paper (Imtiaz and Seungmo, 2017) only referred to the 5G frequency of 28 GHz, one of the pioneer ones, with the simulation of only one user device connected, using the whole frequency band in static and stationary conditions.

Another paper (Baracca et al., 2018) from the Nokia group, taking into account massive MIMO base station (BSs), proposes a statistical approach for assessing the RF exposure conditions around massive MIMO BSs based on the 3D spatial channel model developed by the Third Generation Partnership Project (3GPP) and evaluates how the power is focused in a practical system when realistic assumptions regarding user equipment (UE) distribution and traffic models are taken into account. The methodology consists in performing system simulations that take into account realistic deployment scenarios in terms of installation height, user equipment, device distribution, and traffic, to evaluate the cumulative distribution function (CDF) of the BS actualtransmission power. "*The proposed statistical approach contributes to improve the calculation methods already defined by the International Electrotechnical Commission (IEC, 2017) and support the deployment of massive MIMO BSs for 5G and beyond cellular networks".*As a concluding remark, the Authors highlight that*: "All the statistical approaches including our own, although based on realistic assumptions, anyhow require complementary techniques, based for instance on power control and beamforming adaptation (*Sambo et al., 2015*), to ensure that the EMF constraints are met at the BSs for all the possible actual configurations*".

Regarding exposure assessment, Neufeld and Kuster (2018) issued a warning in a paper in Health Physics, urging that existing exposure standards be revised with shorter averaging times to address potential thermal damage from short and strong pulses: "*Extreme broadband wireless devices operating above 10 GHz may transmit data in bursts of a few milliseconds to seconds. Even though the time- and area-averaged power density values remain within the acceptable safety limits for continuous exposure, these bursts may lead to short temperature spikes in the skin of exposed people. ... [Our] results also show that the peak-to-average ratio of 1,000 tolerated by the ICNIRP guidelines may lead to permanent tissue damage after even short exposures, highlighting the importance of revisiting existing exposure guidelines*" (Neufeld and Kuster, 2018).

Kenneth Foster of the University of Pennsylvania, countered that their claims do not hold up: "*Because real-world communications technologies produce pulses of much lower fluence than the extreme pulses considered by Neufeld and Kuster, the resulting thermal transients from them will be very tiny in any event*" (Foster, 2019).

The Istituto Superiore di Sanità (Italian National Institute of Health) in the ISTISAN 2019 Report (available only in Italian) recognises that (translation by the author) : *"(…) on the basis of the technical characteristics of [5G] base stations, in order to correctly monitor the exposure, the mean value of measurements of electromagnetic fields should not be considered alone, but together with the maximum levels reached for short periods of exposure. This aspect calls for an updating of the national law which, up to now, has not considered short time exposures, but only continuous exposure as mean values within 6 minutes [20 V/m, occasional exposure] or 24 hrs [6V/m,residential/occupational exposure for more than 4hrs/day)"* (ISTSAN 19/11, 2019).

Uncertainty on exposure assessment remains unresolved. The above mentioned papers, shows that the question of exposure assessment with the introduction of 5G is complicated, above all concerning the monitoring of the continuous changes in activity of both base stations (BSs) and users (UEs) related to MIMO technology, while the technical position on exposure in the new scenario related to 2G, 3G, 4G, 5G emissions, is still being formulated and is hence uncertain. Exposure assessment constitutes a central matter of discussion before MMW and MIMO technology is disseminated all over the planet.

1.3 Overview of the policy action internationally and in Europe

1.3.1 International organisations

The International Agency for Research on Cancer (Baan et al., 2011; IARC, 2013) classified RF-EMF as "*possibly carcinogenic to humans*" (Group 2B).

The World Health Organization (WHO) recently relaunched a call for expressions of interest for systematic reviews (2020). The WHO is undertaking a health risk assessment of RF-EMF, to be published as a monograph in the Environmental Health Criteria Series. This publication will complement the monographs on static fields (2006) and extremely low frequency fields (2007), and will update the monograph on RF fields published in 1993 (WHO, 1993).

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) in March 2020 published new guidelines covering several new technologies, including 5G (ICNIRP, 2020a). The new guidelines introduce new and revised restrictions concerning 5G. On the ICNIRP website there is extensive information on the new guidelines and differences between the 1998 and 2020 guidelines. The guidelines refer only to thermal effects caused by 6 minutes and 30 minutes of exposure to RF-EMF, so the guidelines concern only short-term exposure. Safety guidelines for the currently deployed of 5G technology have been established though insufficient scientific research has yet been performed, while peer-reviewed science on non-thermal effects of RF already in use has not been evaluated in all ICNIRP guidelines (ICNIRP, 2020c).

1.3.2 European organisations and governments (by year)

The Council of Europe Resolution 1815 highlights that: "*The independence and credibility of the scientific expertise employed is crucial for a transparent and balanced assessment of possible negative effects on human health and environment. The resolution recommends: taking all reasonable measures to reduce exposure to EMF (especially from mobile phones) and particularly to protect children and young people who seem to be most at risk of developing head tumours; reconsidering the scientific basis for the present standards on exposure to electromagnetic fields set by the International Commission on Non-Ionising Radiation Protection, which have serious limitations; distributing information and awareness-raising campaigns on the risks of potentially harmful long-term biological effects on the environment and on human health, especially targeting children, teenagers and young people of reproductive age; giving preference to wired internet connections (for children in general and particularly in schools), and strictly regulating the use of mobile phones by schoolchildren on school premises; increasing public funding of independent research to evaluate health risks.*" (European Parliament Assembly, 2011)

The French Agency For Food, Environmental And Occupational Health and Safety (ANSES) in 2013, "(...) *issues recommendations for limiting exposure to radio frequencies limited levels of evidence do point to different biological effects in humans or animals. In addition, some publications suggest a possible increased risk of brain tumour, over the long term, for heavy users of mobile phones. Given this information, and against a background of rapid development of technologies and practices, ANSES recommends limiting the population's exposure to radiofrequencies – in particular from mobile phones – especially for children and intensive users, and controlling the overall exposure that results from relay antennas. It will also be further developing its work on electro-sensitive individuals, specifically by examining all the available French and international data on this topic that merits closer attention. Therefore, to limit exposure to radiofrequencies, especially in the most vulnerable population groups, the Agency recommends: - for intensive adult mobile phone users (in talk mode): use of hands-free kits and more generally, for all users, favouring the purchase of phones with the lowest SAR [values;- reducing the exposure of children by encouraging only moderate use of mobile phones; continuing to improve characterisation of population exposure in outdoor and indoor environments through the use of measurement campaigns; that the development of new mobile phone network infrastructures be subject to prior studies concerning the characterisation of exposures, and an in-depth study be conducted of the consequences of possibly multiplying the number of relay antennas in order to reduce levels of environmental exposure; - documenting the conditions pertaining at those existing installations causing the highest exposure of the public and investigating in what measure these exposures can be reduced by technical means; - that all common devices emitting electromagnetic fields intended for use near the body (DECT telephones, tablet computers, baby monitors, etc.) display the maximum level of exposure generated (SAR, for example), as is already the case for mobile phones; finally, in order to resolve the various uncertainties it identified when conducting this work, and in addition to the research projects already undertaken under the National Plan for Research on Environmental and Occupational Health, the Agency is also making a series of research recommendations"* (ANSES, 2013).

The European Commission Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) had a mandate to evaluate the risks of EMF and periodically reviews the scientific evidence available to assess whether it still supports the exposure limits proposed in Council Recommendation 1999/519/EC. In its latest opinion of January 2015, SCENIHR suggested that there is a lack of evidence that EMF radiation affects cognitive functions in humans or contributes to an increase of the cases of cancer in adults and children (SCENIHR, 2015). However, the International EMF Alliance (IEMFA) suggested that many members of SCENIHR could have a conflict of interests, as they had professional relationships with or received funding from various telecom companies.

Consequently, the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER), replacing the former SCENIHR, indicated a preliminary estimate of the importance of 5G as high, in a statement in December 2018. Furthermore, it evaluates the scale, urgency and interactions (with ecosystems and species) of possible hazard as high. It suggested that there could be biological consequences from a 5G environment, due to the fact that there is a lack of "*(...) evidence to inform the development of exposure guidelines to 5G technology*" (SCHEER, 2018).

In a briefing of June 2017, the European Parliamentary Research Service stated: *"Finally, little research has been performed on the health impacts of 5G, as most of the studies to date relate to previous generation of mobile technology. According to one recent study, this could prove a further bottleneck should 5G pose health risks owing to, 'its urban concentration and dense cellular structure, its use of much higher microwave frequencies and its highly directional concentration'. In the USA a 2016 government-funded study raised concern, as in its preliminary results it found significantly greater rates of rare tumours of the brain and heart in rats exposed to wireless radiation. Other 2017 research and publications also suggest that long-term mobile phone use could increase brain cancer risk. However the latest opinion published by the Commission's expert group in 2015 and research by the World Health Organization do not recognise a direct link. In France, meanwhile, a review of wireless radiation has concluded that there is a need to evaluate all wireless devices for their impact on children's health and recommends only moderate and supervised use by children. This complex issue therefore remains controversial while further research is ongoing"* (EPRS, 2017).

A more recent EPRS document stated that: *"The recent academic literature illustrates that continuous wireless radiation seems to have biological effects especially considering the particular characteristics of 5G: the combination of MMW, a higher frequency, the quantity of transmitters and the quantity of connections. Various studies suggest that 5G would affect the health of humans, plants, animals, insects, and microbes – and as 5G is an untested technology, a cautious approach would be prudent" (EPRS, 2020).*

The Federal Office for Radiation Protection of Germany published a report, where is stated that: *"In a few years, 5G will lead to higher frequencies. However, the effects of these have not yet been well researched. The Federal Office for Radiation Protection advises a prudent expansion of 5G and will further explore the effects of the new frequency bands"* (FORPG, 2019).

In 2020, the EMF scientific council of the Radiation Safety Authority in Sweden (SSM), published its 14th report. This is a consensus report, which means that all members of the Scientific Council agree with the report in toto. Despite the fact that no health risks with weak EMF have been established to date, the Authority considers that: "*Further research is important, in particular regarding long-term effects as the entire population is exposed. One key issue here is to further investigate the relationship between radio wave exposure and oxidative stress observed in animal studies and to establish whether and to what extent it may affect human health. There is also a need to further investigate the observed decreased sperm counts, sperm viability and decreased serum testosterone due to radio wave exposure of testes in animal studies before any conclusions concerning the possible implications for human health can be drawn*" (SSM, 2020).

The Austrian Institute of Technology (AIT) states: "*1) Electromagnetic fields have already been considered a potential health risk with previous generations of mobile radio communication. In 2011, the International Agency for Research on Cancer (IARC) classified mobile phone radiation as "possibly carcinogenic". To this day, experts continue to discuss this topic with much controversy. 2) 5G, the latest generation of mobile phone networks, promises to transmit larger amounts of data with lower latency. Industry 4.0, augmented reality games or the Internet of things rely on such higher performance. 3) The assessment of risks and gaps of knowledge enables precautionary regulation and a prudent approach to 5G*" (Kastenhofer, 2020).

The Health Council of the Netherlands published its opinion on 5G and health in September 2020. A selection of quotes from the report are as follow: *"The rollout of 5G networks has only just begun. Therefore, there are no studies as yet into the health effects of (long-term) exposure to electromagnetic fields with the frequencies that are reserved for 5G"; "According to the committee, it cannot be excluded that the incidence of cancer, reduced male fertility, poor pregnancy outcomes and birth defects could be associated with exposure to RF electromagnetic fields. However, the committee deems the relationship between exposure and these and other diseases or conditions neither proven nor probable"; "There has been almost no research into the effects of exposure to frequencies around 26 GHz" ; "The committee recommends not using the 26 GHz frequency band for 5G for as long as the potential health risks have not been investigated"; "The committee recommends using the latest guidelines from the International Commission on Non-Ionising Radiation Protection (ICNIRP) as the basis for exposure policy in the Netherlands. Because it cannot be excluded that exposure under the latest ICNIRP standards also has the potential to affect health, the committee recommends taking a cautious approach and keeping exposures as low as reasonably achievable".* In this report, common adverse effects from RF exposure are reported, but as a conclusion the committee only recommends taking a cautious approach (Health Council of the Netherlands, 2020).

In Switzerland, the Federal Office for the Environment (FOEN) is the government body responsible for monitoring and assessing research on health effects of NIR from stationary sources in the environment. This includes informing and updating the public about the current state of research, which is the basis for the ambient regulatory limits stated in the Swiss "ordinance relating to protection from non-ionising radiation (NIR)". In the case of reliable new scientific knowledge and experiences, the FOEN would advise the Federal Council of Switzerland to adapt these ambient regulatory limits. The FOEN has therefore nominated a consultative group of Swiss experts from various disciplines with scientific competence regarding EMF and NIR, which commenced its work in July 2014. The group is called BERENIS, based on an acronym of the respective German term. The BERENIS experts regularly screen the scientific literature, and assess the publications which they consider relevant for the protection of humans from potentially adverse effects. As part of the work of BERENIS, non-ionising radiation (NIR) at frequencies below 10 GHz is addressed.

In the special issue of the BERENIS newsletter (BERENIS, 2021), an up-to-date assessment of a possible correlation between oxidative stress and exposure to EMF and their putative effects on health are presented. For this purpose, relevant animal and cell studies published between 2010 and 2020 were identified and summarised. An extended report presenting these recent studies in more detail will be published soon by FOEN 1 (not yet available at the time of this report). The newsletter contains a short version of the report, writing that: "*The majority of the animal and more than half of the cell studies provided evidence of increased oxidative stress caused by RF-EMF (...). This notion is based on observations in a large number of cell types, applying different exposure times and dosages (SAR [Specific Absorption Rate] or field strengths), also in the range of the regulatory limits.*". This review of the literature evidences that one of the mechanisms underlying adverse effects from RF-EMF is oxidative stress, forming free radicals that impair a number of different functions (Yakymenko, 2016).

1.4 Biologically effects other than the ones analysed in this review (both FR1 and FR2)

The present review examines only carcinogenicity and reproductive/developmental adverse effects related to RF exposure observed in epidemiological and laboratory animal studies, published since 1945. However, in order to better understand the impact of RF on human health, we cannot ignore the fact that other biological non thermal effects have been reported. For instance, we need only cite the preponderance of research published from 1990 through 2020, which has found various significant effects from exposure to radio frequency radiation. Overall, 75% (n=711) of 944 analysed radio frequency radiation studies have reported biological effects (Moskowitz, 2018).

The National Toxicology Program (NTP) found that RF-EMF exposure was associated with an increase in DNA damage. Specifically, they found RF-EMF exposure was linked with significant increases in DNA damage in the frontal cortex of the brain in male mice; the blood cells of female mice, and the hippocampus of male rats. There are many factors that influence whether damaged DNA will lead to tumours. NTP plans to conduct additional studies to learn more about how RF-EMF might cause DNA damage (Smith-Roe et al., 2019). Other adverse effects were observed in the NTP studies, including reduced birth weights, DNA strand breaks in brain cells, which is supportive of the cancer findings (Yakymenko, 2015), increased incidences of proliferative lesions (hyperplasia), and exposure-related increases in the incidence of cardiomyopathy of the right ventricle in male and female rats (NTP, 2018).

MMWs rarely included in the above mentioned studies have specific characteristics. MMWs are mostly absorbed within 1 to 2 millimetres of human skin and in the surface layers of the cornea. Thus, the skin or near-surface zones of tissues are the primary targets of such radiation. Since the skin contains capillaries and nerve endings, MMW bio-effects may be transmitted through molecular mechanisms by the skin or through the nervous system. Thermal (or heating) effects occur when the power density of the waves is above 5–10 mW/cm2 (Foster, 1998).

Such high-intensity MMWs act on human skin and the cornea in a dose-dependent manner—beginning with heat sensation followed by pain and physical damage at higher exposures. Temperature elevation affects the growth, morphology and metabolism of cells, induces production of free radicals, and damages DNA. Few studies have examined prolonged exposure to low-intensity MMWs, and no research has focused on exposure to MMWs combined with other RF radiation. Some studies reported that the radiation inhibits cell cycle progression, and some studies reported no biological effects (Le Drean et al., 2013).

(Ramundo-Orlando, 2010) noted that: "*A large number of cellular studies have indicated that MMW may alter structural and functional properties of membranes*". Exposure to MMWs may affect the plasma membrane either by modifying ion channel activity or by modifying the phospholipid bilayer. Water molecules also seem to play a role in these effects. Skin nerve endings are a likely target of MMWs and the possible starting point of numerous biological effects. MMWs may activate the immune system through stimulation of the peripheral neural system (Ramundo-Orlando, 2010).

In 1998, scientists employed by U.S. Army research institutes published a seminal review of the research on MMWs. They reported: *"Increased sensitivity and even hypersensitivity of individual specimens to MMW may be real. Depending on the exposure characteristics, especially wavelength, a low-intensity MMW radiation was perceived by 8 to 30% of healthy examinees (Lebedeva, 1993, 1995). Some clinical studies reported MMW hypersensitivity, which was or was not limited to a certain wavelength (Golovacheva, 1995). It should also be realized that biological effects of a prolonged or chronic MMW exposure of the whole body or a large body area have never been investigated. Safety limits for these types of exposures are based solely on predictions of energy deposition and MMW heating, but in view of recent studies this approach is not necessarily adequate"* (Pakhomov et al., 1998).

In 1977, Zalyubovskaya published a study which examined the effects of exposing mice to millimetre radiation (37-60 GHz; 1 milliwatt per square centimetre) for 15 minutes daily for 60 days. The animal results were compared to a sample of people working with millimetre generators. The summary of the paper reports: *"Morphological, functional, and biochemical studies conducted in humans and animals revealed that millimeter waves caused changes in body manifested in structural alteration in the skin and internal organs, qualitative and quantitative changes in the blood and bone marrow composition and changes of the conditioned reflex activitiy, tissue respiration, activity of enzymes participating in the processes of tissue respiration and nucleic metabolism. The degree of unfavorable effect of millimeter waves depends on the duration of the radiation and individual characteristics of the organism"* (Zalyubovskaya, 1977).

Microbes are also affected by MMW radiations. In 2014 a review on the effects of MMWs on bacteria was published. The authors summarised their findings as follows: "(…) *bacteria and other cells might communicate with each other by electromagnetic field of sub-extremely high frequency range. These MMW affected Escherichia coli and many other bacteria, mainly depressing their growth and changing properties and activity. These effects were non-thermal and depended on different factors. The consequences of MMW interaction with bacteria are the changes in their sensitivity to different biologically active chemicals, including antibiotics. These effects are of significance for understanding changed metabolic pathways and distinguish the role of bacteria in the environment; they might be leading to antibiotic resistance in bacteria.These effects are of significance for understanding changed metabolic pathways and distinguish the role of bacteria in the environment; they might be leading to antibiotic resistance in bacteria"* (Adebayo et al., 2014).

"Changing the sensitivity of bacteria to antibiotics by MMW irradiation can be important for the understanding of antibiotic resistance in the environment. In this respect, it is interesting that bacteria [that] survived near telecommunication-based stations like Bacillus and Clostridium spp. have been found to be multidrug resistant" (Soghomonyan et al., 2016).

In a recently published paper,it was) found that: *"Taken together, MW-irradiated water [pulsed 3.5GHz high power] microwaves irradiation can alter cellular physiology noticeably, whereas irradiated media and buffered saline solutions induce negligible or irrelevant changes that do not affect cellular health"* (Bhartiya et al., 2021).

Yet we know that athermal bio-responses exist. Indeed, some frequencies are already being used for therapeutic purposes in a number of branches of medicine. These include nerve regeneration, wound healing, graft behaviour, diabetes, and myocardial and cerebral ischaemia (heart attack and stroke), among other conditions. Some studies even suggest possible benefits in controlling malignancy. Low-intensity, intermediate-frequency, alternating electric fields (tumour-treating fields) that target dividing cells in glioblastoma multiforme (brain malignant tumour) while generally not harming normal cells, are used for therapy purposes (Guo et al., 2011; Zimmerman et al., 2013; Alphandéry, 2018).

Since any drug, may also entail some adverse effects, non-thermal adverse effects of RF-EMF should also be considered for risk assessment. In sum, the peer-reviewed research shows that short-term exposure MMW radiation not only affects human cells, it may also result in changes in sensitivity of bacteria harmful to humans, and to various biologically active chemicals, including antibiotics.

Since little research has been conducted on the health consequences from long-term exposure to MMWs, widespread deployment of 5G infrastructure constitutes a massive experiment that may have adverse impacts on public health. Unfortunately, few studies have examined prolonged (long-term) exposure to low-intensity MMWs, and no research that we are aware of has focused on exposure to MMWs combined with other RF radiation.

1.5 Social conflict related to 5G

Another aspect of the 5G discussion is social polarisation. Currently, both activists for the 'Stop 5G' movements and 5G promoters claim there are thousands of studies on the health effects of RF used in wireless communication and their related EMF. Activists claim that studies show a lot of different harmful health effects, 5G promoters claim that studies do not show any adverse health effects. Both sides refer to the EMF Portal, a specialized database in Germany: "*The internet information platform EMF-Portal of the RWTH Aachen University summarizes systematically scientific research data on the effects of electromagnetic fields (EMF). All information is made available in both English and German. The core of the EMF-Portal is an extensive scoping database with an inventory of 32,119 publications and 6,805 summaries of individual scientific studies on the effects of EMF*" (EMF Portal homepage). The number of 32.119 publications (October 20, 2020) includes the studies of all types of biological and technical end points on all EMF originating from RF. However, the collection of 5G MMW frequencies-related studies is scanty (around 100) and, for the most part, regards technical/dosimetric studies. As a consequence, both claims, presence or lack of harms, about 5G MMW safety are based on assumption, not on scientific evidence.

The issue of social conflict is well developed by Leszczynski (2020). It is evident that the scenario in which 5G should be exploited is full of uncertainty on one side, denial on the other, and exaggerated alarmism in yet another.

2. Aims of the study and methodology

This review aims to evaluate the current state of knowledge on non-thermal effects regarding both the carcinogenic and the reproductive/developmental hazards of RF-EMF exploited by 5G as they emerge from in vivo experimental studies and epidemiological studies, considering separately the frequencies 700-3600 MHz and 26,000 MHz.

2.1 Rationale

This review of the currently available scientific evidence focuses on both the carcinogenic and the reproductive/developmental effects of RF from mobile phone telecommunications systems using 2-5G networks, based on both in vivo animal studies and human epidemiological studies.

The studies evaluated have been divided into 2 groups:

1) Studies evaluating health effects due to RF at the lower frequency range (FR) (FR1: 450 to 6000 MHz), which also includes the frequencies used in existing 2-4 generations of the broadband cellular network. The current evidence from 1G-4G studies is the best evidence currently available. The studies were evaluated using narrative methods.

2) Studies evaluating health effects due to RF at the higher frequency range (FR2: 24 to 100 GHz - MMW). The higher frequencies are new, previously not used for mobile communication and specific for the new 5G technology, which have particular physical characteristics and interactions with biological matter (lower penetration, higher energy, etc.): they were considered separately with a scoping review method.

Scoping reviews have great utility for evaluating research evidence and are often used to categorize or group existing scientific evidence in a given field in terms of its nature, quality, other features, and volume. This scoping review was performed assuming the principles of transparency, reproducibility and rigour. This was achieved by adopting the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) as the methodological framework of this work. At least two reviewers worked independently on every stage of this review: uniformity and standardisation in decision making was obtained through discussion and consensus-reaching among the reviewers. A distinction is made between the narrative review (FR1) and the scoping review (FR2), but the selection and assessment criteria indicated for scoping reviews were adopted for both searches and for including/excluding studies on the cancer and reproductive/developmental biological end-points.

2.1.1 Cancer

Epidemiological studies are potentially susceptible to several different sources of error. Study quality was assessed as part of the review process and all informative studies were considered. The informativeness of a study is its ability to show a true association, if there is one, between the agent and cancer, and the lack of an association, if no association exists. Key determinants of informativeness include: having a study population of sufficient size to obtain precise estimates of effect; sufficient time elapsing from exposure to measurement of outcome for the effect, if present, to be observable; presence of an adequate exposure contrast (intensity, frequency, and/or duration); biologically relevant definitions of exposure; and relevant and well-defined time windows for exposure and outcome (IARC Preamble, 2019).

As explained in the IARC Preamble, most human carcinogens that have been studied adequately for carcinogenicity in experimental animals have produced positive results in one or more animal species. For some agents, carcinogenicity in experimental animals was demonstrated before epidemiological studies identified their carcinogenicity in humans. Although such observation cannot establish that all agents that cause cancer in experimental animals also cause cancer in humans, it is biologically plausible that agents for which there is sufficient evidence of carcinogenicity in experimental animals should present a carcinogenic hazard to humans (IARC Preamble, 2019).

All available long-term studies of cancer in experimental animals on RF-EMF were considered in the review, after a thorough evaluation of the study features. Those studies that we judged to be irrelevant to the evaluation or judged to be inadequate (e.g. too short a duration, too few animals, poor survival; exposure assessment, etc) were omitted. Guidelines for conducting long-term carcinogenicity experiments have been published (e.g. OECD, 2018a) and their criteria were considered as a reference for assessing the adequacy of studies.

As concerns cancer-related studies on RF, both epidemiological and experimental, comprehensive reviews of the literature had already been performed in the last decades; in particular, we refer to the IARC Monograph 102, which dealt with the RF range 30 kHz-300 Ghz. In May 2011, 30 scientists from 14 countries met at IARC in Lyon, France, to assess the carcinogenicity of RF-EMF. These assessments were published as Volume 102 of the IARC Monographs. A summary of the conclusions of the Working Group and the rationale for the evaluation together with the studies supporting the conclusions was published in May 2011 (Baan et al., 2011), the full Monograph was published in April 2013 (IARC, 2013).

Preparation of the IARC Monograph on RF was scheduled so as to include the results of the large international case-control study INTERPHONE on mobile phone use (performed in 2003-2004; published in 2010). We thus decided to adopt the IARC publication Monograph 102 (IARC, 2013) as a 'key reference' upon which to update the 2011 data to the year 2020 and hence produce the present report. After collecting and examining the original works related to the IARC 2011 analyis, published in 2013, and cited throughout as (IARC, 2013) considering their assessment criteria so as to conform to them in later assessments, we collected all relevant works dating from 2011 on, following the same criteria.

Once we had selected and examined the literature available according to the criteria described below, consistent with a scoping review, we updated the IARC (2013) tables to 2020. The studies selected, in abstract form, are included in the text, and tables in the "Assessment of individual studies" chapter, divided by end-point studied and by study characteristics. Each study is numbered in the same sequence in both abstract and corresponding table. In the summary tables, the studies are classified without specific comments, but only as adequate/inadequate for sample size, study design, exposure assessment and, when adequate, positive/negative/equivocal results:

- *Adequate*: no major qualitative or quantitative limitations.
- *Inadequate*: major qualitative or quantitative limitations affect the study, not valid for showing either the presence or absence of specific adverse effects.

When adequate:

- *Positive*: statistically significant increase of the specific pathology in association with RF-EMF exposure.
- *Equivocal:* adverse effect is demostrated showing a marginal increase (not statistically significant increase) of the specific pathology that may be associated with RF-EMF.
- *Negative*: no RF-EMF-related increases in specific pathologies.

2.1.2 Reproduction/development

Since no adequate, major review of studies on the reproduction/development effects exists to this date, such a review of all studies published between 1945 and 2020 was performed. Once we had selected and examined the literature according to the criteria described below, we summarized data up to 2020 in specific tables.

Regarding animal studies, in order to select informative studies only, another selection of studies was based on the guidelines NTP Modified One Generation Study and OECD 443, assessed in 2014 (Foster et al., 2014), planned in order to study experimental animals (rodents) for evidence of developmental pathology, endocrine disrupters, female reproduction, male reproduction, the reproductive system. The guideline study design envisages at least 10 animals/sex/group in order to produce statistically robust results.

The abstracts of the selected studies are included in the text and tables in the 'Assessment of individual studies' chapter, divided according to end-point studied and the study characteristics. Each study is numbered and presented in the same sequence of the corresponding table. In the summarising tables, the studies are classified without specific comments, but only as adequate/ inadequate for sample size, study design, exposure assessment and, when adequate, positive/negative/equivocal results:

- *Adequate*: no major qualitative or quantitative limitations.
- *Inadequate*: major qualitative or quantitative limitations affect the study, not valid for showing either the presence or absence of specific adverse effects.

When adequate:

- *Positive*: statistically significant increase of the specific pathology in association with RF-EMF exposure.
- *Equivocal:* adverse effect is demostrated showing a marginal increase (not statistically significant increase) of the specific pathology that may be associated with RF-EMF.
- *Negative*: no RF-EMF-related increases in specific pathologies.

2.2 Search strategy

First a selection of the most appropriate keywords was performed:

Exposure: EMF; RF; 5G; radiofrequency radiation; radiofrequency; electromagnetic field; electromagnetic radiation.

Population (animal): in vivo; experimental; animal; rodent(s); rat(s); mouse; mice.

Population (human): epidemiological; observational; cross-sectional; case-control; worker(s); military; population.

Outcome (carcinogenic effects): cancer; tumour.

Outcome (reproductive effects): reproductive; development; fertility; sperm; ovary; pregnancy; ano-genital; estrus.

Based on the keywords, the following search strings were prepared to collect any studies of interest from PubMed, a major database that comprises more than 30 million citations for biomedical literature from MEDLINE, life science journals, and online books. Citations may include links to full-text content from PubMed Central and publisher web sites.

Studies on Humans, Carcinogenic effects

((epidemiologic* OR observation* OR "cross sectional" OR "case control" OR worker OR military OR population OR child OR employ*) AND (EMF OR RF OR 5G OR "radiofrequency radiation" OR radiofrequency OR "electromagnetic field" OR "electromagnetic radiation") AND (cancer OR tumour)) NOT (therapy OR ablation).

In vivo studies (rodents), Carcinogenic effects

(("in vivo" OR experimental OR animal OR rodent* OR rat OR mouse OR mice OR hamster* OR rabbit*) AND (EMF OR RF OR 5G OR "radiofrequency radiation" OR radiofrequency OR "electromagnetic field" OR "electromagnetic radiation") AND (cancer OR tumour)) NOT (therapy OR ablation)

Studies on Humans, Reproductive- developmental effects

((epidemiologic* OR observation* OR "cross sectional" OR "case control" OR worker OR military OR population OR child OR employ*) AND (EMF OR RF OR 5G OR "radiofrequency radiation" OR radiofrequency OR "electromagnetic field" OR "electromagnetic radiation") AND (reproductive OR development OR fertility OR sperm OR ovary OR pregnancy OR "ano genital" OR estrus)) NOT (therapy OR ablation)

In vivo (rodents) and Reproductive- developmental effects

(("in vivo" OR experimental OR animal OR rodent* OR rat OR mouse OR mice OR hamster* OR rabbit*) AND (EMF OR RF OR 5G OR "radiofrequency radiation" OR radiofrequency OR "electromagnetic field" OR "electromagnetic radiation") AND (reproductive OR development OR fertility OR sperm OR ovary OR pregnancy OR "ano genital" OR estrus)) NOT (therapy OR ablation).

We systematically searched the electronic academic database PubMed and the EMF Portal for potentially eligible records. The PubMed search occurred on 24 February 2020 for epidemiological and experimental carcinogenicity studies, and on the 20 July 2020 for epidemiological and experimental studies on reproductive outcomes - all searches being updated on the EMF Portal in January 2021. The first 100 results obtained from Google and Google Scholar were evaluated to check for any relevant, non-duplicate results. We also checked the bibliographies of the studies selected for the same purpose. Finally, we asked experts in the field to revise our lists and suggest any additional relevant studies.

2.3 Selection of the relevant literature

The "Population, Exposure, Comparator and Outcome" criteria (PECO Statement, Morgan et al. 2018) was adopted to clearly define the scope of this work and consequently the criteria for the selection of literature according to:

Population: RF-exposed population from in vivo studies, in particular experimental bioassays on rodents, as they represent the most predictive models for human health, and workers and the general population included in epidemiological studies;

Exposure: exposure to RF used in 5G networks, in particular the frequencies that were established as standard for use by the European Union: 450 MHz to6 GHz, and 24 to 100 GHz.

Comparator: untreated population (controls) from experimental bioassays on rodents, and, where this was available, groups of healthy or not exposed controls from epidemiological studies;

Type of outcome: health effects of particular concern that have been associated with the exposure to RF, namely reproductive effects, and carcinogenicity effects (Vornoli et al., 2019).

We considered all types of study design for the review; non-original studies, letters, and comments were not considered. Peer-reviewed articles in English, published from 1945 to January 2021 were considered. English is the most widely used language for scientific publications, and papers in other languages usually have an abstract available in English.

2.4 Screening process

The screening process was performed using the online systematic review app Rayyan QCRI. Selection of the literature was performed by two reviewers independently examining all references in two steps: in the first, the decision on exclusion/inclusion was based on title and abstract; in the second, the full texts of the potentially relevant articles were examined thoroughly to verify conformity with the aforementioned PECO criteria. At the second stage of selection, all inclusion/exclusion decisions and all doubts were discussed, solved and agreed upon by the two reviewers. Results of the selection process are illustrated in the following sections using PRISMA flow diagrams (Moher et al., 2009).

2.5 Extraction of information from the relevant literature

It was decided to use two different data-charting forms to extract information from the selected literature, since epidemiological and experimental studies have very different characteristics and peculiarities that need to be accounted for. The tools were chosen to achieve a complete and standardized collection of all information relevant to evaluating the conduct of the study, the exposure assessment and the health effects. The data chart for epidemiological studies was based on the one used for the series of reviews performed to elaborate, perfect and test the *WHO/ILO joint methodology for estimating the work-related burden of disease and injury* (Mandrioli et al, 2018; Sgargi et al., 2020). The data chart for experimental studies was based on the format used in IARC Monographs to evaluate carcinogenicity.

Both forms are validated tools, proven providers of exhaustive data on relevant literature. Calibration and uniformity was obtained through several rounds of independent blind trial extraction, discussion, and reaching of consensus among reviewers.

For epidemiological studies, a wide set of information was extracted, namely:
Ref ID; Type of study; Mode of data collection; Country; Year; N; Sex; Age; Occupation; Source of exposure; Duration of exposure; Frequency of exposure; Intensity of exposure; Any other co-exposure/adjustments; Method for exposure assessment; Observed health effects; Measure of observed health effects; Results; Conclusions; Authors; Affiliations; Conflict of interest; Funding.

For experimental studies, the extracted items from the literature were the following:
Reference ID; Type of study; Strain, Species (Sex); Exposure duration; Frequency; Intensity; Any other co-exposure; Exposure time - No of animals; Increased tumour incidence

The information was extracted by reviewers independently, and then double-checked by all reviewers and a senior expert.

2.6 Evidence synthesis

In finally assessing the results of the review for both epidemiological and experimental study, and for cancer and reproductive/developmental outcomes, we took into account the parameters indicated in (IARC Preamble, 2019), tailored to the needs of the present report, and valid for both end points (i.e. cancer and reproductive/developmental effects):

Sufficient evidence: A causal association between exposure to RF-EMF and the specific adverse effect has been established. That is, a positive association has been observed in the body of evidence on exposure to the agent and the specific adverse effect in studies in which chance, bias, and confounding factors were ruled out with reasonable confidence.

Limited evidence: A causal interpretation of the positive association observed in the body of evidence on exposure to RF-EMF and the specific adverse effect is credible, but chance, bias, or confounding factors cannot be ruled out with reasonable confidence.

No evidence: There are no data available or evidence suggesting lack of adverse effects (to be specified).

2.7 Overall evaluation of the present review

The results of the review for both cancer and reproductive/developmental outcomes, were finally assessed according to the criteria indicated in (IARC Preamble, 2019), tailored to the needs of the present report. Figure 8 presents the streams of evidence used for reaching the overall classification by IARC. The reasoning that the IARC used to reach its evaluation is summarised, so the basis for the evaluation offered is transparent. The IARC Monograph Preamble integrates the major findings from studies of cancer in humans, cancer in experimental animals, and mechanistic evidence (IARC Preamble, 2019).

The IARC criteria regard cancer, but equally apply to assessment of effects on reproductive /developmental parameters. Mechanistic evidence was not considered in the present review, so we integrated the results for cancer and reproductive/developmental effects in humans solely with the results for cancer and reproductive/developmental effects in experimental animals, using the criteria indicated in Figure 9.

Figure 7 – IARC criteria for overall classifications (the evidence in bold italic represents the basis of the overall evaluation) (Source: IARC Preamble, 2019)

Stream of evidence			Classification based on strength of evidence
Evidence of cancer in humans[a]	**Evidence of cancer in experimental animals**	**Mechanistic evidence**	
Sufficient	Not necessary	Not necessary	Carcinogenic to humans (Group 1)
Limited or Inadequate	Sufficient	Strong (b) (1) (exposed humans)	
Limited	Sufficient	Strong (b) (2-3), Limited or Inadequate	Probably carcinogenic to humans (Group 2A)
Inadequate	Sufficient	Strong (b) (2) (human cells or tissues)	
Limited	Less than Sufficient	Strong (b) (1-3)	
Limited or Inadequate	Not necessary	Strong (a) (mechanistic class)	
Limited	Less than Sufficient	Limited or Inadequate	Possibly carcinogenic to humans (Group 2B)
Inadequate	Sufficient	Strong (b) (3), Limited or Inadequate	
Inadequate	Less than Sufficient	Strong (b) (1-3)	
Limited	Sufficient	Strong (c) (does not operate in humans)[b]	
Inadequate	Sufficient	Strong (c) (does not operate in humans)[b]	Not classifiable as to its carcinogenicity to humans (Group 3)
All other situations not listed above			

[a] Human cancer(s) with highest evaluation.
[b] The *strong evidence that the mechanism of carcinogenicity in experimental animals does not operate in humans* must specifically be for the tumour sites supporting the classification of *sufficient evidence in experimental animals*.

Figure 8 – Criteria for overall evaluation in the present review (FR1 and FR2)

Evidence in humans	Evidence in experimentalanimals	Evaluation based on strengh of evidence
Sufficient	Not necessary	Clear association between exposure and the adverse effect
Limited	Sufficient	Probable association between exposure and the adverse effect
Limited	Less than sufficient	Possible association between exposure and the adverse effect
Inadequate	Inadequate or limited	Not classificable

3. Limitations of the present review

3.1 Assessment of individual studies

Experimental studies adopt a standardised methodology, following specific guidelines, making it much easier to assess the individual outcomes and evaluate the quality of the study and of the results. Blinded assessment of outcomes, adequacy of the sample size, and appropriateness of statistical analysis were also evaluated and reported for each study, when available. We selected and analysed animal studies considering their compliance with the pertinent guidelines.

As regards epidemiological studies, errors of recall are a systematic danger with epidemiology affecting retrospective studies when participants are interviewed or compile questionnaires about exposure that occurred in the past. Usually the problem is that people's memories may be inaccurate or incomplete; this becomes a serious problem in case-control studies, where cases, whose health was affected, are likely to be more conscious and clear about past exposure, whereas controls are often less aware and remember less precisely. This may increase or diminish the cause-effect relation observed.

3.2 Exposure assessment

Exposure assessment is a critical issue in epidemiological studies of RF from mobile communication, as it can be very demanding and, when not up to the highest standards, can render the findings uninformative. We excluded studies which do not contribute any useful information due to shortcomings in their conduct and analysis.

Recall bias, as mentioned in the previous section, may be a major issue in all case-control studies with self-reported exposures. Furthermore, substantial misclassification is often a concern in studies where exposure assessment is based on job titles alone or mobile phone subscriptions alone; in such cases, this was merely an estimate of the exposure. For a meaningful interpretation, we tried to evaluate all original reports objectively, comprehensively and consistently, following a standardised method, but without presuming that our review could compete with any systematic review by a specific working group.

For experimental studies, the comparability of the procedures for dealing with the exposed and control groups, including sham exposure, quality of the exposure system and dosimetry, possibility of thermal effects due to tissue heating, were considered for achieving a correct analysis.

As described in the report, the frequencies are (amongst other things) related to depth of penetration into tissues, but other dimensions of exposure may also affect health outcomes. Given certain new features of 5G (MIMO, beamforming) and the related and acknowledged uncertainties regarding exposure and exposure assessment, it is questionable wether the studies on 1G-4G can be directly generalized to 5G (even when using the same frequencies, here FR1). These uncertainties in exposure characterisation will impact on exposure assessment for new studies (particularly for epidemiological studies on 5G, here FR2), and, in terms of risk assessment, some metrics of exposure to RF-EMF and associated adverse health outcomes (suggested or established) could be different. These considerations should not detract from the fact that the current evidence from 1G-4G studies is the best evidence available.

Experimental investigations also include studies that used a mobile phone in GSM mode with an active call at small distances from the animal's body. Active call mode is usually maintained throughout the experiment; the control group (sham exposed group) is treated with the mobile phone switched off. The exposure depends on the quality of the connection with the base station and exposure is measured throughout the study; we considered this kind of study adequate in terms of exposure assessment as they simulate the human counterpart situation.

3.3 Limits for a systematic review on 5G frequencies

STOA asked the author to collect the information available on the impact of 5G frequencies on health. The original aim was to follow the criteria of a systematic review, but we soon realized there are no adequate studies on millimetric waves for the relevant end points. We thus agreed to perform a narrative review of the lowest frequencies (FR1) already assessed by authoritative working groups at least for carcinogenic effects down to 2011, and a scoping review on millimetric waves (FR2) which, as expected, produced no adequate results. However, the review methodology (the scoping review) was kept same for both FR1 and FR2 outcomes.

3.4 Overall evaluation

A scoping review (SR) requires strong subject matter expertise in several disciplines. The assessment of individual studies represented a great challenge for the scientists involved in the review. A systematic assessment would require a full and in-depth review of the underlying studies. This is beyond the scope of this document, which is prepared for, and addressed to, the Members and staff of the European Parliament as background material to assist them in their parliamentary work.

The evaluation criteria adopted by the IARC as described in its Preamble (IARC Preamble, 2019) were tailored to and used for both cancer and reproductive /developmental effects. We used these consolidated criteria in order to work in complete transparency and allow reviewers to check our work.

This report was written by Dr Fiorella Belpoggi, an expert on RF-EMF, experimental carcinogenesis and experimental studies on reproductive and developmental health outcomes. The author was supported by experts with expertise in systematic/scoping review methodology (DM), biostatistics (DS), cancer research (AV), exposure assessment (FaB) and human reproduction and development (CF, AG). Together, the team fields strong expertise in most domains required for this review, perhaps with some room for improvement in cancer epidemiology.

4. Assessment of individual studies

4.1 Carcinogenicity by frequency range

4.1.1 Cancer in epidemiological studies: Studies evaluating health effects due to RF at a lower frequency range (FR1: 450 to 6000 MHz), which also includes the frequencies used in previous generations' broadband cellular networks (1G-4G)

The articles identified through database searching and other sources were 950. After removal of duplicates (20) and excluding non-pertinent articles (685) based on title and abstracts, 245 articles remained. Based on full-text screening, 90 papers were further excluded, so that the articles with appropriate frequencies to be included in this qualitative synthesis were 155.

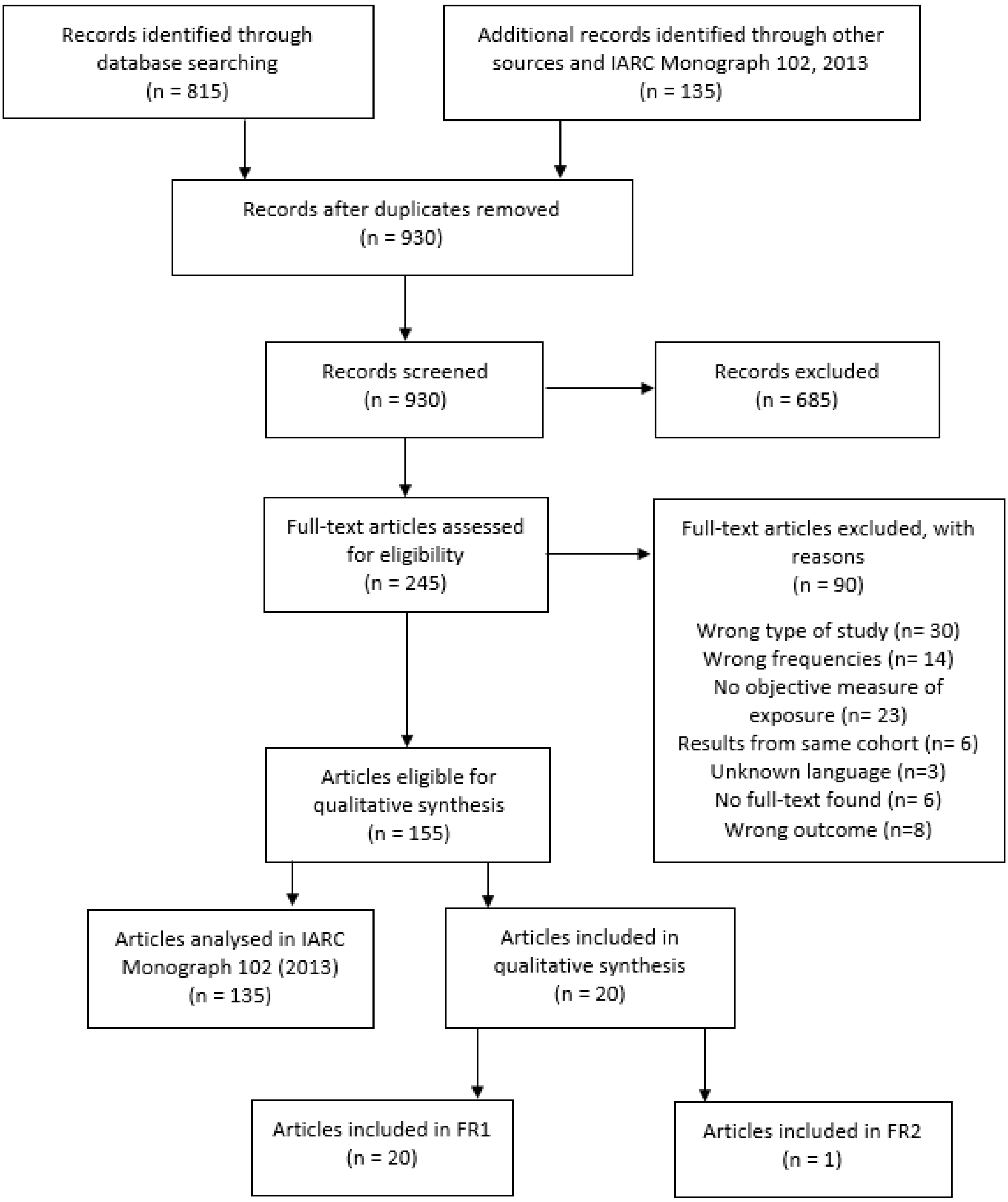
As further explained in the methodology section, we considered IARC (2013) as our key reference for all studies published until 2011: all original papers (135) that were included in the IARC monograph were analysed and referenced in this report as well; of course, for this report we considered only the final IARC classification. The remaining 20 articles published after 2011 were included in this scoping review.

At this stage, a separation based on frequency range was also performed: of the 20 papers included, all 20 reported exposures belonging to the band considered in FR1, and one also reported exposures regarding FR2, in particular MMW from occupational exposure to radar.

For each article, the abstract is presented, together with a table summarising the most important information; furthermore, a senior expert evaluated their adequacy for assessing carcinogenic effects (adequate/inadequate), and expressed an overall synthesis of the results (positive/negative/equivocal) following criteria described in the Methodology section.

The flow chart regarding the selection of papers on cancer epidemiological studies for FR1 is presented in Fig. 9.

Figure 9 – Flow diagram. Epidemiological studies on cancer (FR1)



KEY REFERENCE: IARC 2013

The IARC Monograph 102 (IARC, 2013) is the key reference for the present evaluation. In May 2011, after 1 year of preparing and reviewing drafts, 30 scientists from 14 countries met at the International Agency for Research on Cancer (IARC) in Lyon, France, to assess the carcinogenicity of radiofrequency electromagnetic fields (RF-EMF). This assessment was published as Volume 102 of the IARC Monographs (IARC, 2013). Epidemiological evidence for an association between RF-EMF and cancer comes from cohort, case-control, and time-trend studies. The populations in these studies were exposed to RF-EMF in occupational settings, from sources in the general environment, and from use of wireless (mobile and cordless) telephones, which is the most extensively studied exposure source.

One cohort study (Schüz et al., 2006) and five case-control studies (Muscat et al., 2000; Inskip et al., 2001; Auvinen et al., 2002; INTERPHONE Study Group, 2010; Hardell et al., 2011) were judged by the Working Group to offer potentially useful information regarding associations between use of wireless phones and glioma.

Although both the INTERPHONE study and the Swedish pooled analysis are susceptible to bias—due to recall error and selection for participation— the Working Group concluded that the findings could not be dismissed as reflecting bias alone, and that a causal interpretation between mobile phone RF-EMF exposure and glioma is possible. A similar conclusion was drawn for acoustic neuroma, although the case numbers were substantially smaller than for glioma. Additionally, a study from Japan (Sato et al., 2011) found some evidence of an increased risk of acoustic neuroma associated with ipsilateral mobile phone use.

For meningioma, parotid-gland tumours, leukaemia, lymphoma, and other tumour types, the Working Group found the available evidence insufficient to reach a conclusion on the potential association with mobile phone use. Epidemiological studies of individuals with potential occupational exposure to RF-EMF have investigated brain tumours, leukaemia, lymphoma, and other types of malignancy including uveal melanoma, and cancers of the testis, breast, lung, and skin. The Working Group noted that the studies had methodological limitations and the results were inconsistent. In reviewing studies that addressed the possible association between environmental exposure to RF-EMF and cancer, the Working Group found the available evidence insufficient for any conclusion.The Working Group concluded that there is "*limited evidence in humans*" for the carcinogenicity of RFEMF, based on positive associations between glioma and acoustic neuroma and exposure to RF-EMF from wireless phones.

At that time, a few members of the Working Group considered the current evidence in humans "inadequate". In their opinion there was inconsistency between the two case-control studies and a lack of an exposure-response relationship in the INTERPHONE study results; no increase in rates of glioma or acoustic neuroma was seen in the Danish cohort study (Shuz et al., 2006) and up to that time, reported time trends in incidence rates of glioma had not shown a parallel with time trends in mobile phone use (Baan et al., 2011).

REVIEW OF EPIDEMIOLOGICAL STUDIES 2011-2020

Starting from 2011, the present review evaluates by type of study and by year of publication (2011-2020) the epidemiological studies also summarized in Tables 1-4. The author adds to short abstracts her own brief comments on the results of the different studies.

CASE-CONTROL STUDIES (Tables 1, a-m)

1. Aydin et al., 2011.

Denmark, Sweden, Norway, and Switzerland. 2004-2008.CEFALO multicenter case-control study.

Mobile phone use association with brain tumour risk among children and adolescents is studied. CEFALO is a multicenter case-control study conducted in Denmark, Sweden, Norway, and Switzerland that includes all children and adolescents aged 7-19 years who were diagnosed with a brain tumour between 2004 and 2008. Interviews, in person, with 352 case patients (participation rate: 83%) and 646 control subjects (participation rate: 71%) and their parents. Control subjects were randomly selected from population registries and matched by age, sex, and geographical region. We asked about mobile phone use and included mobile phone operator records when available. Odds ratios (ORs) for brain tumour risk and 95% confidence intervals (CIs) were calculated using conditional logistic regression models. Regular users of mobile phones were not statistically significantly more likely to have been diagnosed with brain tumours compared with nonusers (OR = 1.36; 95% CI = 0.92 to 2.02). Children who started to use mobile phones at least 5 years ago were not at increased risk compared with those who had never regularly used mobile phones (OR = 1.26, 95% CI = 0.70 to 2.28). In a subset of study participants for whom operator recorded data were available, brain tumour risk was related to the time elapsed since the mobile phone subscription was started but not to amount of use. No increased risk of brain tumours was observed for brain areas receiving the highest amount of exposure. The absence of an exposure-response relationship either in terms of the amount of mobile phone use or by localisation of the brain tumour argues against a causal association.

Comment: Extent of exposure not assessed. The study was not statistically powered to detect small risk increases. Several RR increased in highest exposure category, albeit not statistically significant.

2. Atzmon et al., 2012.

Israel, diagnosis between 1989 and 2007. Population-based case control study.

The study was initiated to examine the claims of the residents of the Druze Isifya Village in Northern Israel that their high cancer rates were associated with past exposures to radiation from radio and cellular transmitters.To investigate the association between past exposure to RF/MW transmitters and cancer risks, familial cancer history and occupational exposures and indicators of life-style were taken into account; a population-based case-control study involved 307 residents, of whom 47 were diagnosed between 1989 and 2007 with different types of cancer and 260 controls. Cancer diagnoses were obtained from medical records. Exposure status of individual houses was determined from a map, based on the distances between each house and RF/MW antennas, and calculated using geographic information systems (GIS). Data on additional risk factors for cancer, like smoking and occupation, were obtained from individual questionnaires. The analysis was adjusted for measures of life style and occupational exposure, and Binary multiple logistic regressions was used, for all cancer sites and for individual cancer types for those cancers with at least 5 documented cases. Past occupational exposures to chemicals (e.g., pesticides) and electronics, were found to be strongly associated with increased cancer risks (all sites: OR=2.79; CI=1.14-6.82; $P<0.05$), but no discernible trend in overall cancer risk was associated with proximity to sources of past RF/MW radiation exposure (n=47 OR=1.00; CI=0.99-1.02; $P>0.4$). Colorectal cancer showed a negligible elevated adjusted risk associated with radiation intensity (n=11 OR=1.03; CI=1.01-1.05; $P<0.01$). There was evidence for an increased risk of cancers which were associated with chemicals in manufacturing and agriculture and electronics, where there may have been exposure to EMF, but the study did not confirm the suspicion of increased cancer risks associated with radiation for most cancer types in this village. Misclassification of past exposures could explain the negative finding.

Comment: No appropriate measurement of RF radiation was provided. Results inconclusive.

3. Li et al., 2012.

Taiwan, 1998-2007. Population-based case–control study (childhood neoplasms).

This population-based case-control study in Taiwan considered incident cases aged 15 years or less and admitted from 2003 to 2007 for all neoplasms (ICD-9-CM: 140-239) (n=2606), including 939 leukemia and 394 brain neoplasm cases. Controls were randomly selected, with a case/control ratio of 1:30 and matched by year of birth, from all non-neoplasm children insured in the same year when the index case was admitted. Annual summarized power (ASP, watt-year) was calculated for each of the 71,185 mobile phone base stations (MPBS) in service between 1998 and 2007. Then, the annual power density (APD, watt-year/km(2)) of each township (n=367) was computed as a ratio of the total ASP of all MPBS in a township to the area of that particular township. Exposure of each study subject to radio frequency (RF) was indicated by the averaged APD within 5 years prior to the neoplasm diagnosis (cases) or July 1st of the year when the index case was admitted (controls) in the township where the subject lived. An unconditional logistic regression model with a generalized estimation equation was employed to calculate the covariate-adjusted odds ratio [AOR] of childhood neoplasm in relation to RF exposure. A higher than median averaged APD (approximately 168 WYs/km(2)) was significantly associated with an increased AOR for all neoplasms (1.13; 1.01 to 1.28), but not for leukaemia (1.23; 0.99 to 1.52) or brain neoplasm (1.14, 0.83 to 1.55). This study noted a significantly increased risk of all neoplasms in children with higher-than-median RF exposure to MPBS. The slightly elevated risk was seen for leukaemia and brain neoplasm, but was not statistically significant. These results may occur due to several methodological limitations.

Comment: The authors admit several methodological limitation. Inconclusive study.

4. Soderqvist et al., 2012.

Sweden, 2000-2003. Case–control study.

The objective of this case-control study was to assess whether the use of wireless phones is associated with an increased risk of tumour at this site. Sixty-nine patients with salivary gland tumours (63 with a parotid gland tumour) and 262 randomly recruited controls were included. Unconditional logistic regression - adjusted for age at diagnosis, sex, year of diagnosis and socioeconomic index - was used to produce odds ratios and 95% confidence intervals. The use of wireless phones was not associated with an overall increased risk of salivary gland tumours, odds ratio 0.8, 95% confidence interval 0.4-1.5. Neither was there an increased risk for the different phone types when calculated separately nor was there an increased risk for different latencies or when cumulative use was divided into three groups (1-1000, 1001-2000 and >2000 h). The overall results were similar for the risk of parotid gland tumours. In conclusion, our data add to the evidence against there being an increased risk for parotid gland tumours associated with light-to-moderate use of wireless phones and for less than 10 years of use but offers little information on risk related to more prolonged and/or heavy use.

Comment: Self-reported exposure from postal questionnaire. Any association for parotid gland tumours and light-to-moderate use of mobile phone.

5. Carlberg et al., 2013.

Sweden, 2007-2009. Case-control study.

The association between use of wireless phones and meningioma is studied. A case–control study on brain tumour cases of both genders aged 18–75 years and diagnosed during 2007–2009 is performed. One population-based control matched on gender and age was used to each case. Here we report on meningioma cases including all available controls. Exposures were assessed by a questionnaire. Unconditional logistic regression analysis was performed. In total 709 meningioma cases and 1,368 control subjects answered the questionnaire. Mobile phone use in total produced odds ratio (OR) = 1.0, 95% confidence interval (CI) = 0.7-1.4 and cordless phone use gave OR = 1.1, 95% CI = 0.8-1.5. The risk increased statistically significant per 100 h of cumulative use and highest OR was found in the fourth quartile (>2,376 hours) of cumulative use for all studied phone types. There was no statistically significant increased risk for ipsilateral mobile or cordless phone use, for meningioma in the temporal lobe or per year of latency. Tumour volume was not related to latency or cumulative use in hours of wireless phones. No conclusive evidence of an association between use of mobile and cordless phones and meningioma was found. An indication of increased risk was seen in the group with highest cumulative use but was not supported by statistically significant increasing risk with latency. Results for even longer latency periods of wireless phone use than in this study are desirable.

Comment*: *Self-reported exposure. No conclusive association for meningioma and use of mobile phone was found.

6. Hardell et al., 2013a.

Sweden, 2007-2009. Case-control study.

Previous studies have shown a consistent association between long-term use of mobile and cordless phones and glioma and acoustic neuroma, but not for meningioma. The aim of this study was to further explore the relationship between especially long-term (>10 years) use of wireless phones and the development of malignant brain tumours. A new case-control study of brain tumour cases of both genders aged 18-75 years and diagnosed during 2007-2009 was conducted. One population-based control matched on gender and age (within 5 years) was used in each case. Malignant cases including all available controls are reported. Exposures on e.g. use of mobile phones and cordless phones were assessed by a self-administered questionnaire. An unconditional logistic regression analysis was performed, adjusting for age, gender, year of diagnosis and socio-economic index using the whole control sample. Of the cases with a malignant brain tumour, 87% (n=593) participated, and 85% (n=1,368) of controls in the whole study answered the questionnaire. The odds ratio (OR) for mobile phone use of the analogue type was 1.8, 95% confidence interval (CI)=1.04-3.3, increasing with >25 years of latency (time since first exposure) to an OR=3.3, 95% CI=1.6-6.9. Digital 2G mobile phone use rendered an OR=1.6, 95% CI=0.996-2.7, increasing with latency >15-20 years to an OR=2.1, 95% CI=1.2-3.6. The results for cordless phone use were OR=1.7, 95% CI=1.1-2.9, and, for latency of 15-20 years, the OR=2.1, 95% CI=1.2-3.8. Few participants had used a cordless phone for >20-25 years. Digital type of wireless phones (2G and 3G mobile phones, cordless phones) gave increased risk with latency >1-5 years, then a lower risk in the following latency groups, but again increasing risk with latency >15-20 years. Ipsilateral use resulted in a higher risk than contralateral mobile and cordless phone use. Higher ORs were calculated for tumours in the temporal and overlapping lobes. Using the meningioma cases in the same study as the reference entity gave somewhat higher ORs indicating that the results were unlikely to be explained by recall or observational bias. These findings provide support for the hypothesis that RF-EMFs play a role in both the initiation and promotion stages of carcinogenesis.

Comment*: *Self-reported exposure. This study confirms previous results of an association between heavy mobile and cordless phone use and malignant brain tumours.

7. Hardell et al., 2013b, Hardell and Carlberg, 2015.

Sweden, 1997-2003 and 2007-2009. Case-control study.

A case-control study of acoustic neuroma was previously conducted by the authors. Subjects of both genders aged 20-80 years, diagnosed during 1997-2003 in parts of Sweden, were included, and the results were published. A further study for the time period 2007-2009 including both men and women aged 18-75 years selected from throughout the country was performed. Similar methods were used for both study periods. In each, one population-based control, matched on gender and age (within five years), was identified from the Swedish Population Registry. Exposures were assessed by a self-administered questionnaire supplemented by a phone interview. Since the number of acoustic neuroma cases in the new study was low, pooled results from both study periods based on 316 participating cases and 3,530 controls were presented. An unconditional logistic regression analysis was performed, adjusting for age, gender, year of diagnosis and socio-economic index (SEI). Use of mobile phones of the analogue type gave odds ratio (OR) = 2.9, 95% confidence interval (CI) = 2.0-4.3, increasing with >20 years latency (time since first exposure) to OR = 7.7, 95% CI = 2.8-21. Digital 2G mobile phone use gave OR = 1.5, 95% CI = 1.1-2.1, increasing with latency >15 years to an OR = 1.8, 95% CI = 0.8-4.2. The results for cordless phone use were OR = 1.5, 95% CI = 1.1-2.1, and, for latency of >20 years, OR = 6.5, 95% CI = 1.7-26. Digital type wireless phones (2G and 3G mobile phones and cordless phones) gave OR = 1.5, 95% CI = 1.1-2.0 increasing to OR = 8.1, 95% CI = 2.0-32 with latency >20 years. For total wireless phone use, the highest risk was calculated for the longest latency time >20 years: OR = 4.4, 95% CI = 2.2-9.0. Several of the calculations in the long latency category were based on low numbers of exposed cases. Ipsilateral use resulted in a higher risk than contralateral for both mobile and cordless phones. OR increased per 100 h cumulative use and per year of latency for mobile phones and cordless phones, though the increase was not statistically significant for cordless phones. The percentage tumour volume increased per year of latency and per 100 h of cumulative use, statistically significant for analogue phones. This study confirmed previous results demonstrating an association between mobile and cordless phone use and acoustic neuroma.

A pooled analysis was performed of two case-control studies on malignant brain tumours with patients diagnosed during 1997–2003 and2007–2009. They were aged 20–80 years and 18–75 years, respectively, at the time of diagnosis. Only cases with histopathological verificationof the tumour were included. Population-based controls, matched on age and gender, were used. Exposures were assessed by questionnaire.The whole reference group was used in the unconditional regression analysis adjusted for gender, age, year of diagnosis, and socio-economicindex. In total, 1498 (89%) cases and 3530 (87%) controls participated. Mobile phone use increased the risk of glioma, OR = 1.3, 95%CI = 1.1–1.6 overall, increasing to OR = 3.0, 95% CI = 1.7–5.2 in the >25 year latency group. Use of cordless phones increased the risk toOR = 1.4, 95% CI = 1.1–1.7, with highest risk in the >15–20 years latency group yielding OR = 1.7, 95% CI = 1.1–2.5. The OR increasedstatistically significant both per 100 h of cumulative use, and per year of latency for mobile and cordless phone use. Highest ORs overall werefound for ipsilateral mobile or cordless phone use, OR = 1.8, 95% CI = 1.4–2.2 and OR = 1.7, 95% CI = 1.3–2.1, respectively. The highest riskwas found for glioma in the temporal lobe. First use of mobile or cordless phone before the age of 20 gave higher OR for glioma than in laterage groups.

Comment*: *Self-reported exposure.These studies confirm previous results demonstrating an association between heavy mobile and cordless phone use, with acoustic neuroma and glioma.

8. Coureau et al., 2014.

France. 2004-2006. CERENAT. Case-control study.

The objective was to analyse the association between mobile phone exposure and primary central nervous system tumours (gliomas and meningiomas) in adults. CERENAT is a multicenter case-control study carried out in four areas in France in 2004-2006. Data about mobile phone use were collected through a detailed questionnaire delivered in a face-to-face manner. Conditional logistic regression for matched sets was used to estimate adjusted ORs and 95% CIs. A total of 253 gliomas, 194 meningiomas and 892 matched controls selected from the local electoral rolls were analysed. No association with brain tumours was observed when comparing regular mobile phone users with non-users (OR=1.24; 95% CI 0.86 to 1.77 for gliomas, OR=0.90; 95% CI 0.61 to 1.34 for meningiomas). However, the positive association was statistically significant in the heaviest users when considering life-long cumulative duration (≥896 h, OR=2.89; 95% CI 1.41 to 5.93 for gliomas; OR=2.57; 95% CI 1.02 to 6.44 for meningiomas) and number of calls for gliomas (≥18,360 calls, OR=2.10, 95% CI 1.03 to 4.31). Risks were higher for gliomas, temporal tumours, occupational and urban mobile phone use. These additional data support previous findings concerning a possible association between heavy mobile phone use and brain tumours.

Comment*: *Self reported exposure with face to face interview by trained personel.This study confirms previous results of a possible association between heavy mobile phone use and malignant brain tumours.

9. Pettersson et al., 2014.

Sweden, 2002-2007. Population-based case-control study.

A population-based, nation-wide, case-control study of acoustic neuroma in Sweden was conducted. Eligible cases were persons aged 20 to 69 years, who were diagnosed between 2002 and 2007. Controls were randomly selected from the population registry, matched on age, sex, and residential area. Postal questionnaires were completed by 451 cases (83%) and 710 controls (65%). Ever having used mobile phones regularly (defined as weekly use for at least 6 months) was associated with an odds ratio (OR) of

1.18 (95% confidence interval = 0.88 to 1.59). The association was weaker for the longest induction time (≥10 years) (1.11 [0.76 to 1.61]) and for regular use on the tumour side (0.98 [0.68 to 1.43]). The OR for the highest quartile of cumulative calling time (≥680 hours) was 1.46 (0.98 to 2.17). Restricting analyses to histologically confirmed cases reduced all ORs; the OR for ≥680 hours was 1.14 (0.63 to 2.07). A similar pattern was seen for cordless land-line phones, although with slightly higher ORs. Analyses of the complete history of laterality of mobile phone revealed considerable bias in laterality analyses. The findings do not support the hypothesis that long-term mobile phone use increases the risk of acoustic neuroma. The study suggests that phone use might increase the likelihood that an acoustic neuroma case is detected and that there could be bias in the laterality analyses performed in previous studies

Comment: Self-reported exposure. Weak evidence of association between heavy mobile phone use and acoustic neuroma.

10. Yoon et al., 2015.

Korea; 2002- 2007; case- control study.

Study methods were based on the International Interphone study that aimed to evaluate possible adverse effects of mobile phone use. This study included 285 histologically-confirmed Korean patients 15 to 69 years of age, with gliomas diagnosed between 2002 and 2007 in 9 hospitals. The 285 individually matched controls were healthy individuals that had their medical check-up in the same hospitals. Unconditional logistic regression was used to calculate the adjusted odds ratios (aORs) and 95% confidence intervals (CIs) for use of mobile phones. For the entire group, no significant relationship was investigated between gliomas and regular use of mobile phones, types of mobile phones, lifetime years of use, monthly service fee, and the other exposure indices. Analyses restricted to self-respondents showed similar results. For ipsilateral users, whose body side for usual mobile phone use matched the location of glioma, the aORs (95% CIs) for lifetime years of use and cumulative hours of use were 1.25 (0.55 to 2.88) and 1.77 (0.32 to 1.84), respectively. However, contralateral users showed a slightly lower risk than ipsilateral users. Results do not support the hypothesis that the use of mobile phones increases the risk of glioma; however, we found a non-significant increase in risk among ipsilateral users. These findings suggest further evaluation for glioma risk among long-term mobile phone users.

Comment: Self reported exposure. Weak evidence of association between mobile phone use and brain tumour is found among ipsilateral users.

11. Al-Qahtani, 2016.

Saudi Arabia; 1996-2013; Retrospective case-control study.

A total of 26 patients diagnosed with parotid gland tumours and 61 healthy controls were enrolled through a hospital-based retrospective case-control study. The patients were referred and admitted to a tertiary hospital from January 1996 to March 2013. The Odds of exposure were 3.47 times higher among patients compared to their controls. 95% CI suggested that the true Odds Ratio (OR) at the population level could be somewhere between 1.3 and 9.23 and so the observed OR was statistically significant at 5% level of significance. Overall, an association between the exposure of cellular phone use for more than 1 hour daily and parotid tumour was observed. This association should be interpreted with caution because of the relatively small sample size.

Comment: Small sample size; poor methodology. Inconclusive study.

12. Satta et al., 2018.

Italy; 1998–2004; Population-based case-control study as part of the European multicenter study EPILYMPH.

A case-control study comprised of 322 patients and 444 individuals serving as controls in Sardinia, Italy in 1998-2004. Questionnaire information included the self-reported distance of the three longest held residential addresses from fixed radio-television transmitters and mobile phone base stations. For each address within a 500-meter radius from a mobile phone base station, RF-EMF intensity using predictions from spatial models was estimated, and RF-EMF measurements performed at the door in the subset of the longest held addresses within a 250-meter radius. Risk of lymphoma and its major subtypes associated with the RF-EMF exposure metrics with unconditional logistic regression, adjusting by age, gender and years of education. Risk associated with residence in proximity (within 50 meters) to fixed radio-television transmitters was likewise elevated for lymphoma overall [odds ratio = 2.7, 95% confidence interval = 1.5-4.6], and for the major lymphoma subtypes. With reference to mobile phone base stations, the authors did not observe an association with either the self-reported, or the geocoded distance from mobile phone base stations. RF-EMF measurements did not vary by case-control status. By comparing the self-reports to the geocoded data, cases tended to underestimate the distance from mobile phone base stations differentially from the controls (P = 0.073). The interpretation of findings is compromised by the limited study size, particularly in the analysis of the individual lymphoma subtypes, and the unavailability of the spatial coordinates of radio-television transmitters. Nonetheless, our results do not support the hypothesis of a link between environmental exposure to RF-EMF from mobile phone base stations and risk of lymphoma subtypes.

***Comment*: Limited study size, exposure assessment unclear (far field, radiobase-stations). The study does not support the hypothesis of a link between environmental exposure to RF-EMF from mobile phone base stations and risk of lymphoma subtypes.**

13. Balekouzou et al., 2017.

Central Africa. Case- control study.

Breast cancer is recognized as a major public health problem in developing countries; however, there is very little evidence of behavioral factors associated with breast cancer risk. This study was conducted to identify lifestyles as risk factors for breast cancer among Central African women. A case-control study was conducted with 174 cases confirmed histologically by the pathology unit of the National Laboratory and 348 age-matched controls. Data collection tools included a questionnaire with interviews and medical records of patients. Data were analyzed using SPSS software version 20. Odd ratio (OR) and 95% confidence intervals (95% CI) were obtained by unconditional logistic regression. In total, 522 women were studied with a mean age of 45.8 (SD = 13.4) years. By unconditional logistic regression model, women with breast cancer were more likely to have attained illiterate and elementary education level [11.23 (95% CI, 4.65±27.14) and 2.40 (95% CI, 1.15±4.99)], married [2.09 (95% CI, 1.18±3.71)], positive family history [2.31 (95% CI, 1.36±3.91)], radiation exposure [8.21 (95% CI, 5.04±13.38)], consumption charcuterie [10.82 (95% CI, 2.39±48.90)], fresh fish consumption [4.26 (95% CI, 1.56±11.65)], groundnut consumption [6.46 (95% CI, 2.57± 16.27)], soybean consumption [16.74 (95% CI, 8.03±39.84)], alcohol [2.53 (95% CI, 1.39± 4.60)], habit of keeping money in bras[3.57 (95% CI, 2.24±5.69)], overweight [5.36 (95% CI, 4.46±24.57)] and obesity [3.11(95% CI, 2.39±20.42)]. However, decreased risk of breast cancer was associated with being employed [0.32 (95% CI, 0.19±0.56)], urban residence [0.16 (95% CI, 0.07±0.37)], groundnut oil consumption [0.05 (95% CI, 0.02±0.14)], wine consumption [0.16 (95% CI, 0.09±0.26)], non habit of keeping cell phone in bras [0.56 (95% CI, 0.35±0.89)] and physical activity [0.71(95% CI, 0.14±0.84)]. The study showed that little or no education, marriage, positive family history of cancer, radiation exposure, charcuterie, fresh fish, groundnut, soybean, alcohol, habit of keeping money in bras, overweight and obesity were associated with breast cancer risk among Central African women living in Bangui. Women living in Bangui should be more cautious on the behavioral risk associated with breast cancer.

***Comment*: Limitations in self reporting of data. Many confounders. Any conclusive finding for an association beetween keeping cell phone in bras and mammary cancer.**

14. Vila et al., 2018.

Australia, Canada, France, Germany, Israel, New Zealand and the United Kingdom; 2000-2004; INTEROCC study: international case-control study on mobilephone use and brain cancer risk in seven countries.

This study examines the relation between occupational RF and intermediate frequency (IF) EMF exposure and brain tumour (glioma and meningioma) risk in the INTEROCC multinational population-based case-control study (with nearly 4000 cases and over 5000 controls), using a novel exposure assessment approach. Individual indices of cumulative exposure to RF and IF-EMF (overall and in specific exposure time windows) were assigned to study participants using a source-exposure matrix and detailed interview data on work with or nearby EMF sources. Conditional logistic regression was used to investigate associations with glioma and meningioma risk. Overall, around 10% of study participants were exposed to RF while only 1% were exposed to IF-EMF. There was no clear evidence for a positive association between RF or IF-EMF and the brain tumours studied, with most results showing either no association or odds ratios (ORs) below 1.0. The largest adjusted ORs were obtained for cumulative exposure to RF magnetic fields (as A/m-years) in the highest exposed category (≥90th percentile) for the most recent exposure time window (1-4 years before the diagnosis or reference date) for both glioma, OR = 1.62 (95% confidence interval (CI): 0.86, 3.01) and meningioma (OR = 1.52, 95% CI: 0.65, 3.55). Despite the improved exposure assessment approach used in this study, no clear associations were identified. However, the results obtained for recent exposure to RF electric and magnetic fields are suggestive of a potential role in brain tumour promotion/progression and should be further investigated.

Comment: Study suggestive of a potential role in brain tumour promotion/progression.

15. Luo et al., 2019.

USA. 2010-2011. Population-based case-control study.

This study aims to investigate the association between cell phone use and thyroid cancer. A population-based case-control study was conducted in Connecticut between 2010 and 2011 including 462 histologically confirmed thyroid cancer cases and 498 population-based controls. Multivariate unconditional logistic regression was used to estimate odds ratios (OR) and 95% confidence intervals (95% CI) for associations between cell phone use and thyroid cancer. Cell phone use was not associated with thyroid cancer (OR: 1.05, 95% CI: 0.74–1.48). A suggestive increase in risk of thyroid microcarcinoma (tumour size ≤10mm) was observed for long-term and more frequent users. Compared to cell phone non-users, several groups had nonstatistically significantly increased risk of thyroid microcarcinoma: individuals who had used a cell phone >15 years (OR: 1.29, 95% CI: 0.83–2.00), who had used a cell phone >2 hours per day (OR: 1.40, 95% CI: 0.83–2.35), who had the most cumulative use hours (OR: 1.58, 95% CI: 0.98–2.54), and who had the most cumulative calls (OR: 1.20, 95% CI: 0.78–1.84) Cumulative cell phone use was estimated by multiplying cell phone use hours or calls per day with the duration of use. Each variable was categorized into tertiles based on its distribution among controls.. This study found no significant association between cell phone use and thyroid cancer. A suggestive elevated risk of thyroid microcarcinoma associated with long-term and more frequent uses warrants further investigation.

Comment: Self reported exposure. No significant association was found, but a suggestive elevated risk of thyroid microcarcinoma associated with long-term and more frequent users.

ECOLOGICAL STUDIES (Table 2, a)

16. Gonzalez Rubio et al., 2017.

Spain. 2012-2015. Case-control ecological study.

This paper presents the results of a preliminary epidemiological study, combining Epidemiology, Statistics and Geographical Information Systems (GIS), in which the correlation between exposure to RF-EMF in the city of Albacete (166,000 inhabitants, southeast Spain) and the incidence of several cancers with unspecific causes (lymphomas, and brain tumours) are analysed. Statistical tools to analyze the spatial point patterns and aggregate data so as to study the spatial randomness and to determine the zones with the highest incidence from 95 tumours studied (65 lymphomas, 12 gliomas and 18 meningiomas) were used. A correlation (Spearman) study between the personal exposure to RF-EMF in 14 frequency bands, recorded by an EME Spy 140 (Satimo) exposimeter in the city's administrative regions, and the incidence of the tumours registered from January 2012 to May 2015. The cancer cases studied have a random spatial distribution inside the city. On the other hand, and by means of an ecological study, the exposure to RF-EMF registered in the city of Albacete shows little correlation with the incidence of the tumours studied (gliomas (ρ=0.15), meningiomas (ρ=0.19) and lymphomas (ρ=-0.03)). The proposed methodology inaugurates an unexplored analysis path in this field.

***Comment*: *Little correlation between environmental exposure to RF-EMF and glioma, meningioma and lymphomas. Exposure assessment not clear*.**

COHORT STUDIES (Tables 3, a-d)

17. Frei et al., 2011.

Denmark. Subscribers and non-subscribers of mobile phones before 1995.

All Danes aged ≥30 and born in Denmark after 1925, subdivided into subscribers and non-subscribers of mobile phones before 1995. Main outcome measures Risk of tumours of the central nervous system, identified from the complete Danish Cancer Register. Sex specific incidence rate ratios estimated with log linear Poisson regression models adjusted for age, calendar period, education, and disposable income. Results 358,403 subscription holders accrued 3.8 million person years. In the follow-up period 1990-2007, there were 10,729 cases of tumours of the central nervous system. The risk of such tumours was close to unity for both men and women. When restricted to individuals with the longest mobile phone use—that is, ≥13 years of subscription—the incidence rate ratio was 1.03 (95% confidence interval 0.83 to 1.27) in men and 0.91 (0.41 to 2.04) in women. Among those with subscriptions of ≥10 years, ratios were 1.04 (0.85 to 1.26) in men and 1.04 (0.56 to 1.95) in women for glioma and 0.90 (0.57 to 1.42) in men and 0.93 (0.46 to 1.87) in women for meningioma. There was no indication of dose-response relation either by years since first subscription for a mobile phone or by anatomical location of the tumour—that is, in regions of the brain closest to where the handset is usually held to the head. Conclusions In this update of a large nationwide cohort study of mobile phone use, there were no increased risks of tumours of the central nervous system, providing little evidence for a causal association.

Comment*: *Limits in exposure assessment. No increased risks of tumours of the central nervous system.

18. Benson et al., 2013.

UK. Million Women Study. 1999-2005 and 2005-2009. Prospective cohort study.

The relation between mobile phone use and incidence of intracranial central nervous system (CNS) tumours and other cancers was examined in 791,710 middle-aged women in a UK prospective cohort, the Million Women Study. Cox regression models were used to estimate adjusted relative risks (RRs) and 95% confidence intervals (CIs). Women reported mobile phone use in 1999 to 2005 and again in 2009. Results During 7 years' follow-up, 51 680 incident invasive cancers and 1 261 incident intracranial CNS tumours occurred. Risk among ever vs never users of mobile phones was not increased for all intracranial CNS tumours (RR=1.01, 95% CI=0.90–1.14, P=0.82), for specified CNS tumour types nor for cancer at 18 other specified sites. For longterm users compared with never users, there was no appreciable association for glioma (10þ years: RR¼0.78, 95% CI¼0.55–1.10, P¼0.16) or meningioma (10+ years: RR=1.10, 95% CI=0.66–1.84, P=0.71). For acoustic neuroma, there was an increase in risk with long term use vs never use (10+ years: RR=2.46, 95% CI=1.07– 5.64, P=0.03), the risk increasing with duration of use (trend among users, P=0.03). Conclusions In this large prospective study, mobile phone use was not associated with increased incidence of glioma, meningioma or non-CNS cancers.

Comment: Self reported exposure. For acoustic neuroma, there was an increase in risk with long term use vs never use; the risk increasing with duration of use.

19. Poulsen et al., 2013.

Denmark, 1982-1995, follow up until 2007. Cohort study: CANULI study of social inequality and cancer incidence and survival.

In a nationwide cohort study, 355,701 private mobile phone subscribers in Denmark from 1987 to 1995 were followed up through 2007. We calculated incidence rate ratios (IRRs) for melanoma, basal cell carcinoma, and squamous cell carcinoma by using Poisson regression models adjusted for age, calendar period, educational level, and income. Separate IRRs for head/neck tumours and torso/leg tumours were compared (IRR ratios) to further address potential confounders. We observed no overall increased risk for basal cell carcinoma, squamous cell carcinoma, or melanoma of the head and neck. After a follow-up period of at least 13 years, the IRRs for basal cell carcinoma and squamous cell carcinoma remained near unity. Among men, the IRR for melanoma of the head and neck was 1.20 (95% confidence interval: 0.65, 2.22) after a minimum 13-year follow-up, whereas the corresponding IRR for the torso and legs was 1.16 (95% confidence interval: 0.91, 1.47), yielding an IRR ratio of 1.04 (95% confidence interval: 0.54, 2.00). A similar risk pattern was seen among women, though it was based on smaller numbers. In this large, population-based cohort study, little evidence of an increased skin cancer risk was observed among mobile phone users.

Comment: Extent of exposure not assessed. Little evidence of an increased skin cancer risk was observed among mobile phone users.

20. Hauri et al., 2014.

Switzerland. 2000-2008. Census-based cohort study (far field, radiobase stations).

The association between exposure to radio-frequency electromagnetic fields (RF-EMFs) from broadcasting transmitters and childhood cancer was investigated. Time-to-event analysis including children under age 16 years living in Switzerland on December 5, 2000 was performed. Follow-up lasted until December 31, 2008. All children living in Switzerland for some time between 1985 and 2008 were included in an incidence density cohort. RF-EMF exposure from broadcasting transmitters was modeled. Based on 997 cancer cases, adjusted hazard ratios in the time-to-event analysis for the highest exposure category (>0.2 V/m) as compared with the reference category (<0.05 V/m) were 1.03 (95% confidence interval (CI): 0.74, 1.43) for all cancers, 0.55 (95% CI: 0.26, 1.19) for childhood leukemia, and 1.68 (95% CI: 0.98, 2.91) for childhood central nervous system (CNS) tumours. Results of the incidence density analysis, based on 4,246 cancer cases, were similar for all types of cancer and leukemia but did not indicate a CNS tumour risk (incidence rate ratio = 1.03, 95% CI: 0.73, 1.46). This large census-based cohort study did not suggest an association between predicted RF-EMF exposure from broadcasting and childhood leukemia. Results for CNS tumours were less consistent, but the most comprehensive analysis did not suggest an association.

Comment: Limits in the assessment of residential exposure. No association between RF-EMF and cancer in children is suggested.

Table 1 – Cancer in epidemiological case-control studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
1. Aydin et al. 2011. Denmark, Sweden, Norway, and Switzerland; 2004-2008; CEFALO-Multicenter case-control study.	352 cases; 646 population-based matched controls (M and F). Age 7-19 years. Data from reports from pediatric, oncology, and neurosurgery departments and from national population-based registries.	Use of mobile phones, assessed by face-to-face interviews with the subjects and their parents.	Mobile phone use.	Intracranial central nervous system tumours..	**Odds ratio (OR) and 95% confidence intervals (95% CI) from conditional logistic regression. Trend from two-sided Wald testOR (95% CI) for brain tumours**	**p-value for trend**	Education, family history of cancer, past medical radiation exposure to the head, maternal smoking during pregnancy, past head injuries, use of baby monitors near the head, use of cordless phones, contact with animals, location where the child lived before age, having siblings, birth weight, born premature, ever doctor-diagnosed asthma, ever doctor-diagnosed atopic eczema, and ever doctor-diagnosed hay fever.	Adequate/ Equivocal (brain tumour) Children and adolescent
			Regular use (at least once per week, > 6 months)					
			No		1.0 (ref.)			
			Yes		1.36 (0.92 -2.02)			
			Time since first use (years)					
			Never regular user		1.0 (ref.)	0.37		
			≤3.3		1.35 (0.89 to 2.04)			
			3.3–5.0		1.47 (0.87 to 2.49)			
			>5.0		1.26 (0.70 to 2.28)			
			Cumulative duration of calls (hours)					
			Never regular user		1.0 (ref.)	0.42		
			≤35		1.33 (0.89 to 2.01)			
			36-144		1.44 (0.85 to 2.44)			
			>144		1.55 (0.86 to 2.82)			

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjustments	Comments
2. Atzmon et al 2012. Israel, diagnosis between 1989 and 2007. Population-based case-control study/ The present analysis is a retrospective follow up study at diagnosis.	307 subjects, of whom 47 cases (M and F), median age 48. Cases from medical documents with confirmed diagnosis of cancer. Face-to-face interviews in the participant's home.	Exposure to radio and cellular transmitters located in the village prior to 2000. Individual exposure (E) was estimated using the following formula: E=1/D2, where D is distance (in meters) between a house and the closest transmitter.	Individual exposure and years of residence.	Cancer: colorectal (11), breast cancer (10), lymphoma (6), leukemia (3), lungs (2), uterine (2), liver (2), stomach (2), ovarian (2), pancreas (2), prostate (2), cervix (1), brain (1), and bladder (1). Odds ratios and confidence intervals (OR, 95% CI) from binary logistic regression model.	**OR (95% CI), Colorectal**	**OR (95% CI), Lymphoma**	**OR (95% CI), Uterine**	**OR (95% CI), Prostate**	**OR (95% CI), Brain**	Duration of residence in the same house; alcohol consumption; nutritional habits; frequency of physical exercise; use of cellular phones; exposure to wireless equipment in the house; use of oral contraceptives or hormones replacement therapy and income	**Inadequate**
			Radiation intensity		1.03 (1.01-1.05)	0.95 (0.86-1.06)	0.99 (0.91-1.07)	1.67 (0.04-61.04)	12.45 (0.34–453.54)	**No appropriate measurement of RF exposure**	
			Years of exposure to radiation		0.97 (0.877-1.082)	0.95 (0.82-1.11)	1.12 (0.88-1.42)	0.97 (0.86-1.10)	0.96 (0.84–1.11)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued c)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
3. Li et al. 2012. Taiwan; 2003-2007; Population-based case-control study.	2606 childhood neoplasm cases (M and F), 78180 matched controls (939-28170 for leukemia; 394- 11820 for brain neoplasms). Age < 15 years. Clinical data from the National Health Insurance Research Database (NHIRD).	RF exposure metric was estimated from the averaged Annual Power Density for the five-year period prior to the neoplasm diagnosis in the township where the subject lived at the time of neoplasm diagnosis. Information on MPBS from the Taiwan National Communication Council (NCC).	Exposure to mobile phone base stations (MPBS): 800-900 MHz; 1800-2200 Mhz. Estimate APD	All neoplasms; Leukemia; Brain neoplasms. Odds ratio (OR) and 95% confidence intervals (95% CI) from multiple unconditional logistic regression models	**OR (95% CI) for all neplasms**	**OR (95% CI) for leukemia**	**OR (95% CI) for brain neplasms**	age, gender, calendar year of neoplasm diagnosis, urbanisation level of township, and high-voltage (69/161/345 kV) transmission line (HVTL) density of the township. Limits in exposure assessment	Inadequate
			Level of exposure (compared to median= 167.02 WYs/km2						
			<Median		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			≥Median		1.13 (1.01–1.28)	1.23 (0.99-1.52)	1.14 (0.83-1.55)		
			p-value		0.048	0.052	0.426		
4. Soderqvist et al. 2012. Sweden, 2000-2003. Case–control study.	78 cases; 312 controls (M and F), age 22–80, median 69. Patients were recruited as reported by the Regional Oncology Centre of Uppsala/Orebro and Linkoping, including nine of 21 Swedish counties. Controls were drawn from the population registry at random.	Use of wireless phones, i.e. both mobile and cordless phones. Self-reported exposure from postal questionnaire.	The cumulative number of hours of use was calculated using the number of years and average time used per day. Cumulative hours of use was also divided into three groups, 1–1000, 1001–2000 and more than 2000 h. Use of wireless phones within 1 year before diagnoses were treated as unexposed.	Salivary gland tumour. Odds ratios and 95% confidence intervals from unconditional logistic regression.	**OR (95% CI) for Mobile phones**	**OR (95% CI) for cordless phones**	**OR (95% CI) for wireless phones, total**	No information available Limits in exposure assessment	Inadequate
			Cumulative use (h)						
			Unexposed		1 (Ref.)	1 (Ref.)	1 (Ref.)		
			1–1000		0.9 (0.4–1.7)	0.6 (0.3–1.3)	0.8 (0.5-1.6)		
			1001–2000		0.7 (0.1–3.6)	1.2 (0.2–7.8)	0.7 (0.2–2.7)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued d)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
5. Carlberg et al. 2013. Sweden; 2007-2009; Case-control study.	709 cases; 1368 population-based matched controls (M and F). Age 18-75 years. Data from a cancer register.	Use of wireless phones (mobile and cordless phones), assessed by a self-administered structured phone questionnaire.	Mobile phone use (UMTS, 4G); cordless phone use (1900 MHz).	Meningioma. Odds ratio (OR) and 95% confidence intervals (95% CI) from unconditional logistic regression.	**OR (95% CI) for meningioma, Digital (2G)**	**OR (95% CI) for meningioma, Digital (UMTS, 3G)**	**OR (95% CI) for meningioma, Cordless phone**	**OR (95% CI) for meningioma, Digital type**	Gender, age, year of diagnosis, socio-economic index (SEI).	Adequate/ Positive (meningioma)
			Cumulative use of wireless phones (h)							
			<39-405		1.0 (0.7-1.4)	0.7 (0.3-1.3)	1.0 (0.7-1.4)	1.1 (0.8-1.6)		
			406–1091		1.0(0.7-1.5)	0.4 (0.1-1.2)	0.9 (0.6-1.3)	0.9 (0.6-1.3)		
			1092-2376		0.9 (0.6-1.4)	0.6 (0.2-1.8)	1.2 (0.8-1.8)	0.9 (0.6-1.3)		
			>2376		1.5 (0.9-2.3)	7.3 (1.2-46)	1.8 (1.2-2.8)	1.4 (0.96-2.6)		
			P for trend		0.06	0.04	0.0003	0.002		
6. Hardell et al. 2013a. Sweden, 2007-2009. Case-control study.	593 cases, 1368 controls (M and F), age 18-75. Newly diagnosed brain tumour cases from the regional and national Swedish cancer registers. The Swedish Population Registry was used for identification of controls.	Use of wireless phones, i.e. both mobile and cordless phones. Self-reported exposure from self-administered questionnaire supplemented by a phone interview.	Frequency of use; Duration of exposure.	Malignant brain tumours. Odds ratio (OR) and 95% confidence interval (CI) from unconditional logistic regression analysis.	**OR (95% CI) for Mobile phone use (Analogue, 2G, 3G)**	**OR (95% CI) for digital phone use (2G, 3G, cordless)**	**OR (95% CI) for all wireless phones**		Occupational history, exposure to different agents, smoking habits, medical history including hereditary risk factors, and exposure to ionising radiation.	Adequate/ Positive (Malignant brain tumours)
			Frequency of use							
			Non users (<1 years)		1 (Ref.)	1 (Ref.)	1 (Ref.)			
			Users (>1 years)		1.6 (0.99 - 2.7)	1.7 (1.04 - 2.8)	1.7 (1.04 - 2.8)			
			Duration of use (years)							
			1-5		1.8 (1.002 - 3.4)	2.6 (1.4 - 4.9)	2.6 (1.4 - 5.0)			
			5-10		1.7 (0.98 - 2.8)	1.6 (0.9 - 2.7)	1.6 (0.98 - 2.8)			
			10-15		1.3 (0.8 - 2.2)	1.4 (0.8 - 2.3)	1.3 (0.8 - 2.2)			
			15-20		1.5 (0.8 - 2.6)	2.2 (1.3 - 3.6)	1.7 (1.02 - 3.0)			
			20-25		1.9 (1.1 - 3.5)	1.5 (0.5 - 4.6)	1.9 (1.04 - 3.4)			
			>25		2.9 (1.4 - 5.8)	-	3.0 (1.5 - 6.0)			

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued e)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
7. Hardell et al. 2013b and Hardell and Carlberg 2015. Sweden, 1997-2003 and 2007-2009. Pooled case-control study.	316 cases of acoustic neuroma, 3530 controls (M and F), aged 20–80 years (1997–2003) and18–75 years (2007–2009) at the time of diagnosis. Cases reported from cancer registries.	Use of wireless phones, i.e. both mobile and cordless phones. Self-reported exposure from self-administered questionnaire supplemented by a phone interview.		Acoustic neuroma. Odds ratio (OR) and 95% confidence intervals (CI) from unconditional logistic regression analysis.	**OR (95% CI) for Mobile phone use (Analogue, 2G, 3G)**	**OR (95% CI) for digital phone use (2G, 3G, cordless)**	**OR (95% CI) for all wireless phones**	Occupational history, exposure to different agents, smoking habits, medical history including hereditary risk factors, and exposure to ionising radiation.	Adequate/ Positive (acoustic neuroma and glioma)
			Frequency of use						
			Non users (<1 years)		1 (Ref.)	1 (Ref.)	1 (Ref.)		
			Users (>1 years)		1.6 (1.2 - 2.2)	1.5 (1.1 - 2.0)	1.5 (1.1 - 2.0)		
			Duration of use (years)					Positive association in heavy users	
			1-5		1.3 (0.9 - 1.8)	1.4 (1.01 - 1.9)	1.2 (0.8 - 1.6)		
			5-10		2.3 (1.6 - 3.3)	1.6 (1.1 - 2.3)	1.9 (1.3 - 2.7)		
			10-15		2.1 (1.3 - 3.5)	1.6 (0.97 - 2.8)	2.0 (1.3 - 3.2)		
			15-20		2.1 (1.02 - 4.2)	1.1 (0.5 - 2.5)	1.7 (0.9 - 3.3)		
			>20		4.5 (2.1 - 9.5)	8.1 (2.0 - 32)	4.4 (2.2 - 9.0)		
	1380 cases of glioma, 3530 controls (M and F), aged 20–80 years (1997–2003) and18–75 years (2007–2009) at the time of diagnosis. Cases reported from cancer registries.	Use of wireless phones, i.e. both mobile and cordless phones. Self-reported exposure from self-administered mailed questionnaire.		Glioma. Odds ratio (OR) and 95% confidence intervals (CI) from unconditional logistic regression analysis.	**OR (95% CI) for Mobile phone use (Analogue, 2G, 3G)**	**OR (95% CI) for digital phone use (2G, 3G, cordless)**	**OR (95% CI) for all wireless phones**	Occupational history, exposure to different agents, smoking habits, medical history including hereditary risk factors, and exposure to ionising radiation.	)
			Frequency of use						
			Non users (<1 years)		1 (Ref.)	1 (Ref.)	1 (Ref.)		
			Users (>1 years)		1.6 (1.2 - 2.0)	1.3 (1.1- 1.6)	1.3 (1.1- 1.6)		
			Duration of use (years)						
			1-5		1.1 (0.7- 1.7)	1.2 (0.9- 1.4)	1.1 (0.9- 1.4)		
			5-10		1.1 (0.8- 1.6)	1.6 (1.3 - 2.0)	1.5 (1.2- 1.9)		
			10-15		2.2 (1.5 - 3.7)	1.4 (1.1- 1.9)	1.4 (1.1- 1.8)		
			15-20		2.4 (1.5- 3.7)	2.0 (1.5- 2.8)	1.7 (1.2- 2.3)		
			20- 25		3.2 (1.9- 5.5)	1.6 (0.6- 4.4)	1.9 (1.3- 2.9)		
			> 25		4.8 (2.5- 9.1)	-	3.0 (1.7- 5.2)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued f)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
8. Coureau et al.2014. France. 2004-2006. CERENAT. Case-control study.	596 cases and 1192 controls (M and F) over 16 years of age. Cases identified from populationbased cancer registries. Two controls with no history of CNS tumour were randomly selected from the local electoral rolls matched on age (±2 years), sex and department of residence.	Exposure from mobile phone use. Self-reported exposure from standardised questionnaires delivered as face-to-face non-blinded structured interviews by trained interviewers.	Time since first use (years), Cumulative duration of calls (hours)	Gliomas, meningiomas. Conditional logistic regression for matched sets was used to estimate ORs and 95%Cis	**OR (95% CI) for glioma**	**OR (95% CI) for meningioma**	Level of education, smoking, alcohol consumption. Potential occupational confounders were identified from detailed job calendars, and from specific questions about exposure to pesticides, extremely low-frequency electromagnetic fields (ELF-EMF), RF-EMF, and ionising radiation	Adequate/ Positive (glioma, meningioma)
			Regular mobile phone use					
			Not regular user		1 (Ref.)	1 (Ref.)	Positive association in heavy users	
			Regular user		1.24 (0.86 - 1.77)	0.90 (0.61 - 1.34)		
			Time since first use (years)					
			1-4		0.88 (0.56 - 1.39)	0.79 (0.49 - 1.27)		
			5-10		1.34 (0.87 - 2.06)	0.97 (0.58 - 1.61)		
			>10		1.61 (0.85 - 3.09)	1.57 (0.64 - 3.86)		
			Cumulative duration of calls (hours)					
			<43		0.83 (0.48 - 1.44)	1.12 (0.61 - 2.04)		
			43-112		0.77 (0.42 - 1.41)	0.85 (0.45 - 1.61)		
			113-338		1.07 (0.60 - 1.90)	0.52 (0.25 - 1.07)		
			339-895		1.78 (0.98 - 3.24)	0.52 (0.18 - 1.45)		
			>896		2.89 (1.41 - 5.93)	2.57 (1.02 - 6.44)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued g)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
9. Pettersson et al. 2014. Sweden, 2002-2007. Population-based case-control study.	422 cases with acoustic neuroma, 643 controls for analyses of mobile phone use. 417 cases with acoustic neuroma, 635 controls for analyses of cordless phone use (M and F), age 20-69 years. Cases identified in clinics, the Swedish Regional Cancer Registers and local acoustic neuroma registries. Two matched controls per case randomly selected from the Swedish population register.	Use of mobile phone and cordless phone . Self-reported exposure from mail questionnaire.	Frequency of use; Duration of exposure; Cumulative hours of use	Acoustic Neuroma. Odds Ratios (OR) with 95% CIs from conditional logistic regression	**OR (95% CI) for Mobile phone users**	**OR (95% CI) for Cordless phone users**	Smoking, education, marital status, and parity; for cordless phone analyses: hands-free use. Limits in exposure assessment. Positive association in heavy users.	Adequate/ Equivocal (Acoustic neuroma)
			Frequency of use					
			Never or rarely		1 (Ref.)	1 (Ref.)		
			Regular use		1.18 (0.88 - 1.59)	1.41 (1.07 - 1.86)		
			Duration of use (years)					
			<5		1.06 (0.73 - 1.54)	1.35 (0.97 - 1.89)		
			5 to 9		1.39 (0.97 - 1.97)	1.74 (1.22 - 2.46)		
			=>10		1.09 (0.75 - 1.59)	1.10 (0.73 - 1.64)		
			Cumulative use (hours)					
			<38		1.09 (0.73 - 1.62)	1.22 (0.82 - 1.82)		
			39-189		1.12 (0.74 - 1.69)	1.27 (0.85 - 1.89)		
			190-679		1.13 (0.75 - 1.70)	1.42 (0.96 - 2.09)		
			=>680		1.46 (0.98 - 2.17)	1.67 (1.13 - 2.49)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued h)

Study information	Population	Type of Exposure and assessment method		Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)	Any Other Co-Exposure/adjustments	Comments
10 Yoon et al. 2015. Korea; 2002- 2007; case-control study.	285 cases, 285 controls (M and F), mean age 42.3 (±14.1) cases; 42.5 (±14.0) controls. Patients recruited from five areas including Seoul and checked at department of neurosurgery in nine hospitals. The control group persons who received health screenings at the same hospitals.	Exposure from mobile phone use. Self-reported exposure from questionnaires.		Cumulative hours and lifetime years of use; average daily receiving call and the average daily sending call; average call duration time	Glioma; adjusted odds ratios (aORs) and 95% CIs were calculated using logistic regression	**OR (95% CI) for glioma**	adjusted for sex, age, type of respondent, five residential regions, educational achievement, the use of dye, alcohol drinking, the use of computer, and the use of electric blanket	Adequate/ Equivocal (Glioma)
				Use of mobile phone				
				Non users		1 (Ref.)		
				Users		1.17 (0.63 - 2.14)		
				Lifetime years of use (months)				
				< 48		1.28 (0.62 - 2.64)		
				48-84		1.27 (0.63 - 2.56)		
				>48		1.04 (0.52 - 2.09)		
				Cumulative hours of use (h)				
				< 300		1.25 (0.64 - 2.45)		
				300-900		1.59 (0.72 - 3.21)		
				>900		0.64 (0.30 - 1.34)		
				Average duration time (min)				
				<2		1.18 (0.62 - 2.24)		
				3-4		1.31 (0.65 - 2.63)		
				>5		1.00 (0.45 - 2.24)		
11. Al-Qahtani 2016. Saudi Arabia; 1996-2013; Retrospective case-control study.	26 cases, 61 controls (M and F). <30 years: 28; 30-39 years: 23; 40-49 years: 15; >50 years: 21. Hospital records.	Exposure from mobile phone use. Self-reported exposure from telephone and in-person interviews using standardized questionnaire.		Everyday use: <=1 h/day: unexposed; >1 h/day: exposed. Latency: <10 years of use; =>10 years of use	Parotid gland tumour. OR and 95% confidence interval	**OR (95% CI) for parotid gland tumour**	Smoking Other confounding not considered. Small sample.	Inadequate
				Everyday use				
				Non exposed		1 (Ref.)		
				Exposed		3.47 (1.30 - 9.23)		
				Duration of exposure				
				< 10 years		3.6 (0.97 - 13.36)		
				10 years or more		3.46 (0.77 - 15.56)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued i)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
12. Satta et al. 2018. Sardinia, Italy; 1998–2004; Population-based case-control study as part of the European multicenter study EPILYMPH.	322 lymphoma cases; 444 matched controls (M and F). Cases aged 25 to 74 years. In person interviews using a standardized questionnaire.	Exposure from radio-television transmitter or mobile phone base station near the three most prolonged residential addresses at any time of the life. Distance used as proxy for intensity of exposure; RF-EMF measurements at the door of the longest residential addresses available for the subset of subjects residing within 250 m of the closest transmitter base station, using a Microrade broadband detector.	Radiofrequency field estimates (V/m):	Lymphoma subtypes: B-cell; T-cell; Hodgkin; not otherwise specified NHL; OR and 95% confidence interval from logistic regression.	**OR for all lymphomas**	**OR for B-cell lymphoma**	**OR for Chronic lymphocytic leukemia**		Age, gender, years of education (categorized as 8 years, 9–13 years, 14 years), level of education and quartiles of vehicular traffic in proximity to the residential addresses of study subjects.	Inadequate
			RF field estimates (V/m):							
			<0.01		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		Uncertain exposure assessment	
			0.01- 1.23		0.7 (0.4 - 1.5)	0.8 (0.4 - 2.0)	1.5 (0.5 - 4.4)			
			1.24- 1.50		0.7 (0.3 - 1.5)	0.9 (0.4 - 2.1)	-			
			1.51- 1.7401		1.0 (0.5 - 2.1)	1.1 (0.5 - 2.7)	0.6 (0.1 - 3.1)			
			>1.7401		1.2 (0.6 - 2.6)	1.4 (0.6 - 3.4)	0.9 (0.2 - 4.6)			
13. Balekouzou et al. 2017. Central African Republic; 2003-2015; Case-control study.	174 cases; 348 age-matched controls (F). Age >15 years. Data from a cancer register.	Use of mobile phones,radiation exposure. Trained interviewers administered a standardized in person interview.	Exposure to radiation; habit to keep mobile phone in the bra.	Breast cancer. Odds ratio (OR) and 95% confidence intervals (95% CI) from unconditional logistic regression.	**OR (95% CI) for Breast cancer, univariate analysis**	**p-value**	**OR (95% CI) for Breast cancer, multivariate analysis**	**p-value**	Age, occupation, economic status, education, residence, ethnic group and marital status, family history, radiation exposure, food consumption, physical activity, alcohol, tobacco, use of bra, habit to keep money or cell phones in bras, height, weight and BMI.	Inadequate
			Daily use (h/day)						Self reported habit to keep mobilphone in the bra	
			No		1.00 (ref.)		1.00 (ref.)			
			Yes		8.02 (5.16-12.47)	0.000	8.21 (5.04 – 13.38)	0.000		
			Habit of keeping cell phone in bras							
			Yes		1.00 (ref.)		1.00 (ref.)			
			No		0.45 (0.31-0.65)	0.000	0.56 (0.35-0.89)	0.01		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued j)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
14. Vila et al. 2018. Australia, Canada, France, Germany, Israel, New Zealand and the United Kingdom; 2000-2004; INTEROCC study: international case-control study on mobilephone use and brain cancer risk in seven countries. "	2054 glioma cases; 1924 meningioma cases; 5601 controls (M and F). Cases aged 30 to 59 years of age; up to 69 years in Germany; 18 years and above in Israel; 18 to 69 years in the United Kingdom. In person computer-assisted personal interview.	Self-reported occupational exposure or proximity to radars, telecommunication antennas, transmitters, equipment for semiconductors manufacturing, medical diagnosis and treatment, industrial heating or food heating. A source-exposure matrix (SEM) was used to assign average exposure levels to each RF and IF source reported. Field intensities for each EMF source were weighted using the frequency-dependent reference levels (RLs) by the International Commission on Non-Ionising Radiation Protection (ICNIRP) for occupational exposure. Frequency of exposure: 10 MHz- 300 GHz.	E-field (V/m, Arithmetic mean exposure levels from the SEM. RF sources organized by E-field exposure level)	Glioma and meningioma risk; adjusted OR and 95% confidence intervals.	**OR (95% CI) for Gliomas**	**OR for Meningiomas**	No information available Study suggestive of a potential role in brain tumour promotion/progression	Adequate/ negative (Glioma and meningioma)
			Duration of exposure: 1-4 years					
			Non exposed		1.00 (ref.)	1.00 (ref.)		
			<0.42		0.69 (0.49 - 0.98)	0.60 (0.38 - 0.96)		
			0.42–4.47		0.85 (0.54 - 1.35)	1.13 (0.60 - 2.14)		
			4.48–18.8		0.77 (0.44 - 1.37)	0.86 (0.35 - 2.13)		
			≥18.9		1.38 (0.75 - 2.54)	1.30 (0.58 - 2.91)		
			Duration of exposure: 5-9 years					
			Non exposed		1.00 (ref.)	1.00 (ref.)		
			<0.42		0.84 (0.61 - 1.17)	0.60 (0.38 - 0.97)		
			0.42–4.47		0.93 (0.60 - 1.44)	1.48 (0.84 - 2.61)		
			4.48–18.8		0.82 (0.46 - 1.47)	1.08 (0.66 - 2.39)		
			≥18.9		0.90 (0.44 - 1.83)	1.03 (0.45 - 2.63)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued I)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
15. Luo et al. 2019. Connecticut, USA, 2010-2011; population-based case-control study.	462 cases and 498 population-based controls (M and F), 21-84 years of age.	Use of mobile phones,radiation exposure. Trained interviewers administered a standardized and structured questionnaire.	Use of mobile phones; Duration of exposure.	Thyroid cancer (papillary, follicular, medullary, anaplastic). Multivariate unconditional logistic regression to estimate odds ratios (OR) and 95% confidence intervals (95% CI).	**OR (95% CI) for Thyroid cancer, Overall**	**OR (95% CI) for Thyroid cancer, MM**	**OR (95% CI) for Thyroid cancer, FF**	age, sex, education, family history of thyroid cancer, alcohol consumption, body mass index, previous benign thyroid diseases, occupational radiation exposure, and radiation treatment.	Adequate/ Equivocal (Thyroid cancers)
			Use of mobile phone						
			Non users (< 6 months use)		1 (Ref.)	1 (Ref.)	1 (Ref.)		
			Users (< 6 months use)		1.05 (0.74, 1.48)	1.27 (0.62, 2.61)	0.99 (0.66, 1.47)		
			Daily use (h/day)						
			≤1		1.10 (0.72, 1.66)	1.76 (0.72, 4.32)	0.97 (0.60, 1.56)		
			1-2		1.51 (0.90, 2.53)	1.66 (0.57, 4.82)	1.45 (0.79, 2.65)		
			>2		1.40 (0.83, 2.35)	1.05 (0.35, 3.14)	1.52 (0.83, 2.80)		
			Age at first use (years)						
			≤20		1.08 (0.53, 2.20)	1.49 (0.34, 6.01)	0.95 (0.42, 2.18)		
			21-50		1.06 (0.72, 1.55)	1.44 (0.65, 3.17)	0.96 (0.62, 1.49)		
			>50		1.03 (0.62, 1.70)	0.99 (0.36, 2.70)	1.05 (0.58, 1.90)		
			Duration of use (years)						
			≤12		0.99 (0.66, 1.49)	0.99 (0.39, 2.48)	0.97 (0.61, 1.53)		
			12-15		0.94 (0.63, 1.42)	0.82 (0.34, 1.97)	0.97 (0.61, 1.55)		
			>15		1.29 (0.83, 2.00)	2.11 (0.91, 4.89)	1.03 (0.62, 1.73)	Some evidence in long term users	

Table 2 – Cancer in epidemiological ecological case-control studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjust ments	Comments
16. Gonzalez Rubio et al. 2017. Spain. 2012-2015. Case-control ecological study.	95 cases: 65 lymphomas, 12 gliomas, 18 meningiomas (30 brain tumours); 390 anonymous controls (M and F). Resident population data in the 110 administrative districts from the Spain's National Statistics Institute (INE). Addresses for all cancer cases of gliomas, meningiomas and lymphomas from Oncology Service of the University Hospital of Albacete. Representative random sample of 390 anonymous addresses for the control group from the Statistics Service of the Town Council of Albacete.	Residential exposure to any RF. 14 frequency bands (FM, TV3, TETRA, TV4and5, GSMTx, GSM Rx, DCS Tx, DCS Rx, DECT, UMTS Tx, UMTS Rx,WiFi 2G,WiMAX y WiFI 5G), ranging from 88MHz up to 6 GHz. Personal exposure assessed using an EME Spy 140 (Satimo)exposimeter, conveying the exposimeter in a bicycle. 168266 total measurement, 12019 measurements per frequency, 1540 average measurement records per administrative region.	Average total exposure to RF-EMF (V/m) per administrative region: Min 0.07, max 1.03	Gliomas, meningiomas and lymphomas; Spearman correlation test between exposure and incidence of tumours. Effect estimate not appropriate	**ρ of Spearman for Meningioma, (p-value)**	**ρ of Spearman for Glioma, (p-value)**	**ρ of Spearman for all brain, (p-value)**	**ρ of Spearman for Lymphoma, (p-value)**	**ρ of Spearman for all tumours, (p-value)**	Smoking Other counfounders not analysed Design not clear, particularly given that there seems to be personal exposure assessment	inadequate
	Design not clear, particularly given that there seems to be personal exposure assessment	Not clear exposure assessment			0,19 (0,04)	0,15 (0,13)	0,28 (0,003)	-0,03 (0,72)	0,13 (0,19)		

Table 3 – Cancer in epidemiological cohort studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
17. Frei et al. 2011. Denmark; 1990-2007. Nationwide cohort study.	All Danes aged ≥30 and born in Denmark after 1925, subdivided into subscribers and non-subscribers of mobile phones before 1995.	Use of mobile phones as mobile phone subscription; records for 1982-95 were obtained from the Danish network operators.	Mobile phone use, duration of subscription.	Tumours in the central nervous system. Sex-specific incidence rate ratios (IRR) and 95% confidence intervals from log-linear Poisson regression models.	**IRR (95% CI) for Central nervous system tumours, MM**	**IRR (95% CI) for Central nervous system tumours, FF**	**IRR (95% CI) for Central nervous system tumours, MM with >12 years of education**	Age, calendar period, education, and disposable income.	Inadequate
			Use of mobile phones						
			Non-subscribers		1.0 (ref.)	1.0 (ref.)	1.0 (ref.)		
			Subscribers		1.02 (0.94 to 1.10)	1.02 (0.86 to 1.22)	1.00 (0.83 to 1.22)	Exposure assessment only by subscriptions	
			Years of subscription						
			Non-subscribers		1.0 (ref.)	1.0 (ref.)	1.0 (ref.)		
			1-4		1.07 (0.92 to 1.24)	0.97 (0.69 to 1.36)	1.29 (0.92 to 1.79)		
			5-9		0.95 (0.83 to 1.08)	1.05 (0.81 to 1.37)	0.95 (0.70 to 1.29)		
			10-12		1.08 (0.93 to 1.25)	1.05 (0.75 to 1.47)	0.82 (0.55 to 1.24)		
			≥13		1.03 (0.83 to 1.27)	0.91 (0.41 to 2.04)	0.94 (0.55 to 1.60)		

Table 3 – Cancer in epidemiological cohort studies (450-6000 MHz) (Continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjustments	Comments
18. Benson et al. 2013. United Kingdom,; prospective Cohort study , the Million Women Study.	1.3 million middle-aged women recruited for Breast Screening Programme	Use of mobile phone. Postal questionnaire; questions on mobile phone use were asked in 1999–2005, and again in 2009	Use of mobile phone.	Intracranial central nervous system tumours. Cox regression models to estimate adjusted relative risks (RRs) and 95% confidence intervals (CIs)	**RR (95% CI) for all intracranial CNS tumours**	**RR (95% CI) for glioma**	**RR (95% CI) for meningioma**	**RR (95% CI) for pituitary**	**RR (95% CI) for acoustic neuroma**	Socioeconomic status, region, age at baseline, height, BMI, smoking, alcohol intake, exercise, use of menopausal hormone therapy.	Adequate/ Positive (acoustic neuroma, pituitary gland)
			Ever used a mobile phone							Overadjusted for several outcomes.	
			No		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			Yes		1.01 (0.90-1.14)	0.91 (0.76-1.08)	1.05 (0.81-1.38)	1.52 (0.99-2.33)	1.44 (0.91-2.28)		
			Frequency of use								
			Never user		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			<Daily use		1.02 (0.90-1.15)	0.92 (0.77-1.10)	1.05 (0.80-1.37)	1.53 (0.99-2.36)	1.45 (0.91-2.31)		
			Daily use		1.00 (0.80-1.26)	0.80 (0.56-1.14)	1.11 (0.67-1.85)	1.45 (0.68-3.10)	1.37 (0.61-3.07)		
			Duration of exposure (years)					*p-value for trend = 0.23*	*p-value for trend = 0.03*		
			Never user		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			<5		1.00 (0.84-1.20)	0.93 (0.71-1.21)	0.88 (0.60-1.31)	2.31 (1.31-4.06)	1.00 (0.54-1.82)		
			5-9		1.02 (0.89-1.17)	0.92 (0.75-1.13)	1.21 (0.89-1.65)	1.08 (0.64-1.82)	1.80 (1.08-3.03)		
			10+		1.02 (0.81-1.27)	0.78 (0.55-1.10)	1.10 (0.66-1.84)	1.61 (0.78-3.35)	2.46 (1.07-5.64)		

Table 3 – Cancer in epidemiological cohort studies (450-6000 MHz) (Continued c)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
19. Poulsen et al. 2013. Denmark, 1982-1995, follow up until 2007. Cohort study: CANULI study of social inequality and cancer incidence and survival	355701 (M and F), 30 years to date of the first cancer diagnosis, death, emigration.	Use of mobile phones. Mobile phone subscriptions in Denmark during the period from 1982 until the end of 1995. Person-time within the first year of subscription was defined as unexposed.	Use of mobile phones; Duration of exposure.	Basal Cell Carcinoma of the head and neck, Squamous Cell Carcinoma and Melanoma on the head and neck. Incidence rate ratios (IRRs) and 95% confidence intervals from log-linear Poisson regression models.	**IRR (95% CI) for Basal Cell Carcinoma of the head and neck, FF**	**IRR (95% CI) for Basal Cell Carcinoma of the head and neck, MM**	**IRR (95% CI) for Squamous Cell Carcinoma and Melanoma of the head and neck, FF**	**IRR (95% CI) for Squamous Cell Carcinoma and Melanoma of the head and neck, MM**	Age, calendar year, educational level, and income. Exposure assessment by mobile phone subscription only	Inadequate
			Use of mobile phone							
			Non users (< 1 year subscription)		1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)		
			Users (>1 year subscription)		0.93 (0.82 - 1.05)	0.98 (0.93 - 1.03)	1.01 (0.88 - 1.16)	1.05 (0.80 - 1.37)		
			Duration of use (years)							
			1–4		1.02 (0.80 - 1.30)	1.01 (0.91 - 1.13)	0.86 (0.61 - 1.21)	1.16 (0.69 - 1.94)		
			5-9		0.78 (0.64 - 0.95)	0.96 (0.89 - 1.04)	1.01 (0.81 - 1.26)	1.01 (0.65 - 1.57)		
			10-12		1.02 (0.83 - 1.26)	0.96 (0.87 - 1.05)	1.17 (0.93 - 1.48)	0.92 (0.55 - 1.54)		
			>=13		1.20 (0.79 - 1.82)	1.02 (0.90 - 1.15)	0.91 (0.66 - 1.27)	1.20 (0.65 - 2.22)		

Table 3 – Cancer in epidemiological cohort studies (450-6000 MHz) (Continued d)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
20. Hauri et al. 2014. Switzerland. 2000-2008. Census-based cohort study.	997 cancer cases from Swiss National Cohort: 283 leukemia, 258 CNS tumours, 456 other cancers; 117 cases from Swiss Childhood Cancer Registry, not linked with SNC: 27 leukemia, 26 CNS tumours, 64 other cancers (M and F); ≤15 years.	Residential exposure to broadcast transmitters emitting medium-wave (0.5–1.6 MHz), short-wave (6–22 MHz), very high frequency (VHF; 174–230 MHz), and ultra-high frequency (UHF; 470–862 MHz) EMFs. RF-EMF levels from VHF and UHF transmitters ... were modeled by the Federal Office of Communications for an area with a radius of 10 km around each transmitter for the years 1990 and 2000.	A priori chosen cutpoints to differentiate between low, medium, and high exposure. V/m	Leukemia, acute lymphoblastic leukemia, and Central Nervous System tumours, including benign tumours. Hazard Ratio from time-to-event analysis (Cox Regression), 2000–2008. Incidence Rate Ratio from Poisson regression analysis, 1985–2008.	**HR (95% CI), IRR (95% CI), All cancers**	**HR (95% CI), IRR (95% CI), All leukemias**	**HR (95% CI), IRR (95% CI), CNS tumours**	Sex, benzene, natural background ionising γ radiation, distance to the nearest high-voltage power line, and degree of urbanisation.	Adequate/ Negative (Childood cancers)
			Residential exposure						
			Low		1 (Ref.)	1 (Ref.)	1 (Ref.)		
			Medium		1.14 (0.94 - 1.38) 1.09 (1.00 - 1.20)	0.70 (0.46 - 1.07) 0.92 (0.77 - 1.10)	1.35 (0.94 - 1.95) 1.16 (0.95 - 1.42)		
			High		1.03 (0.74 - 1.43) 0.90 (0.76 - 1.06)	0.55 (0.26 - 1.19) 0.76 (0.55 - 1.05)	1.68 (0.98 - 2.91) 1.03 (0.73 - 1.46)		

Table 4 (summary 1-3) – Collected data on cancer in epidemiological studies (450-6000 MHz)

Total studies FR1*	20			
Adequate studies	11			
Observed Tumour	Total adequate studies	Positive results	Equivocal results	Negative results
Glioma	8	3	2	3
Acoustic neuroma	3	2	1	
Meningioma	4	2		2
Lymphoma	1			1
Thyroid gland	1		1	
Pituitary gland	1	1		

*Some of the studies include more than one tumour site.

1. SUMMARY OF THE RESULTS OF EPIDEMIOLOGICAL STUDIES (FR1: 450 to 6000 MHz) (Table 4)

The epidemiological evidence on possible associations of exposure to RF-EMF with cancer comes from studies of diverse design that assessed a range of exposure sources: the populations included people exposed in occupational settings, people exposed through sources in the general environment, e.g. radio-base stations, and people exposed through use of wireless (mobile and cordless) telephones.

In chapter 4 (Limitations) general methodological concerns related to the assessment of individual studies are covered. The total number of epidemiological studies published after the IARC 2011 evaluation (IARC, 2013) and up to 2020, as selected for the present review for FR1, was 20.

After further deep analyses of the 20 original papers, 11 studies proved to be adequate on the basis of exposure assessment, sample size and appropriateness of confounding analyses.

Gliomas, acoustic neuromas, meningiomas, lymphomas, thyroid and pituitary gland tumours were analysed in the 11 adequate studies for a possible association with exposure to RF-EMF, related to the use of mobile phone, or for environmental/occupational exposure to emissions from radiobase stations. The association of the different neoplasias to RF-EMF exposure is reported below. Between brackets numbers assigned to the various studies are reported.

Glioma: out of 7 adequate studies regarding this outcome, 3 showed a positive association with RF-EMF exposure (Ref: 6, 7, 8), 2 were equivocal (1,10) and 3 negative (Ref: 14,18, 20).

Acoustic neuroma: out of 3 adequate studies regarding this outcome, 2 showed a positive association with the RF-EMF exposure (Ref: 7, 18), 1 was equivocal (Ref:9).

Meningioma: out of 4 adequate studies regarding this outcome, 2 showed a positive association with the RF-EMF exposure (Ref: 5,8), and 2 were negative (Ref: 14, 18).

Lymphoma/leukaemia: the only adequate study (childhood) regarding this outcome was negative (Ref: 20).

Thyroid tumour: the only adequate study regarding this outcome showed equivocal results (Ref: 15).

Pituitary gland tumour: the only adequate study regarding this outcome was positive (Ref: 18).

The results of the different studies for the same outcome are mixed (showing conflicting findings) , as summarized in Table 4. The tumours with more robust evidence of association are glioma and acoustic neuroma. The association of glioma and acoustic neuroma is stronger among long-term heavy users of mobile phones, which is also the most extensively investigated exposure source, and in some cases the onset of tumours was related to the side on which the device was handled.

The IARC evaluation of *limited evidence* of cancerogenicity of RF-EMF in epidemiological studies as regards FR1 is confirmed.

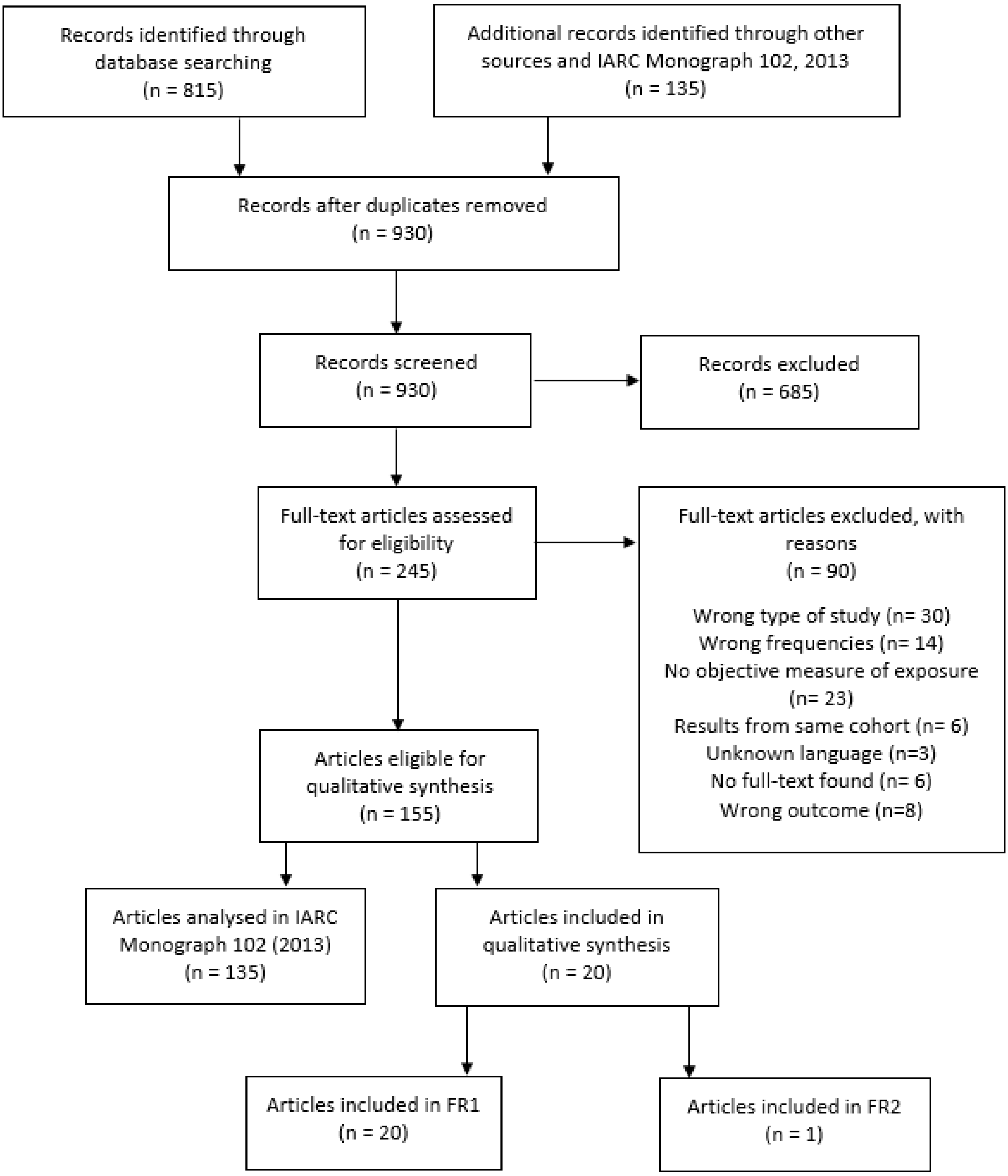
4.1.2 Cancer in epidemiological studies: Studies evaluating health effects due to RF at a higher frequency range (FR2: 24 to 100 GHz, MMW).

The stream of selection of the relevant literature is the same as for FR1, as highlighted in the PRISMA flowchart, 930 articles were screened based on title and abstract and 685 were excluded at this stage; 245 were screened based on full-texts and 90 were excluded at this stage, and after a more thorough assessment, only one published article was eligible for inclusion in the scoping review for the highest range of frequencies (this article reported occupational exposures for both FR1 and FR2, so this doesn't add up to the overall number of included studies) (Fig. 10).

Two articles that were included in IARC Monograph 102 (IARC, 2013) (and are therefore not described here) presented exposures related to FR2 range: it was decided to provide the most important information in the summary tables, since these novel frequencies are the real focal point of this scoping review.

Again, for each article, the abstract is presented, together with a table summarising the most important information; furthermore, a senior expert evaluated their adequacy for assessing carcinogenic effects (adequate/inadequate), and an overall synthesis of the results (positive/negative/equivocal), following the criteria used to assess the adequacy described in the methodology section.

Figure 10 – Flow diagram. Epidemiological studies on cancer for FR2



In conclusion, search on PubMed e EMFPortal databases for epidemiological studies considering exposures from 24GHz to 100 GHz (FR2) included 3 studies. Two were already described in the IARC Monograph 102 (Stang et al., 2001 (1); Baumgardt-Elms et al., 2002 (2)) , one was published after 2011 (Vila et al, 2018 (3)); the latter was also studied in the lower frequencies analysis included in the review.The 3 studies regard occupational exposures of radar operators or workers nearby radar stations. The range of frequencies used by radar telecommunications are represented in Table 5 (IEEE 521-2002). Exposure of workers is not well assessed, as the RF-EMF exposure is self reported, usually quantified by distance from the radar or simply job title:

Table 5 – Range of frequencies used by radar communication.

Range name	Frequency
L	1 - 2 GHz
S	2 – 4 GHz
C	4 – 8 GHz
[3]	8 – 12 GHz
Ku	12 – 18 GHz
K	18 – 27 GHz
Ka	27 – 40 GHz
V	40 – 75 GHz
W	75 – 110 GHz

Summaries of the analysed studies for these frequencies are presented in Tables 6a,b. The epidemiological study not included in the 2011 IARC Working group evaluation is the following:

3. Vila et al., 2018.

Australia, Canada, France, Germany, Israel, New Zealand and the United Kingdom; 2000-2004; INTEROCC study: international case-control study on mobilephone use and brain cancer risk in seven countries.

In 2011, the International Agency for Research on Cancer classified radiofrequency (RF) electromagnetic fields (EMF) as possibly carcinogenic to humans (group 2B), although the epidemiological evidence for the association between occupational exposure to RF-EMF and cancer was judged to be inadequate, due in part to limitations in exposure assessment. This study examines the relation between occupational RF and intermediate frequency (IF) EMF exposure and brain tumour (glioma and meningioma) risk in the INTEROCC multinational population-based case-control study (with nearly 4000 cases and over 5000 controls), using a novel exposure assessment approach. Methods: Individual indices of cumulative exposure to RF and IF-EMF (overall and in specific exposure time windows) were assigned to study participants using a source-exposure matrix and detailed interview data on work with or nearby EMF sources. Conditional logistic regression was used to investigate associations with glioma and meningioma risk. Overall, around 10% of study participants were exposed to RF while only 1% were exposed to IF-EMF. There was no clear evidence for a positive association between RF or IF-EMF and the brain tumours studied, with most results showing either no association or odds ratios (ORs) below 1.0. The largest adjusted ORs were obtained for cumulative exposure to RF magnetic fields (as A/m-years) in the highest exposed category (≥90th percentile) for the most recent exposure time window (1–4 years before the diagnosis or reference date) for both glioma, OR=1.62 (95% confidence interval (CI): 0.86, 3.01) and meningioma (OR=1.52, 95% CI: 0.65, 3.55). Despite the improved exposure assessment approach used in this study, no clear associations were identified. However, the results obtained for recent exposure to RF electric and magnetic fields are suggestive of a potential role in brain tumour promotion/progression and should be further investigated.

Comment*: *Improved exposure assessment. No clear associations were identified for glioma and meningioma, potential role in brain tumour promotion/progression.

Table 6 – Cancer in epidemiological case-control studies (24 to 100 GHz, MMW) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
1.Stang et al. 2001. Germany. 1994-1997. Hospital-based and population-based case-control study.	118 cases, 475 controls (M and F). 35-74 years. Hospital-based case-control study at the Division of Ophthalmology, University of Essen; Controls in the population-based study were selected randomly from mandatory lists of residence.	Occupational sources of electromagnetic radiation. Self-reported exposure from face-to-face interview.	Lifetime exposure: source of exposure, duration, beginning of exposure.	Uveal Melanoma. Odds ratios (ORs) and 95% CI from conditional logistic regression models.	**OR (95% CI), Uveal Melanoma**		Medical history, phenotypic characteristics, life-style factors, Few participants reported exposure to radar	Adequate/negative (Uveal melanoma)
			EMF Source					
			Radar units		0.4 (0.0-2.6)			
2. Baumgardt-Elms et al. 2002. Germany. 1995-1997. Population-based case–control study.	269 cases, 797 controls (M). 15-69 years. Cases were ascertained through an active reporting system of clinical and pathology departments in the study regions. Controls were selected at random from the mandatory registries of residents.	Occupational exposure to EMF. Self-reported exposure from face-to-face interview.	At least 6 months of exposure. Exposures grouped according to the electromagnetic spectrum and assumptions on the strength of the electric and magnetic fields measured in specific workplaces.	Testicular cancer; Odds ratio and 95% confidence intervals (OR, 95% CI) from conditional logistic regression.	**OR (95% CI), testicular cancer**		Matching factors age (ten 5-year age groups since there were no cases in the highest age group) and region of residence (five strata) through stratification; subgroup analysis for blue- and white-collar workers.	Adequate/negative (Tumours of the testis)
			EMF Source					
			Working near radar units		1.0 (0.60-1.75)			

Table 6 – Cancer in epidemiological case control studies (24 to 100 GHz, MMW) (continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
3. Vila et al. 2018. Australia, Canada, France, Germany, Israel, New Zealand and the United Kingdom; 2000-2004; INTEROCC study: international case-control study on mobilephone use and brain cancer risk in seven countries.	2054 glioma cases; 1924 meningioma cases; 5601 controls (M and F). Cases aged 30 to 59 years of age; up to 69 years in Germany; 18 years and above in Israel; 18 to 69 years in the United Kingdom. In person computer-assisted personal interview.	Self-reported occupational exposure or proximity to radars, telecommunication antennas, transmitters, equipment for semiconductors manufacturing, medical diagnosis and treatment, industrial heating or food heating. A source-exposure matrix (SEM) was used to assign average exposure levels to each RF and IF source reported. Field intensities for each EMF source were weighted using the frequency-dependent reference levels (RLs) by the International Commission on Non-Ionising Radiation Protection (ICNIRP) for occupational exposure. Frequency of exposure: 10 MHz-300 GHz.	E-field (V/m, Arithmetic mean exposure levels from the SEM. RF sources organized by E-field exposure level)	Glioma and meningioma risk; adjusted OR and 95% confidence intervals.	**OR (95% CI) for Gliomas**	**OR for Meningiomas**	No information available Improved exposure assessment. No clear associations were identified for glioma and meningioma, potential role in brain tumour promotion/progression.	Adequate/negative (glioma and meningioma)
			Duration of exposure: 1-4 years					
			Non exposed		1.00 (ref.)	1.00 (ref.)		
			<0.42		0.69 (0.49-0.98)	0.60 (0.38-0.96)		
			0.42–4.47		0.85 (0.54-1.35)	1.13 (0.60-2.14)		
			4.48–18.8		0.77 (0.44-1.37)	0.86 (0.35-2.13)		
			≥18.9		1.38 (0.75-2.54)	1.30 (0.58-2.91)		
			Duration of exposure: 5-9 years					
			Non exposed		1.00 (ref.)	1.00 (ref.)		
			<0.42		0.84 (0.61-1.17)	0.60 (0.38-0.97)		
			0.42–4.47		0.93 (0.60-1.44)	1.48 (0.84-2.61)		
			4.48–18.8		0.82 (0.46-1.47)	1.08 (0.66-2.39)		
			≥18.9		0.90 (0.44-1.83)	1.03 (0.45-2.63)		

Table 7 (Summary 6 a, b) – Summary table for epidemiological studies on Cancer, FR2: 24-100 GHz

Total studies*	3			
Adequate studies	3			
Observed Tumour	Total adequate studies	Positive results	Equivocal results	Negative results
Glioma	1			1
Meningioma	1			1
Uveal melanoma	1			1
Testicular cancer	1			1

*one of the studies includes more than one tumour site.

- **SUMMARY OF THE RESULTS EPIDEMIOLOGICAL STUDIES ON CANCER (FR2: 24 to 100 GHz, MMW) (Table 6a, b)**

All 3 adequate studies reviewed did not show any clear association between exposure to higher frequencies (FR2) and the selected cancer (table 7).

The IARC Working group in the summary of data reported for occupational exposure regarding also FR2, concluded:

"Tumours of the brain*: "…exposure misclassification and insufficient attention to possible confounding limit the interpretation of findings. Thus, there is no clear indication of an association of occupational exposure to RF radiation with risk of cancer of the brain. "*

"Leukaemia/Lymphoma*: In summary, while there were weak suggestions of a possible increase in risk of leukaemia or lymphoma associated with occupational exposure to RF radiation, the limited exposure assessment and possible confounding make these results difficult to interpret".*

Other kinds of tumour emerged as potentially associated with exposure to high frequencies (uveal melanoma, cancer of the testis, breast, lung, and skin), but many of the studies showed methodological limitations and the results were inconsistent (IARC 2013). Afterwards, any other adequate study was performed regarding the association of these types of tumours with the exposure to RF-EMF (FR2).

The present review bears out these remarks, so we must confirm that, where the highest 5G (FR2) frequency is concerned, the only 3 epidemiological studies examined for FR2 exposure are *not adequate* to assess the impact on health.

4.1.3 Cancer in experimental animals: Studies evaluating health effects due to RF at a lower frequency range (FR1: 450 to 6000 MHZ), which also includes the frequencies used in previous generations' broadband cellular networks (1G, 2G, 3G and 4G).

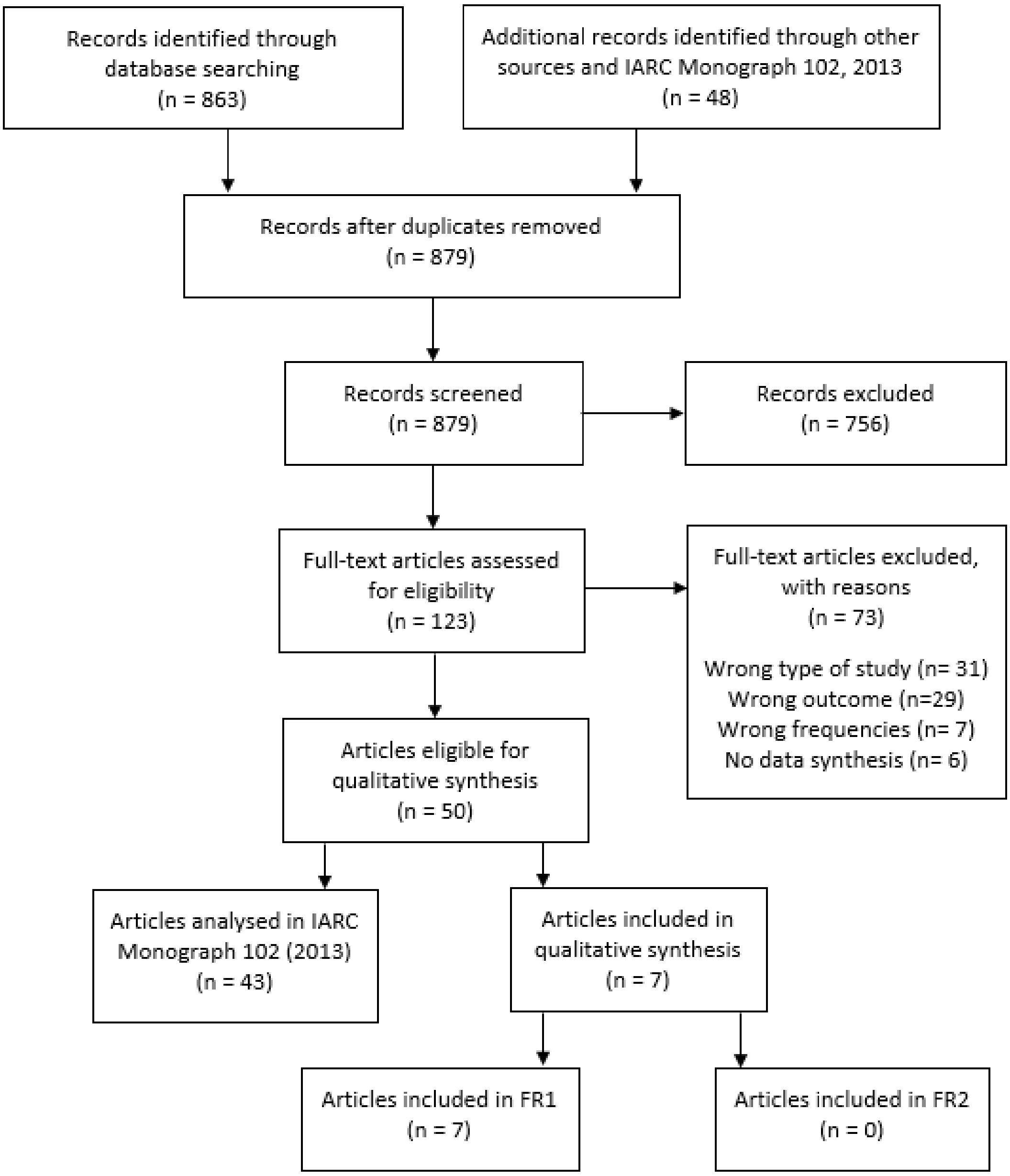
The articles identified through database searching and other sources were 911. After removing duplicates (32) and excluding non-pertinent articles (756) based on title and abstracts, 123 articles remained. Based on full-text screening, 73 papers were further excluded, so that the articles with frequencies appropriate for inclusion in this qualitative synthesis were 50.

As further explained in the methodology section, we considered IARC Monograph 102 (IARC, 2013) as our key reference for all studies on cancer in experimental animals published until 2011: all original papers (43) that were included in the IARC monograph were analysed and referenced in this report as well; of course, we considered for this report only the final IARC classification. Seven adequate studies were published after 2011.

At this stage, a separation based on frequency range was also performed: of the 7 papers included, all reported exposures belonging to the band considered in FR1, and none reported exposures regarding FR2 (Fig. 11).

For each article selected, the abstract is presented, together with the tables summarising the most important information; furthermore, a senior expert evaluated their adequacy for assessing carcinogenic effects adequate/inadequate), and expressed an overall synthesis of the results (positive/negative/equivocal), following the criteria described in the methodology chapter.

Figure 11 – Flow diagram. Cancer in experimental animal studies FR1



KEY REFERENCE: IARC 2013 (43 studies)

The IARC Monograph 102 is the key reference for the present review. The evaluation of the adequate available studies at that time is reported below (IARC, 2013).

In May, 2011, 30 scientists from 14 countries met at the International Agency for Research on Cancer(IARC) in Lyon, France, to assess the carcinogenicity of radiofrequency electromagnetic fields (RF-EMF). These assessments was published as Volume 102 of the IARC Monographs (IARC, 2013).

Four classes of cancer bioassays in animals were reviewed and assessed by the Working Group. These studies involved a variety of animal models, exposure metrics, duration of exposure, and other criteria on which the evaluation of carcinogenicity was based.

The Working Group evaluated:

- 7 two-year cancer bioassays of RF radiation, two in mice and five in rats; six studies were performed to examine the effects of exposure to mobile-phone RF metrics, and one study involved exposure to pulsed RF radiation. When compared with sham controls, no statistically significant increases in the incidence of benign or malignant neoplasms at any organ site were identified in animals exposed to mobilephone RF radiation in any study. In the study with exposure to pulsed RF radiation, an increased incidence of total malignant tumours (all sites combined) was observed in rats; however, the Working Group considered this finding to be of limited biological significance since it resulted from pooling of non-significant changes in tumour incidence at several sites. Exposure to RF radiation did not increase total tumour incidence in any of the other six studies that were evaluated. The Working Group concluded that the results of the 2-year cancer bioassays provided no evidence that long-term exposure to RF radiation increases the incidence of any benign or malignant neoplasm in standard-bred mice or rats.

- 12 studies that used four different tumour-prone animal models; two of these studies demonstrated an increased incidence of tumours in animals exposed to RF radiation. The first study with positive results demonstrated an increased incidence of lymphoma in *Eμ-Piml-transgenic* mice exposed to GSM mobile-phone RF radiation at 900 MHz; however, two subsequent studies by other investigators using the same model system failed to confirm this finding. In the second study with positive results, an increased incidence of tumours of the mammary gland was observed in C3H/HeA mice exposed to RF radiation at 2450 MHz; although two later studies using the same exposure metric did not confirm this finding, these follow-on studies were performed at lower levels of exposure. The Working Group concluded that the results of studies in three tumour-prone animal models (the *Eμ-Piml* mouse model of lymphoma, the *AKR* mouse model of lymphoma, and the *Patchedr -1* mouse model of brain cancer) do not support the hypothesis that the incidence of tumours in the brain or lymphoid tissue would increase as a result of exposure to RF radiation.

- 16 studies of initiation and promotion that were performed with animal models of tumourigenesis in skin, mammary gland, brain, and lymphoid tissue. None of the five studies in models of skin cancer and none of the six studies in models of brain cancer showed an association with exposure to RF radiation. One of four studies with the model of mammary-gland tumour in Sprague-Dawley rats gave positive results; the other three studies - one with a nearly identical protocol - did not show an association, although they used the same experimental model and the same conditions of exposure to RF radiation. Likewise, the study with the model of lymphoma was negative. The Working Group concluded that the evidence from these studies of initiation and promotion failed to demonstrate a consistent pattern of enhancement of carcinogenesis by exposure to RF radiation in any of the tissues studied.

- 6 co-carcinogenesis studies involving five different animal models. Four positive responses were reported. Two studies giving positive results, one in Wistar rats continuously exposed to drinking-water containing MX - a by-product of water disinfection - and another study in pregnant B6C3F1 mice given a single dose of ethyl-nitrosourea, involved exposures to mobile-phone RF radiation at 900 and 1966 MHz, respectively. The other two studies with positive results involved coexposure of BALB/c mice to RF radiation at 2450 MHz and benzo[a]pyrene. Although the value of two of these studies was weakened by their unknown relevance to cancer in humans, the Working Group concluded that they did provide some additional evidence supporting the carcinogenicity of RF radiation in experimental animals.

The conclusion for the animal studies evaluation was: "*There is limited evidence in experimental animals for the carcinogenicity of radiofrequency radiation*" (IARC, 2013).

- REVIEW OF THE ANIMAL STUDIES 2011-2020

Starting from 2011, the present review evaluates by type of study and by year of publication (2011-2020) the animal studies also summarized in Table 3 (a, b, c, d). The author adds to short abstracts her own brief comments on the results of the different studies.

TWO YEAR CANCER BIOASSAY IN MICE (Table 8a)

1. NTP TR 596, 2018.

GSM-modulated RFR, B6C3F1/N mice (M, F), for 24 months, Carcinogenicity study.

Groups of 105 male and 105 female mice were housed in reverberation chambers and received whole-body exposures to GSM-modulated cell phone RFR at power levels of 0 (sham control), 2.5, 5, or 10 W/kg, 9 hours and 10 minutes per day, 7 days per week for 106 (males) or 108 (females) weeks with continuous cycling of 10 minutes on and 10 minutes off during a period of 18 hours and 20 minutes each day. The sham control animals were housed in reverberation chambers identical to those used for the exposed groups, but were not exposed to RFR; shared groups of unexposed mice of each sex served as sham controls for both RFR modulations. Fifteen mice per group were randomly selected from the core group after 10 weeks of study; 10 of those 15 mice per group were used for interim evaluation at 14 weeks, and five mice per group were used for genetic toxicity testing at 14 weeks. The remaining 90 animals per group were exposed up to 2 years. In the 2-year study, percent survival was significantly higher for the 5 W/kg males than the sham control group. Survival of the other exposed groups of males and females was generally similar to that of the sham controls. Mean body weights of exposed groups of males and females were similar to those of the sham controls throughout the study. The combined incidences of fibrosarcoma, sarcoma, or malignant fibrous histiocytoma of the skin were increased in 5 and 10 W/kg males, although not significantly or in a SAR-related manner; however, the incidences exceeded the overall historical control ranges for malignant fibrous histiocytoma. In the lung, there was a significant positive trend in the incidences of alveolar/ bronchiolar adenoma or carcinoma (combined) in males. Compared to the sham controls, all exposed groups of females had increased incidences of malignant lymphoma and the incidences in the 2.5 and 5 W/kg groups were significantly increased. The sham control group had a low incidence of malignant lymphoma compared to the range seen in historical controls. There were no nonneoplastic lesions that were considered related to exposure to GSM-modulated cell phone RFR.

2. NTP TR 596, 2018.

CDMA-modulated RFR, B6C3F1/N mice (M, F), for 24 months, Carcinogenicity study.

Groups of 105 male and 105 female mice were housed in reverberation chambers and received whole-body exposures to CDMA-modulated cell phone RFR at power levels of 0 (sham control), 2.5, 5, or 10 W/kg, 9 hours and 10 minutes per day, 7 days per week for 106 (males) or 108 (females) weeks with continuous cycling of 10 minutes on and 10 minutes off during a period of 18 hours and 20 minutes each day. The sham control animals were housed in reverberation chambers identical to those used for the exposed groups, but were not exposed to RFR; shared groups of unexposed mice of each sex served as sham controls for both RFR modulations. Fifteen mice per group were randomly selected from the core group after 10 weeks of study; 10 of those 15 mice per group were used for interim evaluation at 14 weeks, and five mice per group were used for genetic toxicity testing at 14 weeks. The remaining 90 animals per group were exposed up to 2 years. Percent survival was significantly higher in 2.5 W/kg males compared to that in the sham controls in the 2-year study. Survival of males and females in all other exposed groups was generally similar to that of the sham controls. Mean body weights of exposed groups of males and females were similar to those of the sham controls throughout the study. There was a significantly increased incidence of hepatoblastoma in 5 W/kg males. Compared to the sham controls, the incidences of malignant lymphoma were increased in all exposed groups of females, and the increase was significant in the 2.5 W/kg group. As noted for the GSM study, the shared sham control group had a low incidence of malignant lymphoma compared to the range observed in historical controls.There were no nonneoplastic lesions that were considered related to exposure to CDMA-modulated cell phone RFR.

Comprehensive summary: Under the conditions of these 2-year studies, there was equivocal evidence of carcinogenic activity of GSM-modulated cell phone RFR at 1,900 MHz in male B6C3F1/N mice based on the combined incidences of fibrosarcoma, sarcoma, or malignant fibrous histiocytoma in the skin, and the incidences of alveolar/ bronchiolar adenoma or carcinoma (combined) in the lung. There was equivocal evidence of carcinogenic activity of GSM-modulated cell phone RFR at 1,900 MHz in female B6C3F1/N mice based on the incidences of malignant lymphoma (all organs). There was equivocal evidence of carcinogenic activity of CDMA-modulated cell phone RFR at 1,900 MHz in male B6C3F1/N mice based on the incidences of hepatoblastoma of the liver. There was equivocal evidence of carcinogenic activity of CDMA-modulated cell phone RFR at 1,900 MHz in female B6C3F1/N mice based on the incidences of malignant lymphoma (all organs).

Comprehensive comment*: *Equivocal evidence of carcinogenicity in mice for GSM and CDMA-modulated RFR.

TWO YEAR CANCER BIOASSAY IN RATS (Table 9 a)

3. NTP TR 595, 2018.

GSM-modulated RFR, Harlan SD rats (M, F), prenatal exposure for 24 months, carcinogenicity study.

Beginning on GD 5, groups of 56 time-matched F0 female rats were housed in specially designed reverberation chambers and received whole-body exposures to GSM-modulated cell phone RFR at power levels of 0 (sham control), 1.5, 3, or 6 W/kg for 7 days per week, continuing throughout gestation and lactation. Exposure was up to 18 hours and 20 minutes per day with continuous cycling of 10 minutes on and 10 minutes off during the exposure periods. There were seven exposure groups per sex, including a shared sham control and three exposure groups for each modulation. At weaning, three males and three females per litter from 35 litters were randomly selected per exposure group for continuation. Weaning occurred on the day the last litter reached PND 21, marking the beginning of the 2-year studies. Groups of 105 male and 105 female F1 offspring continued to receive whole-body exposures to GSM-modulated cell phone RFR at the same power levels and under the same exposure paradigm, 7 days per week for up to 104 weeks. After 14 weeks of exposure, 10 rats per group were randomly selected for interim histopathologic evaluation and five were designated for genetic toxicity evaluation. In the heart at the end of the 2-year studies, malignant schwannoma (synonymous neurinoma) was observed in all exposed male groups and the 3 W/kg female group, but none occurred in the sham controls. Endocardial Schwann cell hyperplasia also occurred in a single 1.5 W/kg male and two 6 W/kg males. There were also significantly increased incidences of right ventricle cardiomyopathy in 3 and 6 W/kg males and females. In the brain of males, there were increased incidences of malignant glioma and glial cell hyperplasia in all exposed groups, but none in the sham controls. There was also increased incidences of benign or malignant granular cell tumours in all exposed groups. There were significantly increased incidences of benign pheochromocytoma and benign, malignant, or complex pheochromocytoma (combined) of the adrenal medulla in males exposed to 1.5 or 3 W/kg. In the adrenal medulla of females exposed to 6 W/kg, there were significantly increased incidences of hyperplasia. In the prostate gland of male rats, there were increased incidences of adenoma or adenoma or carcinoma (combined) in 3 W/kg males and epithelium hyperplasia in all exposed male groups. In the pituitary gland (pars distalis), there were increased incidences of adenoma in all exposed male groups. There were also increased incidences of adenoma or carcinoma (combined) of the pancreatic islets in all exposed groups of male rats, but only the incidence in the 1.5 W/kg group was significant. In female rats, there were significantly increased incidences of C-cell hyperplasia of the thyroid gland in all exposed groups, and significantly increased incidences of hyperplasia of the adrenal cortex in the 3 and 6 W/kg groups.

GSM-modulated RFR: Under the conditions of this 2-year whole-body exposure study, there was clear evidence of carcinogenic activity of GSM-modulated cell phone RFR at 900 MHz in male Hsd:Sprague Dawley SD rats based on the incidences of malignant schwannoma of the heart. The incidences of malignant glioma of the brain and benign, malignant, or complex pheochromocytoma (combined) of the adrenal medulla were also related to RFR exposure. The incidences of benign or malignant granular cell tumours of the brain, adenoma or carcinoma (combined) of the prostate gland, adenoma of the pars distalis of the pituitary gland, and pancreatic islet cell adenoma or carcinoma (combined) may have been related to RFR exposure. There was equivocal evidence of carcinogenic activity of GSM-modulated cell phone RFR at 900 MHz in female Hsd:Sprague Dawley SD rats based on the incidences of schwannomas of the heart. Increases in nonneoplastic lesions of the heart, brain, and prostate gland in male rats, and of the heart, thyroid gland, and adrenal gland in female rats occurred with exposures to GSM-modulated RFR at 900 MHz.

Comment*: *Positive evidence of carcinogenicity for malignant Schwannoma (neurinoma) of the heart associated to RF-EMF exposure in the near field (GSM-modulated RFR); the incidences of malignant glioma of the brain and benign, malignant, or complex pheochromocytoma (combined) of the adrenal medulla were also related to RFR exposure. Note: brain tumours and neurinomas are also increased in epidemiological studies.

4. Falcioni et al., 2018.

SD rats (M, F), prenatal exposure until spontaneous death, Carcinogenicity study.

Male and female Sprague-Dawley rats were exposed from prenatal life until natural death to a 1.8 GHz GSM far field of 0, 5, 25, 50 V/m with a whole-body exposure for 19 h/day. A statistically significant increase in the incidence of heart Schwannomas was observed in treated male rats at the highest dose (50 V/m). Furthermore, an increase in the incidence of heart Schwann cells hyperplasia was observed in treated male and female rats at the highest dose (50 V/m), although this was not statistically significant. An increase in the incidence of malignant glial tumours was observed in treated female rats at the highest dose (50 V/m), although not statistically significant. The RI findings on far field exposure to RFR are consistent with and reinforce the results of the NTP study on near field exposure, as both reported an increase in the incidence of tumours of the brain and heart in RFR-exposed Sprague-Dawley rats. These tumours are of the same histotype as those observed in some epidemiological studies on cell phone users. These experimental studies provide sufficient evidence to call for re-evaluation of the IARC conclusions regarding the carcinogenic potential of RFR in humans.

Comment* : *Positive evidence for an association of RF-EMF in the far field (environmental) exposure with an increase in heart Schwannoma (neurinoma is a synonymous) [pubblication of the whole study is ongoing]. Note: brain tumours and neurinomas are also increased in epidemiological studies.

TUMOUR-PRONE MICE (Table 10 a)

5. Lee et al., 2011

AKR/J mice (M, F), 42 weeks (~10 months), Lymphoma-prone.

Carcinogenic effects of combined signal RF-EMFs on AKR/J mice, which were used for the lymphoma animal model, were investigated. Six-week-old AKR/J mice were simultaneously exposed to two types of RF signals: single code division multiple access (CDMA) and wideband code division multiple access (WCDMA). AKR/J mice were exposed to combined RF-EMFs for 45 min/day, 5 days/week, for a total of 42 weeks. The whole-body average specific absorption rate (SAR) of CDMA and WCDMA fields was 2.0 W/kg each, 4.0 W/kg in total. When we examined final survival, lymphoma incidence, and splenomegaly incidence, no differences were found between sham- and RF-exposed mice. However, occurrence of metastasis infiltration to the brain in lymphoma-bearing mice was significantly different in RF-exposed mice when compared to sham-exposed mice, even though no consistent correlation (increase or decrease) was observed between male and female mice. However, infiltration occurrence to liver, lung, and spleen was not different between the groups. From the results, we suggested that simultaneous exposure to CDMA and WCDMA RF-EMFs did not affect lymphoma development in AKR/J mice.

Comment*: *Short period of exposure. Exposure did not affect lymphoma development in AKR/J mice.

PROMOTION STUDIES IN MICE (Table 11a)

6. Lerchl et al., 2015, B6C3F1 mice (F), 24 months, Promotion study.

(Tillmann et al., 2010) suggested tumour-promoting effects of RF-EMF. A replication study using higher numbers of animals per group and including two additional exposure levels (0 (sham), 0.04, 0.4 and 2 W/kg SAR) was performed. Numbers of tumours of the lungs and livers in exposed animals were significantly higher than in sham-exposed controls. In addition, lymphomas were also found to be significantly elevated by exposure. A clear dose-response effect was absent. We hypothesize that these tumour-promoting effects may be caused by metabolic changes due to exposure. Since many of the tumour-promoting effects in our study were seen at low to moderate exposure levels (0.04 and 0.4 W/kg SAR), thus well below exposure limits for the users of mobile phones, further studies are warranted to investigate the underlying mechanisms. Our findings may help to understand the repeatedly reported increased incidences of brain tumours in heavy users of mobile phones.

Comment: The study does not exactly replicate the Tillmann et al., (2010) study. It shows positive evidence of association between lung, liver tumours, and lymphomas with exposure to RF-EMF.

Table 8 – Cancer in experimental animals: two years cancer bioassays in mice (450-6000 MHz) (a)

Reference, Strain, Species (sex), Duration, Type of study	RF Exposure Level Frequencies, Intensities; Any Other Co-Exposure	Exposure time, No. of Animals	Increased Tumour Incidence (Significance)	Comments
1. NTP TR 596, B6C3F1/N mice (M, F), prenatal exposure for 24 months, carcinogenicity study, 2018	GSM, (1900 MHz), 2.5, 5, and 10 W/Kg	9 h/day, 7 days/week, 105/sex/group	Combined incidences of fibrosarcoma, sarcoma, or malignant fibrous histiocytoma in the skin and the incidences of alveolar/ bronchiolar adenoma or carcinoma (combined) in the lung. In females increased incidences of malignant lymphoma (all organs).	Adequate, equivocal
2. NTP TR 596, B6C3F1/N mice (M, F), prenatal exposure for 24 months, carcinogenicity study, 2018	CDMA (1900 MHz), 2.5, 5, and 10 W/Kg	9 h/day, 7 days/week, 105/sex/group	Hepatoblastoma of the liver. in female increased incidences of malignant lymphoma (all organs).	Adequate, equivocal

Table 9 – Cancer in experimental animals: two years cancer bioassays in rats (450-6000 MHz) (a)

Reference, Strain, Species (sex), Duration, Type of study	RF Exposure Level Frequencies, Intensities; Any Other Co-Exposure	Exposure time, No. of Animals	Increased Tumour Incidence (Significance)	Comments
3. NTP TR 595, SD rats (M, F), prenatal exposure for 24 months, carcinogenicity study, 2018	GSM, CDMA (900 MHz), 1.5, 3, 5 W/kg	9 h/day, 7 days/week, 105/sex/group	Male brain glioma, heart Schwannoma, and combined adrenal pheochromocytoma ($p < 0.05$)	Adequate, positive for heart Schwannomas and brain tumours; positive for adrenal tumours
4. NTP TR 595, SD rats (M, F),), prenatal exposure for 24 months, carcinogenicity study, 2018	GSM, CDMA (900 MHz), 1.5, 3, 5 W/kg	9 h/day, 7 days/week, 105/sex/group	Male brain glioma, heart Schwannoma, and combined adrenal pheochromocytoma ($p < 0.05$)	Adequate, positive for heart Schwannomas and brain tumours; positive for adrenal tumours
5. Falcioni et al., 2018, SD rats (M, F), prenatal exposure until spontaneous death, carcinogenicity study	GSM (1800 MHz), 0.1, 0.03, 0.001 W/Kg	19 h/day, 7 days/week, 200,400 /sex/group	Male heart Schwannoma ($p < 0.05$) and female brain glioma	Adequate, positive for heart Schwannomas; borderline for brain tumours

Table 10a - Cancer in experimental animals: tumour-prone mice (450-6000 MHz) (a)

Reference, Strain, Species (sex), Duration, Type of study	RF Exposure Level Frequencies, Intensities; Any Other Co-Exposure	Exposure time, No. of Animals	Increased Tumour Incidence (Significance)	Comments
6. Lee et al., 2011, AKR/J mice (M, F), 42 weeks (~10 months), Lymphoma-prone	CDMA (849 MHz) and WCDMA (1950 MHz), 4 W/kg (combined)	45 min/day, 5 days/week, 40/sex/group	No statistically significant increase in tumour incidence	Inadequate (Short daily exposure)

Table 10b - Cancer in experimental animals: promotion studies in mice (450-6000 MHz) (a)

Reference, Strain, Species (sex), Duration, Type of study	RF Exposure Level Frequencies, Intensities; Any Other Co-Exposure	Exposure time, No. of Animals	Increased Tumour Incidence (Significance)	Comments
7. Lerchl et al., 2015, B6C3F1 mice (F), 24 months, Promotion study	UMTS fields, 0.04, 0.4 and 2.0 W/kg; prenatal ENU 40mg/kg b.w.	23.5 h/day, 7 days/week, 96/group	Female lymphoma, lung adenoma and carcinoma, liver carcinoma (tumour promotion) ($p < 0.05$)	Adequate, positive

Table 11 (summary tables 8-10) - Collected data for experimental studies on Cancer (FR1: 450-6000 MHz)

Total studies FR1*	7							
Adequate studies	7							
	Rat				Mouse			
Observed Tumour	Total adequate studies[a]	Positive results	Equivocal results	Negative results	Total adequate studies[b]	Positive results	Equivocal results	Negative results
Glioma	3	2	1					
Heart Schwannoma	3	3						
Alveolar-bronchiolar adenoma, carcinoma					3	1	2	
Liver tumours	2		1		3	1	2	
Adrenal pheochromocytoma	2	2						
Pancreatic islet adenoma+carcinoma	2		2					
Prostate adenoma+carcinoma	2		2					
Pituitary gland adenoma	2		2					
Lymphoma					4	1	2	1
Fibrosarcoma, fibro-histiocitic sarcoma of the skin					3		2	

*Some of the studies include more than one tumour site. [a] 1 study published only partial results on brain and heart.[b]1 study on lymphoma prone mice

SUMMARY OF THE RESULTS OF CANCER IN EXPERIMENTAL ANIMALS STUDIES (FR1: 450 to 6000 MHZ)(Table 11)

Based on full-text screening, the articles with frequencies appropriate for inclusion in this qualitative synthesis were 50. As further explained in the methodology section, we considered IARC Monograph 102 (IARC, 2013) as our key reference for all studies on cancer in experimental animals published until 2011: all original papers (43) that were included in the IARC monograph were analysed and referenced in this report as well; of course, we considered for this report only the final IARC classification. Seven adequate studies were published after 2011. From the present review, 7 studies on carcinogenicity in experimental animals were selected. 4 studies were performed on mice, 3 were performed on rats. Summaries of the results are presented in Table 27.

Out of the 7 adequate studies, the results were:

- Carcinogenicity in mice:

Two adequate carcinogenicity studies were performed to investigate possible non-thermal adverse effects on carcinogenicity related to RF-EMF exposure in mice. The studies were performed by the NTP laboratory in the USA .

Ref: 1: GSM-modulated cell phone RFR at 1,900 MHz in male B6C3F1/N mice showed: *positive* association of RF-EMF exposure with combined incidences of fibrosarcoma, sarcoma, or malignant fibrous histiocytoma in the skin, and the incidences of alveolar/ bronchiolar adenoma or carcinoma (combined) in the lung. There was *equivocal* evidence of carcinogenic activity in female B6C3F1/N mice based on the incidences of malignant lymphoma (all organs).

Ref: 2: There was *equivocal* evidence of carcinogenic activity of CDMA-modulated cell phone RFR at 1,900 MHz in male B6C3F1/N mice based on the incidences of hepatoblastoma of the liver. There was equivocal evidence of carcinogenic activity of CDMA-modulated cell phone RFR at 1,900 MHz in female B6C3F1/N mice based on the incidences of malignant lymphoma (all organs).

Two studies with different animal model and design were also performed on mice:

Ref: 6: one study on lymphoma-prone mice did not show any increase in lymphoma (*no* evidence).

Ref: 7: one two-years promotion study showed a statistically significant increase of tumours of the lung and liver in exposed animals. In addition, lymphomas were also found to be significantly increased (*positive* ass0ciation)

- Carcinogenicity in rats

Three adequate carcinogenicity studies were performed to investigate possible non-thermal adverse effects on carcinogenicity related to RF-EMF exposure in rats. Two studies were performed by the NTP laboratory in the USA (Ref:3,4) , one study (partially published) by the Ramazzini Institute in Italy (Ref: 5).

The most convincing evidence for the 3 studies regards the statistically significant increase (positive association) of brain tumours (Ref: 3, 4) supported by the *equivocal* association of the same tumour in the third study (Ref: 5) and the statistically significant increase of a very rare tumour of the heart, malignant Schwannoma, in all 3 studies (*positive* association). The increase of adrenal pheochromocytoma was statistically significant (positive association), and pancreatic islet adenoma+carcinoma, prostate adenoma+carcinoma, pituitary gland adenoma were also increased in treated groups (Ref: 3, 4) (*equivocal* association).

FR1: Our review on experimental studies on rats and mice shows a sufficient evidence of carcinogenicity of RF-EMF at lower frequencies (FR1). The observation of tumours of the nervous system (central and peripheral) in male rats is of particular significance, because supporting findings of epidemiological studies.

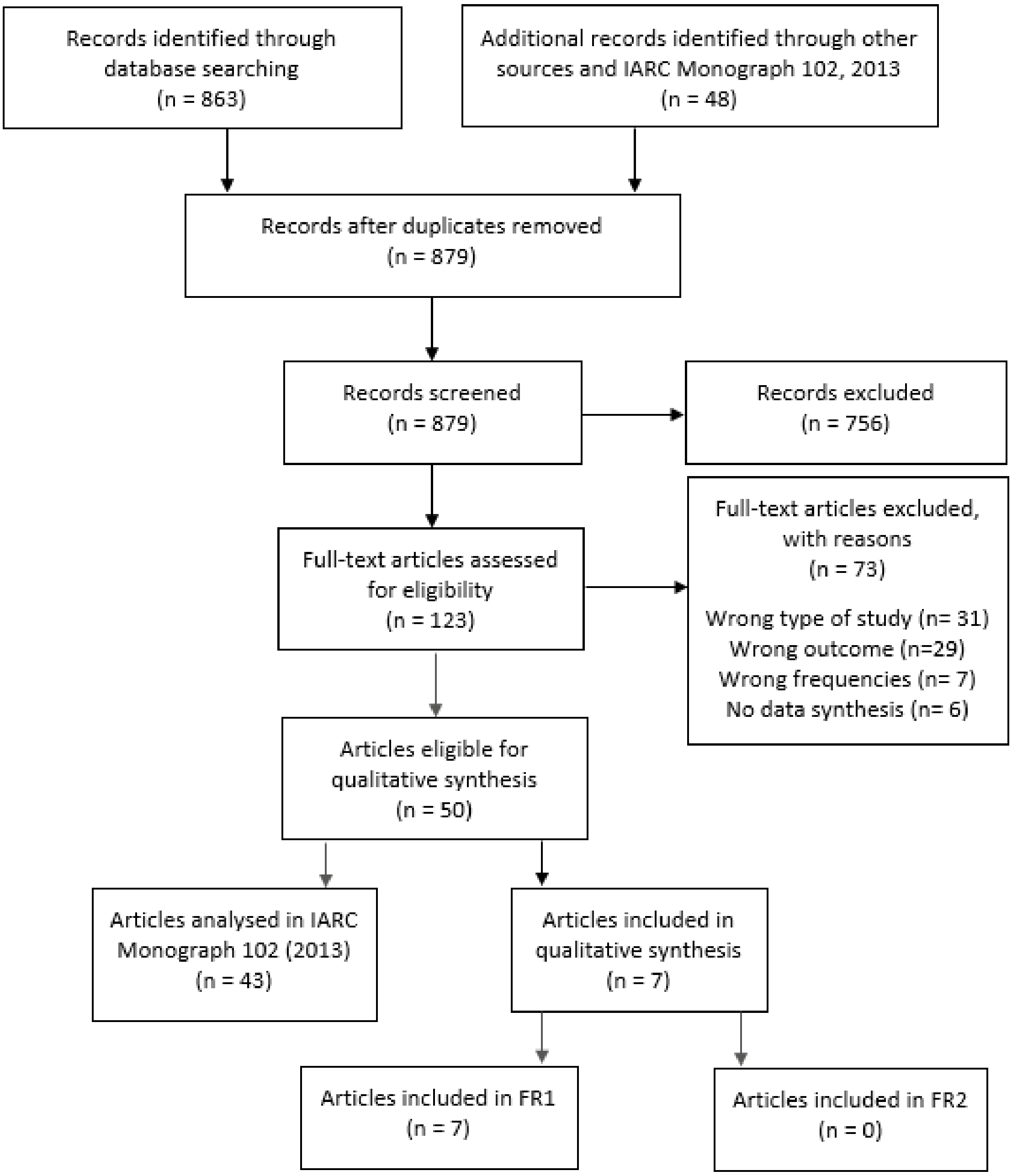
4.1.4 Cancer in experimental animals: Studies evaluating health effects due to RF at a higher frequency range (FR2: 24 to 100 GHz, MMW).

The articles identified through database searching and other sources were 911. After removing duplicates (32) and excluding non-pertinent articles (756) based on title and abstracts, 123 articles remained. Based on full-text screening, 73 papers were further excluded, so that the articles with frequencies appropriate for inclusion in this qualitative synthesis were 50 (Fig. 12).

As further explained in the methodology section, we considered IARC Monograph 102 (IARC, 2013) as our key reference for all studies on cancer in experimental animals published until 2011: all original papers (43) that were included in the IARC monograph were analysed and referenced in this report as well; of course, we considered for this report only the final IARC classification. Seven adequate studies were published after 2011.

At this stage, a separation based on frequency range was also performed: of the 7 papers included, all reported exposures belonging to the band considered in FR1, and none reported exposures regarding FR2. In conclusion, there is no available literature regarding the association between RF radiation at the range 24 to 100 GHz (MMW) in experimental carcinogenicity studies.

Figure 12 – Flow diagram. Cancer in experimental animal studies FR2



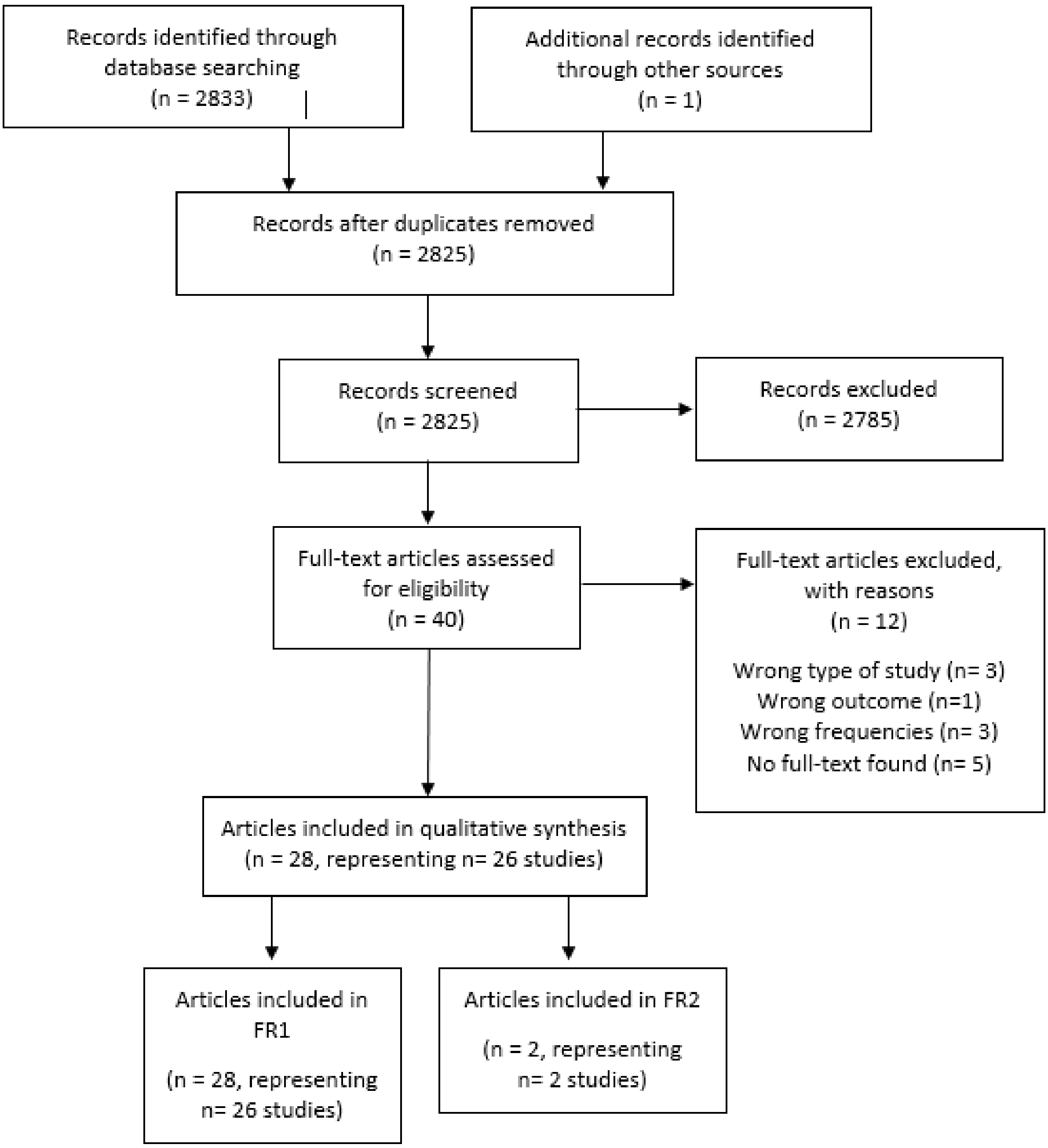
4.2 Reproductive/developmental adverse effects by frequency range

4.2.1 Reproductive/developmental effects in epidemiological studies: Studies evaluating health effects due to RF at a lower frequency range (FR1: 450 to 6000 MHZ), which also includes the frequencies used in previous generations' broadband cellular networks (1G, 2G, 3G and 4G).

The articles identified through database searching and other sources were 2834. After removing duplicates (9) and excluding non-pertinent articles (2785) based on title and abstracts, 40 articles remained. Based on full-text screening, 12 papers were further excluded, so that the published articles with appropriate frequencies to be included in this qualitative synthesis were 28, corresponding to 26 studies (in two cases, two papers were published reporting information on the same study) (Fig. 13).

At this stage, selection based on frequency range was also performed: 28 papers/26 studies referred to exposures belonging to the FR1 range, and 2 referred to FR2 as well. These 2 papers report exposures suitable for both FR1 and FR2, so they don't add up to the overall number of included studies; the same study is analysed therefore twice, once in every frequency range.

Figure 13 – Flow diagram. Epidemiological studies on reproductive/developmental effects FR1



MALE FERTILITY

Case-control studies (Tables 12a)

1. Al-Quzwini et al., 2016.

Iraq. Case-control study.

A seminal fluid analysis is clinical marker of male reproductive potential. To find out whether environmental hazard such as mobile phone tower has an effect on male reproductive ability. Two hundred couples were enrolled, one hundred subfertile couples as a study group (n=100), and one hundred fertile couples as a control group (n= 100). Environmental exposure to electromagnetic radiation from mobile phone towers and occupational state was assessed by standard questionnaire. Semen analysis was done for the subfertile males, because the fertile males (control group) refused to give semen samples. The occupational hazard expressed significant difference between the subfertile and the control groups (38% versus 12%) ($p< 0.05$), with odds ratio (OR) =4.5 and 95% Confidence Interval (CI): 2.175–9.288, and also the environmental factor (mobile tower within fifty meters from their house) showed significant difference (29% versus 12%) ($p< 0.05$), with OR= 3; 95% CI: 1.426–6.290. SFA of the subfertile males was 40% abnormal versus 60% normal semen analysis. These abnormalities were classified into 35% oligozoospermia, 55% asthenospermia, and 10% teratozoospermia. Oligozoospermia was associated with more occupational hazard (OR= 1.8, 95% CI: 0.569–5.527). Teratozoospermia was associated with more occupational hazard (OR= 5.23, 95% CI: 0.524–52.204), and with exposure to environmental hazard (OR = 2.6, 95% CI: 0.342– 19.070), and associated with smoking hazard (OR =1.7, 95% CI: 0.225–12.353). Male fertility represented by quality of semen might be affected by occupational and environmental exposures, so it seems that prevention of occupational and environmental risk factors, may lead to improvement of semen quality in subfertile men.

Comment*: *Inadequate/Inconclusive.

Cross-sectional studies (Tables 13, a-d)

2. Baste et al., 2008.

Norway. 2002-2004. Cross-sectional study, occupational exposure.

The authors performed a cross-sectional study among military men employed in the Royal Norwegian Navy, including information about work close to equipment emitting radiofrequency electromagnetic fields, one-year infertility, children and sex of the offspring. Among 10,497 respondents, 22% had worked close to high-frequency aerials to a "high" or "very high" degree. Infertility increased significantly along with increasing self-reported exposure to radiofrequency electromagnetic fields. In a logistic regression, the odds ratio (OR) for infertility among those who had worked closer than 10 m from high-frequency aerials to a "very high" degree relative to those who reported no work near high-frequency aerials was 1.86 (95% confidenceinterval (CI): 1.46–2.37), adjusted for age, smoking habits, alcohol consumption and exposure to organic solvents, welding and lead. Similar adjusted OR for those exposed to a "high", "some" and "low" degree were 1.93 (95% CI: 1.55–2.40), 1.52 (95% CI: 1.25–1.84), and 1.39 (95% CI: 1.15–1.68), respectively. In all age groups there were significant linear trends with higher prevalence of involuntary childlessness with higher self-reported exposure to radiofrequency fields. However, the degree of exposure to radiofrequency radiation and the number of children were not associated. For self-reported exposure both to high-frequency aerials and communication equipment there were significant linear trends with a lower ratio of boys to girls at birth when the father reported a higher degree of radiofrequency electromagnetic exposure.

Comment*: *Self-reported level of exposure. Higher degree of RF-EMF exposure associated to infertility and a lower ratio of boys to girls at birth.

3. Mollerlekken and Moen, 2008.

Norway. 2002. Cross-sectional, occupational exposure.

The aim of this study was to examine the relationship between workers exposed to electromagnetic fields and their reproductive health. We obtained data using a questionnaire in a cross-sectional study of naval military men, response rate 63% (n¼1487). The respondents were asked about exposure, lifestyle, reproductive health, previous diseases, work and education. An expert group categorized the work categories related to electromagnetic field exposure. We categorized the work categories "tele/communication," "electronics" and "radar/sonar" as being exposed to electromagnetic fields. Logistic regression adjusted for age, ever smoked, military education, and physical exercise at work showed increased risk of infertility among tele/ communication odds ratio (OR≤1.72, 95% confidence interval 1.04–2.85), and radar/sonar odds ratio (OR≤2.28, 95% confidence interval 1.27–4.09). The electronics group had no increased risk. This study shows a possible relationship between exposure to radiofrequency fields during work with radiofrequency equipment and radar and reduced fertility. However, the results must be interpreted with caution.

Comment*: *Self-reported exposure. Possible increased risk of infertility among telecommunication and radar/sonar operators.

4. Fejez et al., 2005.

Hungary. Cross-sectional study.

The history-taking of men in our university clinic was supplemented with questions concerning cell phone use habits, including possession, daily standby position and daily transmission times. Semen analyses were performed by conventional methods. Statistics were calculated with SPSS statistical software. A total of 371 were included in the study. The duration of possession and the daily transmission time correlated negatively with the proportion of rapid progressive motile sperm ($r = 0.12$ and $r = 0.19$, respectively), and positively with the proportion of slow progressive motile sperm ($r = 0.12$ and $r = 0.28$, respectively). The low and high transmitter groups also differed in the proportion of rapid progressive motile sperm (48.7% vs. 40.6%). The prolonged use of cell phones may have negative effects on the sperm motility characteristics.

Comment*: *Exposure self-reported. Confounding factors not analysed.

5. Jurewicz et al., 2014, Radwan et al., 2016 (they published the same study).

Poland. Cross-sectional study.

The aim of the study was to examine the association between modifiable lifestyle factors and main semen parameters, sperm morphology, and sperm chromatin structure. The study population consisted of 344 men who were attending an infertility clinic for diagnostic purposes with normal semen concentration of 20–300 M/ml or with slight oligozoospermia (semen total concentration of 15–20 M/ml) [WHO 1999]. Participants were interviewed and provided semen samples. The interview included questions about demographics, socio-economic status, medical history, lifestyle factors (consumption of alcohol, tobacco, coffee intake, cell phone and sauna usage), and physical activity. The results of the study suggest that lifestyle factors may affect semen quality. A negative association was found between increased body mass index (BMI) and semen volume ($p \le 0.03$). Leisure time activity was positively associated with sperm concentration ($p \le 0.04$) and coffee drinking with the percentage of motile sperm cells, and the percentage of sperm head and neck abnormalities ($p \le 0.01$, $p \le 0.05$, and $p \le 0.03$, respectively). Drinking red wine 1–3 times per week was negatively related to sperm neck abnormalities ($p \le 0.01$). Additionally, using a cell phone more than 10 years decreased the percentage of motile sperm cells ($p \le 0.02$). Men who wore boxer shorts had a lower percentage of sperm neck abnormalities ($p \le 0.002$) and percentage of sperm with DNA damage ($p \le 0.02$). These findings may have important implications for semen quality and lifestyle.

Comment*: *Self-reported exposure. Different confounders could affect results.

6. Yildirim et al., 2015.

Turkey. Cross-sectional study.

Semen for analyses from the male patients coming to our infertility division and also asked them to fill out an anonymous questionnaire. We queried their mobile phone and wireless internet usage frequencies in order to determine their radiofrequency-electromagnetic radiation exposure. A total of 1082 patients filled the questionnaire but 51 of them were excluded from the study because of azoospermia. There was no significant difference between sperm counts and sperm morphology excluding sperm motility, due to mobile phone usage period, ($p = 0.074$, $p = 0.909$, and $p = 0.05$, respectively). The total motile sperm count and the progressive motile sperm count decreased due to the increase of internet usage ($p = 0.032$ and $p = 0.033$, respectively). In line with the total motile sperm count, progressive motile sperm count also decreased with wireless internet usage compared with the wired internet connection usage ($p = 0.009$ and $p = 0.018$, respectively). There was a negative correlation between wireless internet usage duration and the total sperm count ($r = -0.089$, $p = 0.039$). We have also explored the negative effect of wireless internet use on sperm motility according to our preliminary results.

Comment*: *Exposure self-reported. Confounding factors were not analysed. Any difference between sperm parameters and cell phone and wireless internet usage is the authors conclusions.

7. Zilberlicht et al., 2015.

Israel. Cross-sectional.

Male infertility constitutes 30–40% of all infertility cases. Some studies have shown a continuous decline in semen quality since the beginning of the 20th century. One postulated contributing factor is radio frequency electromagnetic radiation emitted from cell phones. This study investigates an association between characteristics of cell phone usage and semen quality. Questionnaires accessing demographic data and characteristics of cell phone usage were completed by 106 men referred for semen analysis. Results were analysed according to WHO 2010 criteria. Talking for ≥1 h/day and during device charging were associated with higher rates of abnormal semen concentration (60.9% versus 35.7%, $P < 0.04$ and 66.7% versus 35.6%, $P < 0.02$, respectively). Among men who reported holding their phones ≤50 cm from the groin, a non-significantly higher rate of abnormal sperm concentration was found (47.1% versus 11.1%). Multivariate analysis revealed that talking while charging the device and smoking were risk factors for abnormal sperm concentration (OR = 4.13 [95% CI 1.28–13.3], $P < 0.018$ and OR = 3.04 [95% CI 1.14–8.13], $P < 0.027$, respectively). Our findings suggest that certain aspects of cell phone usage may bear adverse effects on sperm concentration. Investigation using largescale studies is thus needed.

Comment*: *Self-reported exposure. Some association was found.

8. Al-Bayyari, 2017.

Jordan. Cross-sectional observational study.

The objective was to study the effect of cell phone usage on semen quality and men's fertility. A cross-sectional observational study conducted on 159 men attending infertility clinics at North, Middle and South Governorates in Jordan and undergoing infertility evaluation were divided into two groups according to their active cell phone use: group A: ≤1 h/day and group B: >1 h/day. No interventions were given to patients and semen samples were collected by masturbation in a sterile container after an abstinence period of 5 days. The main outcome measures were sperm volume, liquefaction time, pH, viscosity, count, motility and morphology.

Time of talking by cell phone was recorded and the subjects were divided into 2 groups; group A ≤ 1 h/day (n = 104); group B > 1 h/day (n = 52) and participants who did not use cell phone (n = 3) were excluded from the statistical analysis regarding studying the effect of time spent in calling or receiving calls.There were no statistical significance differences (p > 0.05) between both groups regarding sperm quality parameters according to cell phone use, but there were statistical differences in the frequencies of sperm concentration, volume, viscosity, liquefaction time and means of immotile sperms and abnormal morphology. In addition, time spend on watching television and using wireless phones were significantly (p ≤0.05) associated with decreasing mean percentages of normal morphology. The distance from telecommunication tower was significantly (p ≤0.05) associated with decreasing sperms volume. Meanwhile, the time spent on sending or receiving messages was significantly (p ≤ 0.05) associated with decreasing sperms count and carrying mobile phone in trouser pocket was significantly associated with increasing means of immotile sperms. Cell phone use might have a negative effect on semen quality parameters and further research is needed.

Comment*: *Self-reported exposure. Cell phone use might have a negative effect on semen quality parameters.

9. Shi et al., 2018.

Cross-sectional study.

Three hundred and twenty-eight subjects who underwent semen analysis were recruited. Routine SA, sperm vitality, acrosome reaction (AR) assay and sperm DNA fragmentation index (DFI) were analyzed. Demographic and lifestyle information, including (1) BMI, (2) current smoking and alcohol drinking frequency, (3) sleep habits, (4) daily fluid intake, (5) weekly meat intake, (6) sports frequency, (7) trouser cell phone use, (8) age, and (9) abstinence time, were collected. Generalized additive models were used to analyze the possible non-linear association. The results showed that total sperm count (TSC) was significantly associated with age (P = 0.001), abstinence time (P = 0.001) and daily coffee intake (P = 0.044). Semen volume was significantly associated with age (P < 0.001) and daily coffee intake (P < 0.001). Sperm concentration was significantly associated with abstinence time (P = 0.011) and average sleep duration (P = 0.010). Sperm motility was significantly associated with age (P = 0.002) and daily juice intake (P = 0.001). Total motile sperm count was significantly associated with age (P = 0.003) and abstinence time (P = 0.009). DFI was significantly associated with age (P = 0.002), irregular sleeping habit (P = 0.008) and abstinence time (P = 0.032). The percentage of AR sperm was significantly associated with daily juice intake (P = 0.013). In conclusion, DFI and TSC were the most sensitive semen parameters for demographic and lifestyle features, whereas age had more influence on semen parameters than other demographic and lifestyle features. Trouser cell phone use was not significantly associated with any alteration of the sperm parameters examined.

Comment*: *Self-reported exposure. Many confounders in age and lifestyle. Any association with sperm alteration.

10. Blay et al., 2020.

Ghana. Cross-sectional study.

Male infertility is known to contribute about half of all infertility cases. In Ghana, the prevalence of male infertility is higher (15.8%) than in females (11.8%). Sperm quality is associated with the likelihood of pregnancy and known to be the cause of male fertility problems 90% of the time. Exposure to certain environmental factors reduces semen quality in men. The study examined the effects of environmental and lifestyle factors on semen quality in Ghanaian men. Materials and Methods. This was a cross-sectional study involving 80 apparent healthy adult males in their reproductive age. Participants were males referred to the laboratory (Immunology Unit of the Korle-Bu Teaching Hospital) for semen analysis test and/or culture and sensitivity. Participants were made to fill out a questionnaire which entailed selected environmental factors (accidents or trauma, exposure to chemicals, radiation, and heat) and lifestyle habits (including alcohol consumption, smoking, and whether participants sat more or less than 4 hours per day).

Semen samples were then collected by masturbation into sterile containers and analysed in accordance with WHO guidance for semen analysis within 60 minutes after ejaculation and collection. Results. About 69% of participants had semen pH within the normal range compared to 15% whose pH were lower than 7.2. There was a significantly high number of immotile sperm cells (p value = 0.017) in participants who sat for more than 4 hours as compared to those that sat for less than 4 hours in a day. Active sperm motility and viability showed significant increase (p value = 0.002 and 0.009, respectively) in participants who kept their cell phones in their side pockets. Smoking produced a twofold decrease in sperm count as smokers had a significantly lower sperm count (12:28 ± 10:95 × 106/ml) compared to the smoke-free (23:85 ± 22:14 × 106/ml). For exposure to STDs, no significant differences were recorded among study groups concerning semen quality. Conclusion. Sperm quality in Ghanaian men is associated with lifestyle habits. Smoking and sitting for long hours influenced sperm motility and count, respectively. Knowledge of the factors that influence sperm quality in this geographical region can contribute to informed decisions on effective management of infertility in Ghanaian men.

Comment*: *Self-reported exposure, uncertain. Increased activity and viability associated to cell phone in their side pockets. Many confounders.

Cohort studies (Tables 14, a-c)

11. Zhang, 2016.

China. 2013-2015. Cohort study.

Recruiting participants from infertility clinic not from general population may raise the possibility of a selection bias. To investigate effects of cell phone use on semen parameters in a general population. We screened and documented the cell phone use information of 794 young men from the Male Reproductive Health in Chongqing College students (MARHCS) cohort study in 2013, followed by 666 and 568 in 2014 and 2015, respectively. In the univariate regression analyses, we found that the daily duration of talking on the cell phone was significantly associated with decreased semen parameters, including sperm concentration [β coefficient = −6.32% per unit daily duration of talking on the cell phone (h); 95% confidence interval (CI), −11.94, −0.34] and total sperm count (−8.23; 95% CI, −14.38, −1.63) in 2013; semen volume (−8.37; 95% CI, −15.93, −0.13) and total sperm count (−16.59; 95% CI, −29.91, −0.73) in 2015]. Internet use via cellular networks was also associatedwith decreased sperm concentration and total sperm counts in 2013 and decreased semen volume in 2015. Multivariate analyseswere used to adjust for the effects of potential confounders, and significant negative associations between internet use and semen parameters remained. Consistent but nonsignificant negative associations between talking on the cell phone and semen parameters persisted throughout the three study years, and the negative association was statistically significant in a mixed model that considered all three years of data on talking on the cell phone and semen quality. Our results showed that certain aspects of cell phone use may negatively affect sperm quality inmen by decreasing the semen volume, sperm concentration, or sperm count, thus impairing male fertility.

Comment*: *Self-reported exposure. Confounding not analysed. Association with impairment of male fertility.

12. Lewis et al., 2017.

USA. 2004-2015. Longitudinal cohort study, part of the EARTH Study.

This is a longitudinal cohort study that recruited couples seeking infertility treatment from the Massachusetts General Hospital (MGH) Fertility Center; difficulty conceiving may be related to a male factor, a female factor, or a combination of both male and female factors. The relationship between mobile phone use patterns and markers of semen quality was explored in a longitudinal cohort study of 153 men that attended an academic fertility clinic in Boston, Massachusetts. Men between the ages of 18–56 years were eligible to participate. Information on mobile phone use duration (no use, <2 h/day,2–4 h/day, >4 h/day), headset or earpiece use (never, occasionally, some of the time, most of the time, all of the time), and location in which the mobile phone was carried (pants pocket, belt, bag, other) was ascertained via nurse-administered questionnaire. Semen samples (n = 350) were collected and analysed onsite. To account for multiple semen samples per man, linear mixed models with random intercepts were used to investigate the association between mobile phone use and semen parameters. Overall, there was no evidence for a relationship between mobile phone use and semen quality.

***Comment*: Self-reported exposure. No evidence for a relationship between mobile phone use and semen quality.**

DEVELOPMENTAL STUDIES

Case-control studies (Tables 15 a-f)

13. Tan et al., 2014.

Singapore. Case-control study.

Threatened miscarriage occurs in 20% of pregnancies. We conducted a case-control study to assess the association between maternal lifestyle factors and risk of threatened miscarriage. Cases were 154 women presenting with threatened miscarriage in the 5th to 10th weeks of gestation; controls were 264 women without threatened miscarriage seen in antenatal clinic in the 5th to 10th week of pregnancy. Lifestyle variables were: current and past cigarette smoking, current second-hand cigarette smoke exposure, computer and mobile-phone use, perceived stress, past contraceptive use, past menstrual regularity and consumption of fish oils, caffeine and alcohol. Logistic regression was performed. In multivariate analysis, we found a positive association of threatened miscarriage with second-hand smoke exposure (OR 2.93, 95% CI 1.32–6.48), computer usage (>4 hours/day) (OR 6.03, 95% CI 2.82–12.88), mobile-phone usage (>1 hour/day) (OR 2.94 95% CI 1.32–6.53) and caffeine consumption (OR 2.95 95% CI 1.57– 5.57). Any fish oil consumption was associated with reduced risk of threatened miscarriage (OR 0.20, 95% CI 0.09–0.42). Prolonged mobile phone and computer use and fish oil supplementation are potential novel correlates of threatened miscarriage that deserve further study.

***Comment*: Self-reported exposure. Stress as a confounding variable not considered. Correlation between mobile phone and computer use and threatened miscarriage observed.**

14. Mahmoudabadi et al., 2015.

Iran. Case-control study.

Exposure to electromagnetic fields of cell phones increasingly occurs, but the potential influence on spontaneous abortion has not been thoroughly investigated. Methods: In a case–control study, 292 women who had an unexplained spontaneous abortion at < 14 weeks gestation and 308 pregnant women > 14 weeks gestation were enrolled. Two data collection forms were completed; one was used to collect data about socioeconomic and obstetric characteristics, medical and reproductive history, and lifestyles. Another was used to collect data about the use of cell phones during pregnancy. For the consideration of cell phone effects, we measured the average calling time per day, the location of the cell phones when not in use, use of hands-free equipment, use of phones for other applications, the specific absorption rate (SAR) reported by the manufacturer and the average of the effective SAR (average duration of calling time per day × SAR). Analyses were carried out with statistical package state software (SPSS)v.16. The association between use of cell phones and the risk of spontaneous abortions against potential confounders was supported by evidence that despite adjustments for many known or suspected risk factors in logistic regression analyses, the estimation was not significantly altered. All the data pertaining to mobile phones were different between the two groups except the use of hands-free devices ($p < 0.001$). Our result suggests that use of mobile phones can be related to the early spontaneous abortions.

Comment*: *Self-reported exposure. Use of mobile phones may be related to the early spontaneous abortions.

Cross-sectional studies (Tables 16, a,b)

15. Col-Araz, 2013.

Turkey. 2009. Cross-sectional study.

The study was conducted in Turkey at Gazintep University, Faculty of Medicine's Outpatient Clinic at the Paediatric Ward. It comprised 500 patients who presented at the clinic from May to December 2009. All participants were administered a questionnaire regarding their pregnancy history. SPSS 13 was used for statistical analysis. In the study, 90 (19%) patients had pre-term birth , and 64 (12.9%) had low birth weight rate Birth weight was positively correlated with maternal age and baseline maternal weight (r= 0.115, p= 0.010; r= 0.168, p= 0.000, respectively). Pre-term birth and birth weight less than 2500g were more common in mothers with a history of disease during pregnancy (p=0.046 and p=0.008, respectively). The habit of watching television and using mobile phones and computer by mothers did not demonstrate any relationship with birth weight. Mothers who used mobile phones or computers during pregnancy had more deliveries before 37 weeks (p=0.018, p=0.034; respectively). Similarly, pregnancy duration was shorter in mothers who used either mobile phone or computers during pregnancy (p=0.005, p=0.048, respectively). Mobile phones and computers may have an effect on pre-term birth.

Comment*: *Self-reported exposure. Mobile phones and computers may have an effect on pre-term birth.

16. Zarei S. et al., 2015.

Iran. 2014. Cross-sectional study.

The purpose of this study was to investigate whether the maternal exposure to different sources of electromagnetic fields affects the rate and severity of speech problems in their offspring. In this study, mothers of 35 healthy 3-5 years old children (control group) and 77 children diagnosed with speech problems who had been referred to a speech treatment centre in Shiraz, Iran were interviewed. These mothers were asked whether they had exposure to different sources of electromagnetic fields such as mobile phones, mobile base stations, Wi-Fi, cordless phones, laptops and power lines. A significant association between either the call time (P=0.002) or history of mobile phone use (months used) and speech problems in the offspring (P=0.003) was found. However, other exposures had no effect on the occurrence of speech problems. To the best of our knowledge, this is the first study to investigate a possible association between maternal exposure to electromagnetic fields and speech problems in the offspring. Although a major limitation in our study is the relatively small sample size, this study indicates that the maternal exposure to common sources of electromagnetic fields such as mobile phones can affect the occurrence of speech problems in the offspring.

Comment*: *Small sample size, limit in exposure assessment. Association between maternal use of mobile phone and speech problems in the offspring.

17. Abad et al., 2016.

Iran. Cross-sectional study.

Investigation of the associations between electromagnetic field exposure and miscarriage among women of Tehran. In this longitudinal study, 462 pregnant women with gestational age <12 wks from seven main regions of Teheran city in Iran with similar social and cultural status were participated. The mean age of women was 28.22±4.53 years old. The frequency of spontaneous miscarriage was 56 cases. The incidence of abortion was 12.3%. Women were interviewed face-to face to collect data. Reproductive information was collected using medical file recorded in those hospitals the subjects had delivery. The measuring device measured electromagnetic waves, Narda safety test solutions with valid calibration date at the entrance door of their houses. A significant likelihood of miscarriage in women who exposed to significant level of electromagnetic wave. However, this association was not confirmed by Wald test. This study may not provide strong or consistent evidence that electromagnetic field exposure is associated or cause miscarriage. This issue may be due to small sample size in this study.

Comment : Self-reported exposure. Small sample. Uncertain association between miscarriage and use of mobile phone.

18. Lu et al., 2017.

Japan. 2012-2014. Cross sectional study from cohort data.

The aim of the study was to determine the associations of excessive mobile phone use with neonatal birth weight and infant health status. A sample of 461 mother and child pairs participated in a survey on maternal characteristics, infant characteristics, and information about maternal mobile phone usage during pregnancy. Results showed that pregnant women tend to use mobile phones excessively in Japan. The mean infant birth weight was lower in the excessive use group than in the ordinary use group, and the frequency of infant emergency transport was significantly higher in the excessive use group than in the ordinary use group. Excessive mobile phone use during pregnancy may be a risk factor for lower birth weight and a high rate of infant emergency transport.

Comment: Self-reported exposure. Limited sample size. Limited assessment of mothers' exposure. Inconclusive.

Cohort studies (Tables 17, a-f)

19. Mjøen et al., 2006.

Norway. 1976-1995. Cohort study on adverse pregnancy outcome, occupational exposure.

The objective was to assess associations between paternal occupational exposure to RF-EMF and adverse pregnancy outcomes including birth defects using population-based data from Norway. Data on reproductive outcomes derived from the Medical Birth Registry of Norway were linked with data on paternal occupation derived from the general population censuses. Maritime occupations, telephone repair and installation workers and welders were chosen as three separate groups. An expert panel categorized occupations according to exposure. Three occupational exposure levels were assessed, reflecting probability of exposure to RFR; one group was "probably not exposed" (376,837 births), one group of "possibly exposed" (139,871 births), and one group of "probably exposed" (24,885 births). Using logistic regression 24 categories of birth defects as well as other adverse outcomes were analysed. In the offspring of fathers most likely to have been exposed, increased risk was observed for preterm birth (OR: 1.08, 95% confidence interval (CI): 1.03, 1.15). In this group we also observed a decreased risk of cleft lip (OR: 0.63, 95% CI: 0.41, 0.97). In the medium exposed group, we observed increased risk for a category of "other defects" (OR: 2.40, 95% CI:1.22, 4.70), and a decreased risk for a category of "other syndromes" (OR: 0.75, 95% CI: 0.56, 0.99) and upper gastrointestinal defects (OR: 0.61, 95% CI: 0.40, 0.93). The study is partly reassuring for occupationally exposed fathers.

Comment: Level of exposure uncertain. No evidence for a relationship between occupational exposure to RF-EMF and adverse pregnancy outcome.

20. Divan at al., 2008; Divan et al., 2011.

Denmark. Children born between 1997 and 1999, then updated to 2002. Cohort study.

The association between prenatal and postnatal exposure to cell phones and behavioral problems in young children was examined. Mothers were recruited to the Danish National Birth Cohort early in pregnancy. When the children of those pregnancies reached 7 years of age in 2005 and 2006, mothers were asked to complete a questionnaire regarding the current health and behavioral status of children, as well as past exposure to cell phone use. Mothers evaluated the child's behavior problems using the Strength and Difficulties Questionnaire. Mothers of 13,159 children completed the follow-up questionnaire reporting their use of cell phones during pregnancy as well as current cell phone use by the child. Greater odds ratios for behavioral problems were observed for children who had possible prenatal or postnatal exposure to cell phone use. After adjustment for potential confounders, the odds ratio for a higher overall behavioral problems score was 1.80 (95% confidence interval 1.45–2.23) in children with both prenatal and postnatal exposure to cell phones. Exposure to cell phones prenatally—and, to a lesser degree, postnatally—was associated with behavioral difficulties such as emotional and hyperactivity problems around the age of school entry.

Comment*: *Self-reported exposure and other possible confounders. Exposure to cell phone prenatally—and, to a lesser degree, postnatally—was associated with behavioral difficulties such as emotional and hyperactivity problems around the age of school entry.

Denmark. Children born between 1996 and 2002. Cohort study.

The aim of the second study was to examine if prenatal use of cell phones by pregnant mothers is associated with developmental milestones delays among offspring up to 18 months of age.
Methods Our work is based upon the Danish National Birth Cohort (DNBC), which recruited pregnant mothers from 1996–2002, and was initiated to collect a variety of detailed information regarding in utero exposures and various health outcomes. At the end of 2008, over 41 000 singleton, live births had been followed with the Age-7 questionnaire, which collected cell-phone-use exposure for mothers during pregnancy. Outcomes for developmental milestones were obtained from telephone interviews completed by mothers at age 6- and 18-months postpartum. Results A logistic regression model estimated the odds ratios (OR) for developmental milestone delays, adjusted for potential confounders. Less than 5% of children at age 6 and 18 months had cognitive/language or motor developmental delays. At 6 months, the adjusted OR was 0.8 [95% confidence interval (95% CI) 0.7–1.0] for cognitive/ language delay and 0.9 (95% CI 0.8–1.1) for motor development delay. At 18 months, the adjusted OR were 1.1 (95% CI 0.9–1.3) and 0.9 (95% CI 0.8–1.0) for cognitive/language and motor development delay, respectively. Conclusions No evidence of an association between prenatal cell phone use and motor or cognitive/language developmental delays among infants at 6 and 18 months of age was observed. Even when considering dose–response associations for cell phone use, associations were null.

***Comment*: *Self-reported exposure. No evidence of an association between prenatal cell phone use and motor or cognitive/language developmental delays*.**

21. Guxens et al., 2013.

The Netherlands. 2003-2004 enrolment; 2008-2009 assessment of behavioural problems; 2010-2011 retrospective exposure assessment.

The study was embedded in a population-based prospective birth cohort study. Together with cell phones, cordless phones represent the main exposure source of radiofrequency-electromagnetic fields to the head. Therefore, we assessed the association between maternal cell phone and cordless phone use during pregnancy and teacher-reported and maternal-reported child behaviour problems at age 5. The study was embedded in the Amsterdam Born Children and their Development study, a population-based birth cohort study in Amsterdam, the Netherlands (2003–2004). Teachers and mothers reported child behaviour problems using the Strength and Difficulties Questionnaire at age 5. Maternal cell phone and cordless phone use during pregnancy was asked about when children were 7 years old. A total of 2618 children were included. As compared to non-users, those exposed to prenatal cell phone use showed an increased but non-significant association of having teacher-reported overall behaviour problems, although without dose-response relationship. with the number of calls (OR=2.12 (95% CI 0.95 to 4.74) for <1 call/day, OR=1.58 (95% CI 0.69 to 3.60) for 1–4 calls/day and OR=2.04 (95% CI 0.86 to 4.80) for ≥5 calls/day). ORs for having teacher-reported overall behaviour problems across categories of cordless phone use were below 1 or close to unity. Associations of maternal cell phone and cordless phone use with maternal-reported overall behaviour problems remained non-significant. Non-significant associations were found for the specific behaviour problem subscales. Our results do not suggest that maternal cell phone or cordless phone use during pregnancy increases the odds of behaviour problems in their children.

Comment*: *Self-reported exposure and other possible confounders. Use of mobile phone during pregnancy increases specific behaviour problems, non significant.

22. Choi et al., 2017.

South Korea. 2006-2016. Multi-centre prospective cohort study (the Mothers and Children's Environmental Health (MOCEH) study).

Studies examining prenatal exposure to mobile phone use and its effect on child neurodevelopment show different results, according to the child's developmental stages. To examine neurodevelopment in children up to 36 months of age, following prenatal mobile phone use and radiofrequency radiation (RF-EMF) exposure, in relation to prenatal lead exposure, we analyzed 1198 mother-child pairs from a prospective cohort study (the Mothers and Children's Environmental Health Study). Questionnaires were provided to pregnant women at ≤20 weeks of gestation to assess mobile phone call frequency and duration. A personal exposure meter (PEM) was used to measure RF-EMF exposure for 24 h in 210 pregnant women. Maternal blood lead level (BLL) was measured during pregnancy. Child neurodevelopment was assessed using the Korean version of the Bayley Scales of Infant Development- Revised at 6, 12, 24, and 36 months of age. Logistic regression analysis applied to groups classified by trajectory analysis showing neurodevelopmental patterns over time. The psychomotor development index (PDI) and the mental development index (MDI) at 6, 12, 24, and 36 months of age were not significantly associated with maternal mobile phone use during pregnancy. However, among children exposed to high maternal BLL in utero, there was a significantly increased risk of having a low PDI up to 36 months of age, in relation to an increasing average calling time (p-trend=0.008). There was also a risk of having decreasing MDI up to 36 months of age, in relation to an increasing average calling time or frequency during pregnancy (p-trend=0.05 and 0.007 for time and frequency, respectively). There was no significant association between child neurodevelopment and prenatal RF-EMF exposure measured by PEM in all subjects or in groups stratified by maternal BLL during pregnancy. No association between prenatal exposure to RF-EMF and child neurodevelopment during the first three years of life was found; however, a potential combined effect of prenatal exposure to lead and mobile phone use was suggested.

Comment*: *Maternal blood lead level as main confounding factor. A potential combined effect is suggested.

23. Papadopoulou et al., 2017.

Norway. 1999-2008. Prospective population-based pregnancy cohort study MoBa, Norwegian Institute of Public Health.

The association between maternal cell phone use in pregnancy and child's language, communication and motor skills at 3 and 5 years was studied. This prospective study includes 45,389 mother-child pairs, participants of the MoBa, recruited at mid-pregnancy from 1999 to 2008. Maternal frequency of cell phone use in early pregnancy and child language, communication and motor skills at 3 and 5 years, were assessed by questionnaires. Logistic regression was used to estimate the associations. Results: No cell phone use in early pregnancy was reported by 9.8% of women, while 39%, 46.9% and 4.3% of the women were categorized as low, medium and high cell phone users. Children of cell phone user mothers had 17% (OR = 0.83, 95% CI: 0.77, 0.89) lower adjusted risk of having low sentence complexity at

3 years, compared to children of non-users. The risk was 13%, 22% and 29% lower by low, medium and high maternal cell phone use. Additionally, children of cell phone users had lower risk of low motor skills score at 3 years, compared to children of non-users, but this association was not found at 5 years. We found no association between maternal cell phone use and low communication skills. We reported a decreased risk of low language and motor skills at three years in relation to prenatal cell phone use, which might be explained by enhanced maternal-child interaction among cell phone users. No evidence of adverse neurodevelopmental effects of prenatal cell phone use was reported.

Comment*: *Self-reported exposure. No evidence of adverse neurodevelopmental effects of prenatal cell phone use was reported.

24. Sudan et al., 2018.

Denmark DNBC, Spain INMA, and Korea MOCEH.

The relationship between maternal cell phone use during pregnancy and cognitive performance in 5-years old children is studied. This study included data from 3 birth cohorts: the Danish National Birth Cohort (DNBC) (n=1209), Spanish Environment and Childhood Project (INMA) (n=1383), and Korean Mothers and Children's Environment Health Study (MOCEH) (n=497). All cohorts collected information about maternal cell phone use during pregnancy and cognitive performance in children at age 5. Linear regression to compute mean differences (MD) and 95% confidence intervals (CI) in children's general, verbal, and non-verbal cognition scores comparing frequency of maternal prenatal cell phone use with adjustments for numerous potential confounding factors were performed. Models were computed separately for each cohort and using pooled data in meta-analysis. No associations were detected between frequency of prenatal cell phone use and children's cognition scores. Scores tended to be lower in the highest frequency of use category; MD (95% CI) in general cognition scores were 0.78 (−0.76, 2.33) for none, 0.11 (−0.81, 1.03) for medium, and −0.41 (−1.54, 0.73) for high compared to low frequency of use. This pattern was seen across all cognitive dimensions, but the results were imprecise overall. Patterns of lower mean cognition scores among children in relation to high frequency maternal prenatal cell phone use were observed. The causal nature and mechanism of this relationship remain unknown.

Comment*: *Self-reported exposure. Patterns of lower mean cognition scores among children in relation to high frequency maternal prenatal cell phone use were observed.

25. Tsarna et al., 2019.

Denmark, Netherlands, Spain, South Korea. 1996-2011. Four population-based birth cohort studies participating in the GERoNiMO Project—namely, the Danish National Birth Cohort (DNBC), the Amsterdam Born Children and Their Development Study (ABCD), the Spanish Environment and Childhood Project (INMA), and the Korean Mothers and Children's Environment Health Study (MOCEH).

Results from studies evaluating potential effects of prenatal exposure to radio-frequency electromagnetic fields from cell phones on birth outcomes have been inconsistent. Using data on 55,507 pregnant women and their children from Denmark (1996–2002), the Netherlands (2003–2004), Spain (2003–2008), and South Korea (2006–2011), we explored whether maternal cell-phone use was associated with pregnancy duration and fetal growth. On the basis of self-reported number of cell-phone calls per day, exposure was grouped as none, low (referent), intermediate, or high. Pregnancy duration (gestational age at birth, preterm/post-term birth), fetal growth (birth weight ratio, small/large size for gestational age), and birth weight variables (birth weight, low/ high birth weight) and meta-analysed cohort-specific estimates were examined. The intermediate exposure group had a higher risk of giving birth at a lower gestational age (hazard ratio = 1.04, 95% confidence interval: 1.01, 1.07), and exposure response relationships were found for shorter pregnancy duration ($P < 0.001$) and preterm birth ($P = 0.003$). We observed no association with fetal growth or birth weight. Maternal cell-phone use during pregnancy may be associated with shorter pregnancy duration and increased risk of preterm birth, but these results should be interpreted with caution, since they may reflect stress during pregnancy or other residual confounding rather than a direct effect of cell-phone exposure.

Comment: Stress as a confounding factor. Uncertain association.

26. Boileau et al, 2020.

France. 2014-2017.Prospective, longitudinal, multicenter observational cohort study

The aim of this study was to evaluate the association between mobile phone use by pregnant women and fetal development during pregnancy in the general population.Data came from the NéHaVi cohort ("prospective follow-up, from intrauterine development to the age of 18 years, for children born in Haute-Vienne"), a prospective, longitudinal, multicenter (three maternity units in Haute-Vienne) observational cohort focusing on children born between April 2014 and April 2017. Main objective was to investigate the association of mobile phone use on fetal growth. Univariate and multivariate models were generated adjusted for the socioprofessional category variables of the mother, and other variables likely to influence fetal growth. For the analysis 1378 medical charts were considered from which 1368 mothers (99.3 %) used their mobile phones during pregnancy. Mean phone time was 29.8 min (range: 0.0–240.0 min) per day. After adjustment, newborns whose mothers used their mobile phones for more than 30 min/day were significantly more likely to have an AUDIPOG score ≤10th percentile than those whose mothers used their mobile phones for less than 5 min/day during pregnancy (aOR = 1.54 [1.03; 2.31], $p = 0.0374$). For women using their cell phones 5–15 min and 15–30 min, there wasn't a significant association with an AUDIPOG score ≤ 10th, respectively aOR = 0.98 [0.58; 1.65] and aOR = 1.68 [0.99; 2.82]. Using a mobile phone for calls for more than 30 min per day during pregnancy may have a negative impact on fetal growth. A prospective study should be performed to further evaluate this potential link.

Comment*: *Fetal growth restriction observed when mother were using mobile phone more than 30'/day.

Table 12 - Reproductive/developmental effects in humans: man fertility, epidemiologic case-control studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjustments	Comments
1. Al-Quzwini et al., 2016. Iraq, 2014-2015. Case-control study.	100 randomly selected subfertile couples that attended the infertility clinic of Babylon Teaching Hospital for Maternity and Pediatric in Al-Hilla city in Iraq; 100 volounteers fertile couples fro staff or relatives from same hospital as control group.	Environmental exposure to electromagnetic radiation from mobile phone towers and occupational state was assessed by standard questionnaire.	Living near to mobile phone base station (<50m) and with power intensity of 71.226 mW/m2, duration of exposure to the electromagnetic radiation. Occupational exposure to work hazard (ex. "driver" sitting for long period, "worker" painters and construction workers and "militaries")	Seminal fluid analysis of the subfertile males. Odds ratios and 95% CI, and Chi-square test for differences.	**Oligozoospermia among subfertile males, OR (95% CI)**	**Asthenospermia among subfertile males, OR (95% CI)**	**Teratozoospermia among subfertile males, OR (95% CI)**			Smoking	Inadequate Semen analysis was done for the subfertile males, because the fertile males (control group) refused to give semen samples.
			Type of hazard								
			Occupational		**1.8 (0.57-5.53)**	1.07 (0.87-1.32)	**5.23 (0.52-52.20)**				
			Environmental		1.03 (0.841.19)	1.19 (0.43-3.31)	**2.6 (0.34-19.07)**				

Table 13 - Reproductive/developmental effects in humans: man fertility, epidemiologic cross sectional -studies (450-6000 MHz) (occupational) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)						Any Other Co-Exposure/adjust ments	Comments
2. Baste et al., 2008. Norway. 2002-2004. Cross-sectional study	9925 current and former male military employees in the Royal Norwegian Navy, defined by the military employment list (M); mean age 49.	High-frequency aerials, communication equipment, radar. Self-assessed occupational exposure and age categories assessed by mail questionnaire.	Exposure to radiofrequency electromagnetic fields: work closer than 10 m from high-frequency aerials, work closer than 3 m from communication equipment and work closer than 5 m from radar.	Infertility. Odds ratios and 95% CI from adjusted logistic regression models; Mantel–Haenszel test for linear trend.	**Total Infertility - <10 m from high-frequency aerials, OR (95% CI)**	**Test for linear trend (Mantel–Haenszel chi-square)**	**Total Infertility - <3 m from communication equipment, OR (95% CI)**	**Test for linear trend (Mantel–Haenszel chi-square)**	**Total Infertility - <5 m from radar, OR (95% CI)**	**Test for linear trend (Mantel–Haenszel chi-square)**	Infertility. Odds ratios and 95% CI from adjusted logistic regression models; Mantel–Haenszel test for linear trend.	**Adequate/ Positive**
			Age <29									
			Not exposed									
			Low		1.00 (ref.)	0.013	1.00 (ref.)	0.077	1.00 (ref.)	0.001	Self-reported level of exposure.	
			Some		1.10 (0.30–4.07)		1.86 (0.54–6.40)		0.87 (0.25–2.99)			
			High		0.71 (0.15–3.34)		3.56 (1.05–12.08)		2.13 (0.64–7.06)			
			Very high		3.84 (1.09–13.52)		3.50 (0.83–14.78)		1.11 (0.20–6.00)			
			Age 30-39		2.70 (0.76–9.53)		2.49 (0.60–10.42)		5.09 (1.59–16.30)			
			Not exposed									
			Low		1.00 (ref.)	0.011	1.00 (ref.)	0.007	1.00 (ref.)	0.005		
			Some		1.24 (0.83–1.87)		1.53 (1.04–2.26)		1.46 (0.99–2.15)			
			High		1.36 (0.90–2.04)		1.88 (1.25–2.82)		1.32 (0.87–2.02)			
			Very high		1.51 (0.97–2.37)		1.76 (1.11–2.80)		1.79 (1.14–2.82)			
			Age 40-49		1.72 (1.08–2.74)		1.80 (1.10–2.96)		1.91 (1.19–3.07)			
			Not exposed									
			Low		1.00 (ref.)	<0.001	1.00 (ref.)	<0.001	1.00 (ref.)	0.002		
			Some		1.46 (1.03–2.07)		1.04 (0.75–1.45)		1.22 (0.87–1.71)			
			High		1.43 (0.99–2.07)		1.28 (0.91–1.81)		1.24 (0.87–1.79)			
			Very high		1.82 (1.21–2.75)		1.37 (0.91–2.08)		1.59 (1.05–2.41)			
			Age >50		1.90 (1.20–3.01)		1.86 (1.18–2.94)		1.50 (0.95–2.35)			
			Not exposed									
			Low		1.00 (ref.)	<0.001	1.00 (ref.)	<0.001	1.00 (ref.)	0.001		
			Some		1.28 (0.96–1.69)		1.02 (0.78–1.34)		1.11 (0.84–1.46)			
			High		1.59 (1.20–2.11)		1.31 (0.99–1.73)		1.58 (1.20–2.09)			
			Very high		2.02 (1.45–2.81)		1.71 (1.23–2.37)		1.39 (0.98–1.97)			

Table 13 - Reproductive/developmental effects in humans: man fertility, epidemiologic cross- sectional studies (450-6000 MHz) (occupational) (continue b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjustments	Comments
3. Møllerløkken et al., 2008. Norway. 2002. Cross-sectional study.	2265 (M) employees who were currently serving in the Navy, both military and civilians. Mean age of 36 years of age, range 20–62.	Occupational exposure from military communication equipment. Information on occupational history from mail questionnaire. An expert group determined work categories related to electromagnetic field exposure.	Workers in the radar/sonar-, the tele/communication, electronics, other jobs (unexposed).	Infertility, Biological Children, Anomalies, Chromosomal Errors, Preterm and Stillbirths or Infant Deaths. Incidence of outcome by exposure group (%); Chi2 or Fisher Exact Tests to assess significance of differences among groups.	**Infertility - % (p-value from Chi2 tests)**	**Having biological children - % (p-value from Chi2 tests)**	**Children with anomalies or chromosomal errors - % (p-value from Chi2 or Fisher's Exact tests)**	**Children with preterm births - % (p-value from Chi2 or Fisher's Exact tests)**	**Stillbirths and infant deaths within 1 year - % (p-value from Fisher's Exact tests)**	Age, ever smoked, military education, and physical exercise at work.	Adequate /positive
			Other jobs (unexposed group)		8.6	62.0	3.5	7.9	2.3		
			Tele/communication workers (communication equipment, radio)		**14.8 (0.01)**	63.5 (0.70)	6.0 (0.18)	10.8 (0.18)	3.6 (0.22)		
			Electronics (electronics for weapons and communication systems)		12.1 (0.15)	58.6 (0.40)	1.8 (0.19)	9.5 (0.44)	1.8 (0.47)		
			Radar/sonar workers (radar)		**17.5 (<0.01)**	70.4 (0.10)	7.1 (0.11)	9.1 (0.37)	2.0 (0.61)		

Table 13 - Reproductive/developmental effects in humans: man fertility, epidemiologic cross-sectional studies (450-6000 MHz) (continued c)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjustments	Comments
4. Fejez et al. 2005. Hungary. Cross-sectional study.	611 consecutive Caucasian men of reproductive age from clinic for infertility problems.	Self reported	Duration of possession (in months), duration of standby position closer than 50 cm to the patient (in hours) and duration of daily transmission (in minutes).	Quality of semen. Parametric t-test and the Pearson correlation tests were applied.	**Volume (ml), correlation, p-value**	**Sperm concentration (mln/ml)**	**Total motility (%)**	**Total sperm count (mln/ ejaculate)**	**Total motile sperm count (mln/ ejaculate)**	Occupational exposure to some chemical pesticides, petroleum, solvents, lead and nitrosamines, tobacco consumption.	Inadequate
			Duration of possession (months)		-0.02, 0.64	-0.01, 0.91	-0.08, 0.14	-0.01, 0.81	-0.03, 0.53	Many confounders not analysed	
			Duration of daily standby (h)		0.05, 0.42	-0.01, 0.39	-0.03, 0.64	-0.05, 0.41	-0.07, 0.22		
			Duration of daily transmission (min)		-0.01, 0.84	0.04, 0.84	-0.07, 0.16	0.03, 0.58	0.00, 0.54		
5. Jurewicz et al. 2014, and Radwan et al. 2016. Poland. Cross-sectional study.	344 men, age <45 years, attending infertility clinics in Lodz, Poland in 2008-2011 for diagnostic purposes.	Modifiable lifestyle factors, among which use of cell phone, assessed using self-administered questionnaire.	Duration of exposure from use of cell phones, assessed in years.	Semen quality (WHO 1999 reference values) and DNA fragmentation. Multiple linear regressions were used to assess association.	**Coeff for cell phone use, 0-5 years (p-value)**	**Coeff for cell phone use, 6-10 years (p-value)**	**Coeff for cell phone use, 11-25 years (p-value)**			Using cell phone more than 10 years decreased the percentage of motile sperm cells	Adequate/ positive
				Volume	1.16 (ref.)	-0.06 (0.32)	-0.01 (0.84)				
				Concentration	3.03 (ref.)	0.29 (0.22)	0.42 (0.13)				
				Motility	60.77 (ref.)	-4.13 (0.30)	**-11.27 (0.01)**				
				Atypical	45.73 (ref.)	4.44 (0.42)	**19.00 (0.01)**				
				Sperm head abnormalities	32.42 (ref.)	2.28 (0.69)	**17.58 (0.01)**				
				Sperm neck abnormalities	12.04 (ref.)	-0.25 (0.86)	0.12 (0.94)				
				Sperm tail abnormalities	2.02 (ref.)	-0.01 (0.96)	-0.02 (0.93)				
				DNA fragmentation index	2.52 (ref.)	0.01 (0.97)	0.20 (0.22)				

Table 13 - Reproductive/developmental effects in humans: man fertility, epidemiologic cross-sectional studies (450-6000 MHz) (continued d)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate					Any Other Co-Exposure/adjustments	Comments
6. Yildirim et al., 2015. Turkey, 2013-2014. Cross-sectional study.	1031 healthy men from the Andrology subdivision of the Urology Dept (Turgut Ozal University)	Use of mobile cell (850-1800 MHz) and wireless internet (2400 MHz), assessed using an anonymous questionnaire.	Daily the cell phone usage duration, habits of carrying mobile phone, wireless internet usage duration, and type of internet use.	Sperm parameters. Pearson correlation Coefficients, Student t test (2-tailed) and one way analysis of variance (ANOVA).	**Volume**	**Total sperm count (mln)**	**Total motile sperm count (mln)**	**Progressive motile sperm count (mln)**	**Morphology**	-	Inadequate
		Self-reported	*Duration of cell phone use (h)*	One way analysis of variance, p-value	0.194	0.074	**0.05**	0.083	0.909	Confounding factors not analysed	
			< 0.5		2.9 ± 1.41	42.3 ± 16.3	61.1 ± 60.6	47.5 ± 50.8	2.8 ± 1.9		
			0.5-2		2.9 ± 1.19	39.2 ± 16.3	54.6 ± 50.6	42.5 ± 42.1	2.57 ± 1.76		
			>2		3.01 ± 1.45	37.8 ± 16.1	53.8 ± 59	41.6 ± 51.2	2.74 ± 1.72		
			Mobile phone carrying habits	One way analysis of variance, p-value	0.973	0.256	0.168	0.538	**0.034**		
			Trouser pocket		2.9 ± 1.37	39.1 ± 31.1	56.5 ± 60.1	43.8 ± 51	2.72 ± 1.81		
			Handbag		3.08 ± 1.4	45 ± 31.6	63 ± 48.6	49.6 ± 41.4	3.18 ± 2.47		
			Jacket pocket		3.02 ± 1.38	40.3 ± 27	53.6 ± 49.1	41.9 ± 41.1	2.43 ± 1.38		
			Duration of wireless internet use (h)	One way analysis of variance, p-value	0.43	0.093	**0.032**	**0.033**	0.305		
			< 0.5		2.99 ± 1.4	43 ± 33	61.7 ± 60.2	48.2 ± 53.7	2.73 ± 1.84		
			0.5-2		2.81 ± 1.32	41.8 ± 28.2	56.2 ± 57.5	43 ± 42.1	2.65 ± 1.75		
			>2		2.99 ± 1.36	37.4 ± 29.4	53.8 ± 57.5	41.8 ± 49.6	2.73 ± 1.85		
			Internet usage	Student t test, p-value	0.064	0.054	**0.009**	**0.018**	0.182		
			Cable		2.92 ± 1.25	42 ± 32.3	62.7 ± 61.3	48.9 ± 50.3	2.82 ± 1.72		
			Wireless		2.98 ± 1.43	38.8 ± 29.6	53.6 ± 55.2	41.1 ± 47.7	2.67 ± 1.88		
7. Zilberlicht et al, 2015. Israel, 2011–2012. Cross-sectional study.	80 male patients at infertility workup in the Fertility and IVF division of Carmel Medical Centre.	Daily habits of cell phone use assessed from self-administered questionnaire.	Daily habits of cell phone usage.	Semen quality was assessed using four parameters: volume, concentration, motility and morphology. Variables that were statistically significant in univariate analysis were included in a multivariate logistic regression analysis. OR were calculated with 95% confidence interval (CI).	**P-value of association of Sperm concentration, abnormal vs normal**	**OR (95% CI) for abnormal sperm concentration**	**p-value**			Smoking, age, residential area, occupation, n of children, years of education.	Adequate / positive
			Total daily talking time (≤1h / >1h)		0.040	Not reported	n.s.				
			Talk while charging the device (Yes/no)		0.020	4.13 (1.28-13.3)	0.018				

Table 13 - Reproductive/developmental effects in humans: man fertility, epidemiologic cross-sectional studies (450-6000 MHz) (continued e)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate	Any Other Co-Exposure/adjustments	Comments
8. Al-Bayyari, 2017. Jordan, 2015–2016. cross-sectional observational study.	159 men attending infertility clinics at North, Middle and South Governorates in Jordan.	Daily habits of cell phone use assessed from interviews using a structured questionnaire.	Time of talking by cell phone.	Semen quality. The Pearson's Chi-square (v2) and Fisher's exact tests were applied to assess the association.	**Total daily talking time (≤1 h/day vs >1h/day), p-value**	-	Inadequate
				Sperm concentration (cut-off 20 mln/ml)	0.494	All from an Infertility clinic	
				Volume (ctu-off 3 ml)	0.457		
				Viscosity (Normal vs abnormal)	0.556		
				Liquefaction time (cut-off 20 min)	0.534		
				Sperm motility (%)	n.s.		
				Sperm morphology (%)	n.s.		
9. Shi et al., 2018. China, 2015–2016. Cross-sectional study.	328 men <65 years, attending clinics for sperm analysis.	Use of cell phone assessed using self-report questionnaire.	Habit to carry phone in trousers.	SA, sperm vitality, acrosome reaction (AR) assay and sperm DNA fragmentation index (DFI). Generalized additive models were used to analyze the possible non-linear association.	**Duration of trousers pocket cell phone use (hours/day)**	BMI, smoking and alcohol drinking, sleep, daily fluid intake, weekly meat intake, sports frequency, trouser cell phone use, age, abstinence time.	Inadequate
				Volume	n.s.		
				Concentration	n.s.	All from an Infertility clinic	
				TSC	n.s.		
				Motility	n.s.		
				TMC	n.s.		
				Vitality	n.s.		
				DFI	n.s.		
				AR	n.s.		
10. Blay et al., 2020. Ghana. 2004-2015. Cross-sectional study.	80 men, 21-62 years, recruited from a fertility clinic in Accra, Ghana.	Lifestyle habits assessed using a structured questionnaire.	Mobile phones use and site of common storage on the body.	Parameters of semen quality. Independent Student t-test and Pearson's chi squared test were used to test the association between variables.	**Site of mobile phone storage (side pocket vs other place), p-value**	General characteristics, medical history, particularly disorders of the immune system, smoking habits.	Inadequate
				Volume	0.884	Increased activity and viability associated to cell phone in their side pocket	
				pH	0.741		
				Active motility (%)	**0.002**		
				Sluggish motility (%)	0.269		

				Sluggish motility (%)	0.486	All from an Infertility clinic	
				Viability (%)	**0.009**		
				Count (×106/ml)	0.109		

Table 14 - Reproductive/developmental effects in humans: man fertility epidemiologic cohort studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
11. Zhang et al., 2016. China, 2013-2015. MARHCS cohort study	794 (2013), 666 (2014) and and 568 (2015) young men, age < 18 years, college students, enrolled in the Male Reproductive Health in Chongqing College Students (MARHCS) study.	Use of mobile cell phones, assessed using a questionnaire.	Number of cell phones owned, presence of 3G function, duration of cell phone use, position in which they carry the cell phone, daily duration that the cell phone is turned on (within 50 cm near the body), daily internet time or monthly data traffic via cellular networks, and daily time spent talking on the cell phone in the last three months.	Sperm parameters. Mixed-effects linear regression model was used to globally assess all three years of data on cell phone use and semen parameters	**Volume (ml), Coeff from mixed effects model (95% CI), p-value**	**Sperm concentration (mln/ml), Coeff from mixed effects model (95% CI), p-value**	**Total sperm count (mln), Coeff from mixed effects model (95% CI), p-value**	**Progressive motile sperm (mln), Coeff from mixed effects model (95% CI), p-value**	Age, duration of abstinence, body mass index (BMI), smoking and drinking status, and the consumption of cola, coffee, and fried food	Adequate/ positive
			Duration of cell phone use (h)		-2.19 (-4.39, 0.06), 0.056	-2.90 (-6.91, 1.27), 0.170	**-4.87 (-9.27, -0.27), 0.038**	-0.77 (-2.71, 1.22), 0.445		
			Internet use via cellular network (h, 2013)		0.42 (-0.71, 1.56), 0.472	**-2.74 (-4.53, -0.91), 0.004**	**-2.75 (-4.76, -0.69), 0.009**	0.51 (-0.29, 1.32), 0.213		
			Monthly data traffic (GB, 2014-2015)		**-1.47 (-2.74, -0.19), 0.025**	-1.65 (-4.04, 0.80), 0.185	**-3.22 (-5.85, -0.52), 0.020**	0.19 (-1.08, 1.48), 0.770		

Table 14 - Reproductive/developmental effects in humans: man fertility epidemiologic cohort studies (450-6000 MHz) (continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)						Any Other Co-Exposure/adjustments	Comments
12. Lewis et al., 2017. USA. 2004-2015. Longitudinal cohort study.	384 (M); 18-56 years; Men recruited from a fertility clinic in Boston, Massachusetts, enrolled in the Environment and Reproductive Health (EARTH) Study.	Mobile phones radiofrequencies; Self - reported exposure from mobile phone.	Use, duration (no use, <2 h/day, 2–4 h/day, >4 h/day), headset or earpiece use (H/E, N H/E), and location in which the mobile phone was carried (pants pocket, belt, bag, other).	Sperm motility, total sperm count, total motile sperm count, sperm morphology. Strict Kruger scoring criteria was used to classify men as having normal or below normal morphology by blinded semen analysts. Linear mixed-effects models with random subject effects.	**Absolute differences [ß (95% CI)], Semen volume**	**Absolute differences [ß (95% CI)], Total motility**	**Relative differences [exp(ß) (95% CI)], Total sperm count**	**Relative differences [exp(ß) (95% CI)], Sperm concentration**	**Relative differences [exp(ß) (95% CI)], Total motile sperm count**	**Relative differences [exp(ß) (95% CI)], Normal sperm morphology**	General characteristics, medical history, particularly disorders of the immune system, smoking habits. All from an Infertility clinic	Adequate/ positive
			Category of use (h/day) and headset or earpiece use.									
			No Use		0 (ref.)	0 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			<2 h/day, H/E		0.74 (0.08-1.41)	13.05 (1.57-24.53)	1.60 (1.04-2.46)	1.24 (0.81-1.89)	2.43 (1.17-5.07)	0.94 (0.68-1.31)		
			<2 h/day, N H/E		0.40 (-0.06-0.86)	4.47 (-3.53-12.46)	1.09 (0.80-1.47)	0.99 (0.74-1.33)	1.39 (0.83-2.31)	0.97 (0.77-1.22)		
			>2 h/day, H/E		0.29 (-0.43-1.01)	3.06 (-9.39-15.50)	1.14 (0.71-1.82)	1.03 (0.65-1.63)	1.44 (0.65-3.20)	0.84 (0.59-1.20)		
			>2 h/day, N H/E		-0.12 (-0.93-0.68)	4.10 (-9.72-17.93)	1.47 (0.87-2.47)	1.52 (0.91-2.53)	1.89 (0.78-4.58)	0.83 (0.56-1.23)		

Table 15 - Reproductive/developmental effects in humans: developmental effects, epidemiologic case-control studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
13. Tan et al., 2014. Singapore. November 2010 and February 2011. Case-control study	Women with threatened miscarriage during the 5th to 10th weeks of gestation seen at emergency clinic KK Womens and Childrens Hospital (KKH) in Singapore. (F). Mean age of cases and controls were 30.2 and 30.7, respectively.	Potentially modifiable lifestyle factors were assessed by face to-face interview with cases and controls, conducted at the time of recruitment. Mobile phone and computer usage were quantified as self-reported number of hours of use per day based on the most recent one week.	Exposure to radiofrequency electromagnetic fields of cell phone and television. Greater duration of mobile phone use or computer use was associated with higher risk of threatened miscarriage, with dose-response relationship	Association between potential lifestyle risk factors (cell phone and TV usage) and threatened miscarriage: results of adjusted logistic regression analysis. Multivariate analysis adjusting for all confounders and for gestational age.	**Adjusted odds ratio (95% Confidence Interval):**		Maternal age, paternal age, gestational age, ethnicity, height, weight, regularity of menstrual cycle, housing type, educational level, past medical/ pregnancy/ gynaecological/ psychiatric history, urrent and past cigarette smoking, exposure to second-hand cigarette smoke at home, current and past alcohol consumption, current and past caffeine Consumption, perceived stress levels, DHA consumption, and most recent contraceptive use	**Adequate/ positive**
			Handphone use					
			0 to <1 hour		1		Stress not considered as confounder	
			≥ 1 to <2 hours		2.94 (1.32–6.53)			
			≥ 2hours		6.32 (2.71–14.75)			
			Computer use					
			0 to <1 hour		1			
			≥1 to <4 hours		2.66 (1.16–6.09)			
			≥ 4 hours		6.03 (2.82–12.88)			
14. Mahmoudabadi et al., 2015. Iran. Before 2015. Case-control study	292 women who had an unexplained spontaneous abortion at < 14 weeks gestation and 308 matching pregnant women > 14 weeks gestation were enrolled. The subjects were recruited from 10 hospitals in Tehran.	Data collection form was completed to collect data about the use of cell phones during pregnancy.	Average calling time per day, the location of the cell phones when not in use, use of hands-free equipment, use of phones for other applications, the specific absorption rate (SAR) reported by the manufacturer and the average of the effective SAR (average duration of calling time per day × SAR).	Spontaneous abortions. Logistic regression model was used to calculate OR and 95% CI; *T student test, ** Chi square test or Fisher's exact test were used to assess association.	**OR (95% CI)**	**P(2-tailed)**	Effective SAR, maternal age, paternal age, history of abortion and family relationship Life style confounders not analysed	**Adequate /positive**
			Association of spontaneous abortions with the effective SAR (Specific Absorption Rate)		**1.11 (1.07-1.16)**			
			Calling time per day* (minutes) Mean ± SD			**<0.001**		
			Use of hands free** n (%)			0.09		
			location of phones when not in use** n (%)			**<0.001**		
			use of phone for other applications **n (%)			**<0.001**		
			Effective SAR* Mean ± SD			**<0.001**		

Table 16 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cross-sectional studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
15. Col Araz et al., 2013. Turkey, 2009. Cross-sectional study.	500 mothers from the Outpatient Clinic, Dept of Paediatrics, Gaziantep University.	Use of television, computer and mobile phones during pregnancy assessed using a self-administered questionnaire	Cell phone use, computer use (user vs non-user).	Birth weight and preterm birth. The Chi-square test, independent samples t-test, and OR and 95% CI from logistic regression analysis were used.	**Delivery before 37 weeks, χ^2 (p-value)**	**Delivery week, mean ±SD**	**Delivery week, p-value**	Socio-demographic information, mothers weight, height, weight gained, consumption of tobacco and alcohol during pregnancy, disease history, observance of religious fasting during pregnancy, consumption of tea, milk and yoghurt, birth week and birth weight of the other children, if any.	Adequate /positive
			Cell phone use		**5.584 (<0.018)**		**<0.005**		
			User			38.7±1.9			
			Non user			39.2±1.6			
			Duration of cell phone use				**<0.001**		
			≤1h/day			37.6±2.2			
			>1h/day			38.8±1.8			
			Computer use		**4.510 (<0.034)**		**<0.048**		
			User			38.5±1.8			
			Non user			38.9±1.8			
			Duration of cell phone use				n.s.		
			≤1h/day			Not reported			
			>1h/day			Not reported			
16. Zarei S. et al., 2015. Iran. 2014. Cross-sectional study.	Mothers of 35 healthy children (control group) and 77 children aged 3-5 year and diagnosed with speech problems (F).	Different sources of electromagnetic fields (both RF-EMF and ELF) such as mobile phones, mobile base stations, Wi-Fi, cordless phones, laptops and power lines. Self-assessed exposure to different sources of electromagnetic fields.	The mean daily (mobile phone) call time was about 20 min. Call time, history of mobile phone use (months used), average duration of daily call time, cordless phone use and CRT use during pregnancy.	Speech problems in offspring. A P-value of less than 0.05 was considered as significant.	**Speech problems, P-value of association measure**			Age, proportion of consanguineous marriage, smoking, dental radiography history, mean number of pregnancies	Inadequate
			call time		0.002				
			history of mobile phone use		0.003				
			average duration of daily call time during pregnancy		N.S.				
			cordless phone use		0.528				
			CRT use		0.990				

Table 16 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cross-sectional studies (450-6000 MHz) (continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
17. Abad et al., 2016. Iran, 2009. Cross-sectional study.	413 pregnant women (18-35 years of age) from the Tehran region. Reproductive information was collected using medical file recorded in those hospitals the subjects had delivery.	Environmental exposure to EMF (range 27 MHz-3 GHz) assessed using NARDA at the entrance door of their houses three times during the pregnancy (semesters 1, 2, 3). Other information assessed using a face-to face interview.	Environmental exposure to EMF.	Miscarriage (spontaneous abortion, LBW, preterm delivery, and Intra Uterine Fetal Death). Independent samples t-test.	**Miscarriage, p-value from t-test**				Inadequate
			Digital radio and television broadcast services in central frequency 650 MHz		0.85				
			Mobile communications services 1.5 GHz		0.67				
			Wi-Fi access and MISC in central frequency 2.45 GHz		0.42				
18 Lu et al. 2017. Japan. 2012-2014. Cross sectional study from cohort data.	461 mother and child pairs (M and F). Data from the Japan Environment and Children's Study (JECS) and JECS Adjunct Study in Kumamoto.	Mobile phones radiofrequencies; Self-assessed exposure from self-administered questionnaires on maternal mobile phone usage information during pregnancy. A short version of the Self-Perception of Text-Message Dependency Scale (STDS) was used in this study for assessing text message dependency.	Daily mobile phone use times, location of the phone during the day and at night, and power state (on/off) of the mobile phone during sleep). A cut-off of 15 points for the excessive use score in the STDS was used to determine excessive mobile phone use.	Birth weight and infant health status (birth height, birth head circumference, birth chest circumference, mode of delivery, weeks of pregnancy, placental weight, low birth weight), infant emergency transport, and premature birth; linear regression analysis was used.	**ß (95%CI) for Birth weight**	**Adjusted OR (95%CI), Infant emergency transport**	**Adjusted OR (95%CI), Premature birth**	Maternal age, birth height, maternal BMI before pregnancy, maternal age, birth head circumference, primiparity, maternal smoking.	Inadequate
			Daily mobile phone use						
			Normal users		0 (ref.)	1.00 (ref.)	1.00 (ref.)		
			Mobile excessive users		-66.46 (-114.46- -18.46)	7.93 (1.40-44.85)	0.67 (0.09-4.97)		

Table 17 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cohort studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)						Any Other Co-Exposure/adjustments	Comments
19. Mjøen et al., 2006. Norway. 1976-1995. Cohort study.	541593 births (M and F). Data on all births registered between 1976 and 1995 in Norway from the Medical Birth Registry of Norway; The Norwegian general population censuses contain data on occupations coded according to the Nordic Classification of Occupations.	Paternal occupation categorized as "probably not exposed", "possibly exposed" and "probably exposed", reflecting probability of exposure to RFR. An expert panel assessed exposure to radiofrequency fields in the various occupations.	Level of exposure assigned from experts.	Birth defects, the total number of CNS and musculoskeletal limb defects, and all categories combined, preterm delivery, low birth weight, sex ratio and perinatal mortality. Relative risks for each exposure category were calculated by approximating odds ratios (OR) with 95% confidence intervals (CI) from logistic regression models.	**Preterm delivery (<37 weeks) - OR (95% CI)**	**Low birth weight (<2,500 g) - OR (95%CI)**	**Early stillbirth (between 16 and 28 weeks) - OR (95% CI)**	**Late stillbirth (after 28 weeks) - OR (95% CI)**	**Male gender - OR (95% CI)**	**Any birth defect - OR (95% CI)**	Calendar year, place of birth and level of education.	Adequate/ negative
			Probably not exposed		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			Possibly exposed		0.99 (0.96-1.02)	1.03 (0.98-1.07)	1.01 (0.91-1.12)	1.01 (0.92-1.11)	1.01 (1.00-1.03)	0.98 (0.94-1.02)		
			Probably exposed		1.08 (1.03-1.15)	1.03 (0.94-1.13)	0.98 (0.79-1.22)	1.09 (0.89-1.29)	0.99 (0.97-1.02)	0.94 (0.86-1.01)		

Table 17 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cohort studies (450-6000 MHz) (continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjustme nts	Comments
20. Divan at al., 2008 and Divan et al. 2011. Denmark. Children born between 1997 and 2002. Cohort study.	41541 children (F and M). Mothers and live-born children constitute 2 fixed cohorts. Child's health status assessed at 7th year of age using an internet-based Questionnaire.	Cell phone and cordless phone use, assessed via four telephone interviews.	Cell phone use among children, among mothers during pregnancy (mother's use of cell phone during pregnancy, use of hands-free equipment during pregnancy (proportion of time) and location of the phone when not in use (handbag or clothing pocket), and for children, current use of cellular and other wireless phones.	Cognitive/language development delays, motor development delays and behavioural problems assessed using the "Strengths and Difficulties Questionnaire". Odds ratios and 95% CI from adjusted logistic regression models.	**Cognitive/language development delay at 6 months-Adjusted OR (95% CI)**	**Motor development delay at 6 months-Adjusted OR (95% CI)**	**Cognitive/language development delay at 18 months-Adjusted OR (95% CI)**	**Motor development delay at 18 months-Adjusted OR (95% CI)**	**Overall Behavioural Problems Score at 7 years-Adjusted OR (95% CI)**	Adjusted for gender of child, combined social-occupational status, mother's age at birth, gestational age, and child's birth weight, child care outside home at 18 months.	Adequate/ Negative Exposure to cell phones prenatally—and, to a lesser degree, postnatally—was associated with behavioral difficulties such as emotional and hyperactivity problems around the age of school entry.
			Prenatal Exposure Only			1.12 (0.97–1.30)		**1.21 (1.05–1.40)**	**1.58 (1.29–1.93)**		
			Postnatal Exposure Only			1.06 (0.92–1.23)		1.02 (0.89–1.18)	1.18 (0.96–1.45)		
			Both Prenatal and Postnatal Exposure			**1.25 (1.07–1.47)**		**1.49 (1.28–1.74)**	**1.80 (1.45–2.23)**		
			Prenatal: Times spoken per day								
			0-1		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			2-3		1.0 (0.7–1.4)	0.8 (0.5–1.0)	0.9 (0.6–1.3)	0.7 (0.5–1.0)	1.33 (0.99–1.79)		
			4+		0.8 (0.4–1.3)	0.6 (0.3–1.0)	0.9 (0.5–1.6)	1.2 (0.8–1.8)	**1.51 (1.02–2.22)**		
			Prenatal: Percentage of time turned on								
			0		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			<50		1.1 (0.6–1.9)	1.3 (0.8–2.7)	1.2(0.7–2.3)	1.1 (0.7–1.8)	0.62 (0.35–1.11)		
			50-99		0.9 (0.5–1.6)	1.1 (0.6–1.8)	1.2 (0.5–2.2)	1.2 (0.8–2.0)	0.93 (0.58–1.48)		
			100		1.0 (0.5–2.0)	1.1 (0.6–2.0)	1.5 (0.7–3.0)	1.3 (0.8–2.3)	1.09 (0.70–1.70)		

Table 17 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cohort studies (450-6000 MHz) (continued c)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
21. Guxens et al., 2013. Netherlands. 2003-2004 enrollment; 2008-2009 assessment of behavioural problems; 2010-2011 retrospective exposure assessment. Study embedded in a population-based prospective birth cohort study.	8266 pregnant women, 2618 children (F and M). Pregnant women enrolled during their first prenatal visit to an obstetric care provider. Prenatal phone use assessed retrospectively with postal or via web questionnaire at children 7th year, and child behaviour problems assessed at children 5th year.	Cell phones and cordless phones use during pregnancy. Self-assessed exposure from questionnaire. Given the introduction of Universal Mobile Telecommunications System technology in the Netherlands in the beginning of 2004, mobile phone use reports were expected to be nearly exclusively Global System for Mobile Communications (GSM) 900/1800 technology.	Frequency of cell phone calls were set to 75% of the number of calls for those reporting to use the hands-free equipment 'less than half of the calls', to 25% for those reporting to use it 'more than half of the calls', and to 0 for those reporting to use it 'nearly always'.	Children's behaviour (emotional symptoms, conduct problems, hyperactivity/inattention problems, peer relationship problems and pro-social behaviour) reported by primary school teachers and mothers using the Strengths and Difficulties Questionnaire (SDQ) at age 5. Odds ratios and 95% CI from unadjusted and adjusted logistic regression models.	**Teacher-reported child overall behaviour problems, Unadjusted model - OR (95% CI)**	**Teacher-reported child overall behaviour problems, Adjusted model - OR 95% CI)**	**Mother-reported child overall behaviour problems, Unadjusted model - OR (95% CI)**	**Mother-reported child overall behaviour problems, Adjusted model - OR**	Maternal age, maternal educational level, maternal country of birth, maternal parity, maternal pre-pregnancy weight and height, maternal smoking, maternal second-hand smoke at home, maternal alcohol consumption during pregnancy, maternal pregnancy-related anxiety and maternal anxiety and depression during pregnancy, children's birth addresses as indicator of socioeconomic position. .	Adequate/ negative
			Prenatal frequency of cell phone call							
			None		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			<1/day		2.09 (0.95 - 4.62)	2.12 (0.95 - 4.74)	0.95 (0.39 - 2.29)	0.89 (0.36 - 2.20)		
			1–4/day		1.53 (0.69 - 3.42)	1.58 (0.69 - 3.60)	0.78 (0.32 - 1.92)	0.73 (0.28 - 1.85)		
			≥5/day		1.88 (0.82 - 4.34)	2.04 (0.86 - 4.80)	0.77 (0.29 - 2.06)	0.75 (0.27 - 2.09)		
			Prenatal frequency of cordless phone call							
			None		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			<1/day		0.89 (0.57 - 1.39)	1.19 (0.74 - 1.92)	0.27 (0.15 - 0.50)	0.35 (0.18 - 0.67)		
			1–4/day		0.76 (0.48 - 1.22)	1.07 (0.65 - 1.76)	0.55 (0.32 - 0.96)	0.73 (0.41 - 1.33)		
			≥5/day		0.50 (0.23 - 1.09)	0.61 (0.27 - 1.35)	0.40 (0.15 - 1.07)	0.43 (0.15 - 1.21)		

Table 17 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cohort studies (450-6000 MHz) (continued d)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
22. Choi et al., 2017. South Korea. 2006-2016. Multi-center prospective cohort study (the Mothers and Children's Environmental Health (MOCEH) study).	1198 mother-infant pairs (M and F). Participants were enrolled at ≤20 weeks gestation.	RFR sources of exposure, including cell phone, TV, radio, working on the internet, and mobile phone base stations. Self-assessed exposured from questionnaire regarding average calling frequency (≤2, 3–5, and ≥6 times/day) and average calling time (< 3, 3–10, 10–30, and ≥30 min/day) during pregnancy.	Heavy user defined as calling frequency >6 times per day or calling time >30 min per day. Categories by average calling time (min/day)	MDI: Mental development index, PDI: Psychomotor development index.	**OR (95% CI) for decreasing MDI (6–36 months)**				Occupational exposure to some chemical pesticides, petroleum, solvents, lead and nitrosamines, tobacco consumption.	Inadequate
			Average calling time (min/day)		**All**	**Low Maternal blood lead during pregnancy (< 75%)**	**High Maternal blood lead during pregnancy (<75%)**	**p-interaction**	Maternal blood lead level as main confounding factor	
			<3		0.50 (0.30-0.83)	0.71 (0.42-1.21)	0 (0-Inf)	0.02		
			3-10		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)			
			10-30		0.85 (0.60-1.19)	0.86 (0.57-1.28)	2.11 (0.67-6.68)			
			>30		0.63 (0.37-1.08)	0.76 (0.43-1.34)	0 (0-Inf)			
			P for trend		0.86	0.48	**0.05**			
					OR (95% CI)) for low PDI (6–36 months)					
			Average calling time (min/day)		**All**	**Low Maternal blood lead during pregnancy (< 75%)**	**High Maternal blood lead during pregnancy (<75%)**	**p-interaction**		
			<3		0.47 (0.24-0.94)	0.41 (0.19-0.92)	0.45 (0.23-0.89)	0.44		
			3-10		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)			
			10-30		0.77 (0.49-1.23)	0.81 (0.49-1.35)	1.10 (0.69-1.76)			
			>30		0.64 (0.32-1.29)	0.73 (0.36-1.48)	1.56 (0.74-3.26)			
			P for trend		0.54	0.26	**0.008**			

Table 17 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cohort studies (450-6000 MHz) (continued e)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
23. Papadopoulou et al., 2017. Norway, 1999 -2008. Norwegian mother and child cohort study (MoBa).	45389 mother-child pairs (M and F), participants of the MoBa, recruited at mid-pregnancy. Information assessed by questionnaires.	Maternal frequency of cell phone use in early pregnancy, assessed by a questionnaire administered at 17th and 30th weeks of gestation.	Frequency of talking on the cell phone: “seldom/never” (no use), “few times a week” (low), “daily” (medium), and “more than an hour daily” (high use).	Child language, communication and motor skills at 3 (45389 mother-child pairs) and 5 years (17310 mother-child pairs). Adjusted OR and 95% C.I. from logistic regression to estimate the associations.	**Risk for lower sentence complexity at 3 years- Adjusted OR (95% C.I.)**			Parity, maternal age, education and year of delivery.	**Adequate /negative**
			Maternal cell phone use in early pregnancy						
			No use		1 (ref)				
			Any use		0.83 (0.77, 0.89)				
			Low		0.87 (0.81, 0.94)				
			Medium		0.78 (0.72, 0.84)				
			High		0.71 (0.62, 0.81)				
			P for trend		**<0.001**				
24. Sudan et al., 2018. Denmark 1996-2002, Spain 2003-2008, South Korea 2006-2011. Data from 3 birth cohorts, part of the Generalized EMF Research using Novel Methods (GERoNiMO) Project.	3089 mother-child pairs participating in the Danish National Birth Cohort (DNBC) (n=1209), the Spanish Environment and Childhood Project (INMA) (n=1383), and the Korean Mothers and Children's Environment Health Study (MOCEH) (n=497).	Maternal cell phone use during pregnancy, assessed during pregnancy (ES and KO) or 7 years after birth (DK).	Frequency of talking on the cell phone: “seldom/never” (no use), “few times a week” (low), “daily” (medium), and “more than an hour daily” (high use). In the DNBC, ABCD, and INMA cohorts, no exposure corresponded to no cell-phone use, low exposure to ≤1 calls/day, intermediate exposure to 2–3 calls/day, and high exposure to ≥4 calls/day. In the MOCEH cohort, no exposure corresponded to no cell-phone use, low exposure to ≤2 calls/day, intermediate exposure to 3–5 calls/day, and high exposure to ≥6 calls/day.	Cognitive performance in children at age 5. Linear regression to compute mean differences (MD) and 95% confidence intervals (CI).	**General cognition, Adjusted OR (95% C.I.)**	**Verbal cognition, Adjusted OR (95% C.I.)**	**Non-verbal cognition, Adjusted OR (95% C.I.)**	Sex of child, age of child, maternal IQ, maternal age, parity, mother's history of psychological distress, maternal education, paternal education, prenatal smoking, prenatal alcohol use, and maternal pre-pregnancy BMI	**Adequate /equivocal**
			Maternal cell phone use in early pregnancy						
			No use		0.78 (-0.76, 2.33)	1.42 (-1.12, 3.96)	0.72 (-0.85, 2.28)		
			Low		1 (ref)	1 (ref)	1 (ref)		
			Medium		0.11 (-0.81, 1.03)	-0.23 (-1.29, 0.83)	-0.12 (-1.60, 1.35)		
			High		-0.41 (-1.54, 0.73)	-0.42 (-1.73, 0.89)	-0.85 (-2.23, 0.53)		

Table 17 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cohort studies (450-6000 MHz) (continued f)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
25. Tsarna et al., 2019. Denmark 1996-2002, Spain 2003-2008, South Korea 2006-2011. Data from 3 birth cohorts, part of the Generalized EMF Research using Novel Methods (GERoNiMO) Project.	55507 mother-child pairs (M and F) participating in the Danish National Birth Cohort (DNBC), the Spanish Environment and Childhood Project (INMA), and the Korean Mothers and Children's Environment Health Study (MOCEH).	Use of mobile phone s during pregnancy. Retrospective exposure assessment (DNBC and ABCD) or prospective exposure assessment (INMA and MOCEH) were used.	Exposure were classified into 4 categories (none, low, intermediate, and high) based on daily frequency of cell-phone calls during pregnancy.	Preterm/post-term birth, fetal growth (small or large size for gestational age). Modified Wald, χ2, and Fischer exact tests. The calculated adjusted cohort-specific estimates were meta-analysed using random-effects models.	**Preterm birth - Adjusted OR (95% C.I.)**	**Post term birth - Adjusted OR (95% C.I.)**	**SGA birth - Adjusted OR (95% C.I.)**	**LGA birth - Adjusted OR (95% C.I.)**	Maternal age at child's birth (a natural spline term with 3 degrees of freedom), parity, active and passive smoking during pregnancy, alcohol consumption during pregnancy, pre-pregnancy body mass index.	Adequate/ equivocal
			None		0.96 (0.86-1.07)	0.98 (0.89-1.07)	0.94 (0.86-1.03)	0.98 (0.92-1.04)		
			Low		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	Stress not considered as confounding	
			Intermediate		1.12 (0.97-1.28)	0.85 (0.75-0.97)	1.03 (0.88-1.21)	0.97 (0.89-1.05)		
			High		1.28 (0.87-1.88)	0.98 (0.83-1.16)	0.94 (0.78-1.13)	0.93 (0.83-1.04)		
			P for trend		**0.003**	0.863	0.872	0.488		
26. Boileau et al., 2020. France, children born in 2014-2017. Prospective, longitudinal, multicenter observational cohort study (NéHaVi cohort)	1378 mothers-child pairs (M and F). Questionnaires completed during face-to-face interviews in the post-partum period during stay at the maternity unit, and the child's and parents' medical records.	Use of mobile phone s during pregnancy. Retrospective exposure assessment (DNBC and ABCD) or prospective exposure assessment (INMA and MOCEH) were used.	Phone time recorded in minutes per day.	Fetal growth, assessed using a personalized AUDIPOG score (growth restriction at birth, defined by an AUDIPOG score ≤ 10th percentile at birth)	**AUDIPOG score ≤10th percentile- Adjusted OR (95% C.I.)**	**P-value**			Socio-professional category variables of the mother likely to influence phone time, smoking, alcohol consumption, history of diabetes or high blood pressure, gestational diabetes, gestational hypertension, and potential confounding factors.	Adequate/ positive
			Phone time (min/day)							
			0-5		1.00 (ref.)					
			5-15		0.98 (0.58-1.65)	0.9423				
			15-30		1.68 (0.99-2.82)	0.0508				
			≥30		**1.54 (1.03-2.31)**	**0.0374**				

Table 18 (summary tables 12-17) - Collected data for epidemiological studies on reproductive/ developmental effects (FR1: 450-6000 MHz)

Total studies	26				
Adequate studies	16				
Type of study	Observed Effect	Total* adequate studies	Positive studies	Equivocal studies	Negative studies
Reproductive- man fertility	Decline in semen quality	6	6		
Developmental-mother-offspring effects	Miscarriage	2	2		
	Preterm/post-term birth, foetal growth; chromosomal anomalies	8	2	2	4
	Language/communication/ behavioural /cognitive problems	4		2	2

*Some of the studies include more than one outcome.

SUMMARY OF THE COLLECTED DATA FOR EPIDEMIOLOGICAL STUDIES ON REPRODUCTIVE/DEVELOPMENTAL EFFECTS (FR1: 450 to 6000 MHZ) (Table 18)

The epidemiological evidence on possible associations of exposure to RF-EMF with reproductive developmental effects comes from studies of diverse design that have assessed a range of sources of exposure: the populations included people exposed in occupational settings, people exposed through sources in the general environment, e.g. radio-base stations, and people exposed through use of wireless (mobile and cordless) telephones.

In chapter 4 (Limitations) of the present document, general methodological concerns related to the assessment of individual studies are covered. The total number of epidemiological studies selected for the present review for FR1, was 26. After further deep analyses of the 26 original papers, 16 studies proved to be adequate on the basis of exposure assessment, sample size and appropriateness of confounding analyses.

Decline in semen quality, risk of miscarriage, pre-term/post-term birth, foetal growth, language/communication/ behavioural /cognitive problems were analysed in the 16 adequate studies for a possible association with exposure to RF-EMF, related to the use of mobile phone or to environmental/occupational exposure to emissions from radiobase stations. With reference to the numbers given to the studies in the respective abstracts and tables, the association of the different adverse effects to RF-EMF exposure is:

Decline in semen quality: out of 6 adequate studies regarding this outcome, all showed a positive association with RF-EMF exposure (Ref: 2, 3, 5, 7, 11, 12).

Miscarriage: both of the 2 adequate studies regarding this outcome, showed a positive association with RF-EMF exposure (Ref: 13, 14).

Pre-term/post-term birth, foetal growth: out of 8 adequate studies regarding these outcomes, 2 showed a positive association with RF-EMF exposure (Ref: 15, 26), 2 equivocal association /Ref: 24,25) whilewhile 4 were negative (Ref: 19, 20, 21, 23).

Language/communication/ behavioural /cognitive problems: out of 4 adequate studies, 2 showed equivocal evidence of association to RF-EMF exposure (Ref: 20, 24) and 2 were negative (Ref: 21, 23).

We can conclude as follows:

FR1: 450 to 6000 MHZ:

There is sufficient evidence of adverse effects on fertility in man.

There is limited evidence of adverse effects on fertility in woman.

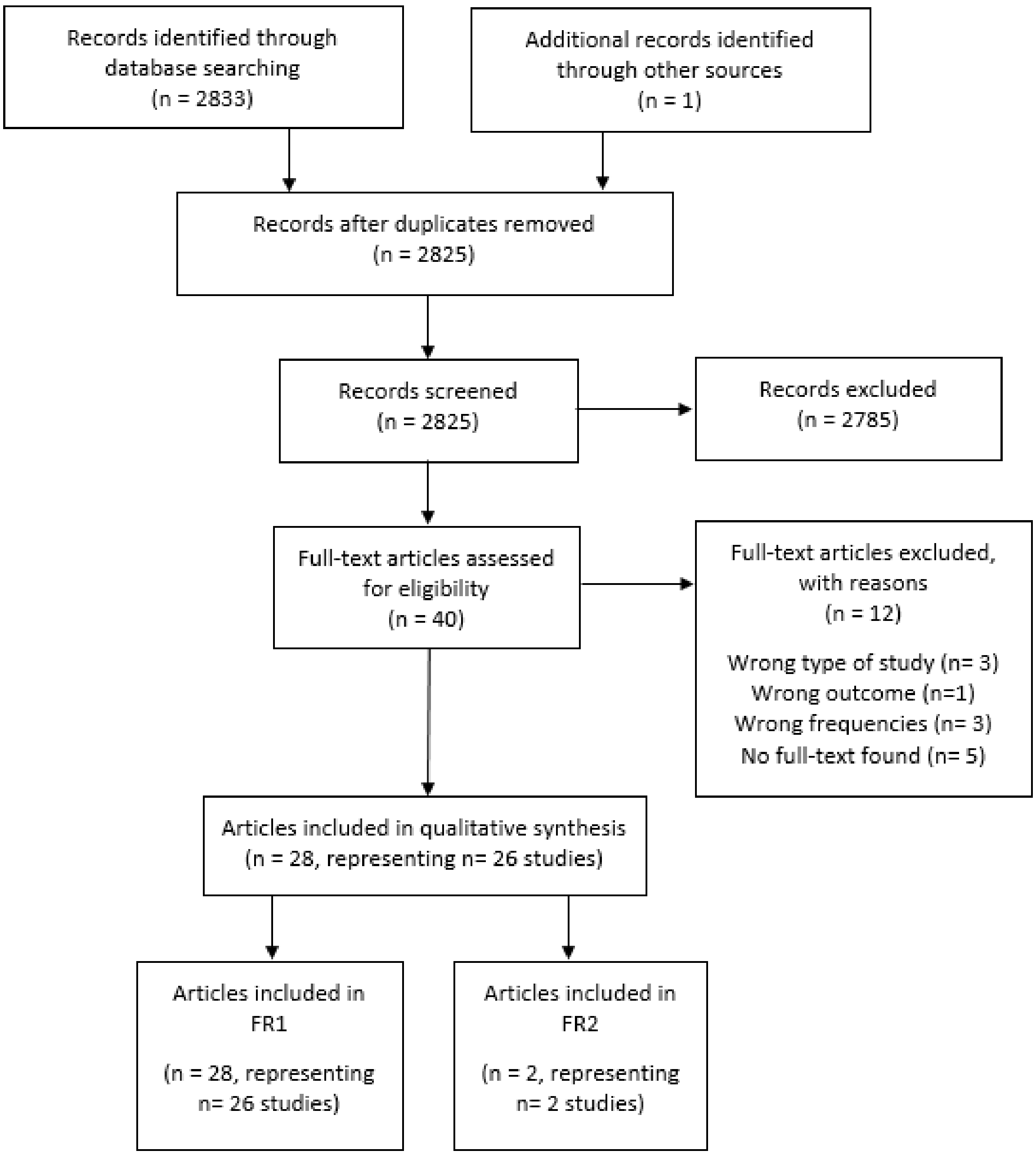
There is limited evidence for adverse effects in pregnant women and their offspring for all developmental end-point examined.

4.2.2 Reproductive/developmental effects in epidemiological studies: Studies evaluating health effects due to RF at a higher frequency range (FR2: 24 to 100 GHz, MMW).

The articles identified through database searching and other sources were 2834. After removing duplicates (9) and excluding non-pertinent articles (2785) based on title and abstracts, 40 articles remained. Based on full-text screening, 12 papers were further excluded, so that the published articles with frequencies appropriate for inclusion in this qualitative synthesis were 28, corresponding to 26 studies. Two papers were published reporting information on the same study (Fig. 14).

At this stage, a selection based on frequency range was also performed: 28 papers/26 studies referred to exposures belonging to the FR1 range, and 2 referred to FR2 as well. These papers reported exposures suitable for both FR1 and FR2, so they don't add up to the overall number of studies included; they are reported twice, once in each frequency range with related outcome.

Figure 14 – Flow diagram. Epidemiological studies on reproductive/developmental effects FR2



MALE FERTILITY

Cross-sectional studies (Table 19 a,b)

1. Baste et al., 2008.

Norway. 2002-2004. Case-control study , occupational exposure.

The authors performed a cross-sectional study among military men employed in the Royal Norwegian Navy, including information about work close to equipment emitting radiofrequency electromagnetic fields, one-year infertility, children and sex of the offspring. Among 10,497 respondents, 22% had worked close to high-frequency aerials to a ''high'' or ''very high'' degree. Infertility increased significantly along with increasing self-reported exposure to radiofrequency electromagnetic fields. In a logistic regression, the odds ratio (OR) for infertility among those who had worked closer than 10 m from high-frequency aerials to a ''very high'' degree relative to those who reported no work near high-frequency aerials was 1.86 (95% confidenceinterval (CI): 1.46–2.37), adjusted for age, smoking habits, alcohol consumption and exposure to organic solvents, welding and lead. Similar adjusted OR for those exposed to a ''high'', ''some'' and ''low'' degree were 1.93 (95% CI: 1.55–2.40), 1.52 (95% CI: 1.25–1.84), and 1.39 (95% CI: 1.15–1.68), respectively. In all age groups there were significant linear trends with higher prevalence of involuntary childlessness with higher self-reported exposure to radiofrequency fields. However, the degree of exposure to radiofrequency radiation and the number of children were not associated. For self-reported exposure both to high-frequency aerials and communication equipment there were significant linear trends with a lower ratio of boys to girls at birth when the father reported a higher degree of radiofrequency electromagnetic exposure.

Comment*: *Self-reported level of exposure. Higher degree of RF-EMF exposure associated to infertility and a lower ratio of boys to girls at birth.

2. Mollerlekken and Moen, 2008.

Norway. 2002. Case-control study, occupational exposure.

The aim of this study was to examine the relationship between workers exposed to electromagnetic fields and their reproductive health. We obtained data using a questionnaire in a cross-sectional study of naval military men, response rate 63% (n¼1487). The respondents were asked about exposure, lifestyle, reproductive health, previous diseases, work and education. An expert group categorized the work categories related to electromagnetic field exposure. We categorized the work categories ''tele/communication,'' ''electronics'' and ''radar/sonar'' as being exposed to electromagnetic fields. Logistic regression adjusted for age, ever smoked, military education, and physical exercise at work showed increased risk of infertility among tele/ communication odds ratio (OR≤1.72, 95% confidence interval 1.04–2.85), and radar/sonar odds ratio (OR≤2.28, 95% confidence interval 1.27–4.09). The electronics group had no increased risk. This study shows a possible relationship between exposure to radiofrequency fields during work with radiofrequency equipment and radar and reduced fertility. However, the results must be interpreted with caution.

Comment*: *Self-reported exposure. Possible increased risk of infertility among telecommunication and radar/sonar operators.

Table 19 - Reproductive/developmental effects in humans: man fertility, epidemiologic case-control studies (24-100 GHz)(a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
1. Baste et al., 2008. Norway. 2002-2004. Case-control study	9925 current and former male military employees in the Royal Norwegian Navy, defined by the military employment list (M); mean age 49.	High-frequency aerials, communication equipment, radar. Self-assessed occupational exposure and age categories assessed by mail questionnaire.	Exposure to radiofrequency electromagnetic fields: work closer than 10 m from high-frequency aerials, work closer than 3 m from communication equipment and work closer than 5 m from radar.	Infertility. Odds ratios and 95% CI from adjusted logistic regression models; Mantel–Haenszel test for linear trend.	**Total Infertility - <5 m from radar, OR (95% CI)**	**Test for linear trend (Mantel–Haenszel chi-square)**	Infertility. Odds ratios and 95% CI from adjusted logistic regression models; Mantel–Haenszel test for linear trend.	**Adequate/ Positive for man infertility**
			Age <29					
			Not exposed					
			Low		1.00 (ref.)	0.001		
			Some		0.87 (0.25–2.99)			
			High		2.13 (0.64–7.06)			
			Very high		1.11 (0.20–6.00)			
			Age 30-39		5.09 (1.59–16.30)			
			Not exposed					
			Low		1.00 (ref.)	0.005		
			Some		1.46 (0.99–2.15)			
			High		1.32 (0.87–2.02)			
			Very high		1.79 (1.14–2.82)			
			Age 40-49		1.91 (1.19–3.07)			
			Not exposed					
			Low		1.00 (ref.)	0.002		
			Some		1.22 (0.87–1.71)			
			High		1.24 (0.87–1.79)			
			Very high		1.59 (1.05–2.41)			
			Age >50		1.50 (0.95–2.35)			
			Not exposed					
			Low		1.00 (ref.)	0.001		
			Some		1.11 (0.84–1.46)			
			High		1.58 (1.20–2.09)			
			Very high		1.39 (0.98–1.97)			

Table 19 - Reproductive/developmental effects in humans: man fertility, epidemiologic case-control studies (24-100 GHz)(continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjustments	Comments
2. Møllerløkken et al., 2008. Norway. 2002. Case-control study.	2265 (M) employees who were currently serving in the Navy, both military and civilians. Mean age of 36 years of age, range 20–62.	Occupational exposure from military communication equipment. Information on occupational history from mail questionnaire. An expert group determined work categories related to electromagnetic field exposure.	Workers in the radar/sonar-, the tele/communication, electronics, other jobs (unexposed).	Infertility, Biological Children, Anomalies, Chromosomal Errors, Preterm and Stillbirths or Infant Deaths. Incidence of outcome by exposure group (%); Chi2 or Fisher Exact Tests to assess significance of differences among groups.	**Infertility - % (p-value from Chi2 tests)**	**Having biological children - % (p-value from Chi2 tests)**	**Children with anomalies or chromosomal errors - % (p-value from Chi2 or Fisher's Exact tests)**	**Children with preterm births - % (p-value from Chi2 or Fisher's Exact tests)**	**Stillbirths and infant deaths within 1 year - % (p-value from Fisher's Exact tests)**	Age, ever smoked, military education, and physical exercise at work.	**Adequate/ Positive for male infertility and developmental parameters in offspring**
			Other jobs (unexposed group)		8.6	62.0	3.5	7.9	2.3		
			Radar/sonar workers (radar)		**17.5 (<0.01)**	70.4 (0.10)	7.1 (0.11)	9.1 (0.37)	2.0 (0.61)		

Table 20 (summary tables 19 a,b) – Collected data for epidemiological studies on reproductive/ developmental effects (FR2: 24-100 GHz).

Total studies*	2				
Adequate studies	2				
Type of study	**Observed Effect**	**Total adequate studies**	**Positive results**	**Negative results**	**Equivocal results**
Reproduction- man fertility	Decline in sperm quality	2	2		
Developmental parameters	Children: preterm birth; chromosomal anomalies	1	1		

The epidemiological evidence on possible associations of exposure to RF-EMF with reproductive/ developmental effects comes from studies of diverse design that have assessed a range of sources of exposure. The studied populations for FR2 include people exposed in occupational settings, in particular military employees.

In chapter 4 (Limitations) of the present document, general methodological concerns related to the assessment of individual studies are covered. The total number of epidemiological studies up to 2020, selected for the present review for FR2, was 2, both considered adequate.

SUMMARY OF THE COLLECTED DATA FOR EPIDEMIOLOGICAL STUDIES ON REPRODUCTIVE/DEVELOPMENTAL EFFECTS (FR2: 24-100 GHz) (Table 20)

FR2 (24-100 GHz)

The two analysed studies on FR2 have limits in exposure assessment, so the real RF/ EMFs levels of exposure are uncertain. However, both studies show *sufficient* evidence of adverse effects on male fertility (Ref: 1, 2).

Limited evidence of developmental effects in offspring of exposed military workers is shown in one of the study (Ref: 2).

However, due to the small number of adequate studies available and the uncertainty about exposure assessment, these results do not allow to confirm or denie an association between exposure to FR2 and reproductive developmental outcome (*not classifiable*).

4.2.3 Reproductive/developmental effects in experimental animals: Studies evaluating health effects due to RF at a lower frequency range (FR1: 450 to 6000 MHZ), which also includes the frequencies used in previous generations' broadband cellular networks (1G, 2G, 3G and 4G).

The articles identified through database searching and other sources were 5052. After removing duplicates (77) and excluding non-pertinent articles (4886) based on title and abstracts, 89 articles remained. Based on full-text screening, 43 papers were further excluded, so that the published articles with appropriate frequencies for the inclusion in this qualitative synthesis were 46, corresponding to 39 studies. In three cases, more than one article was published reporting information on the same study for different reproductive/developmental end points (Fig. 15).

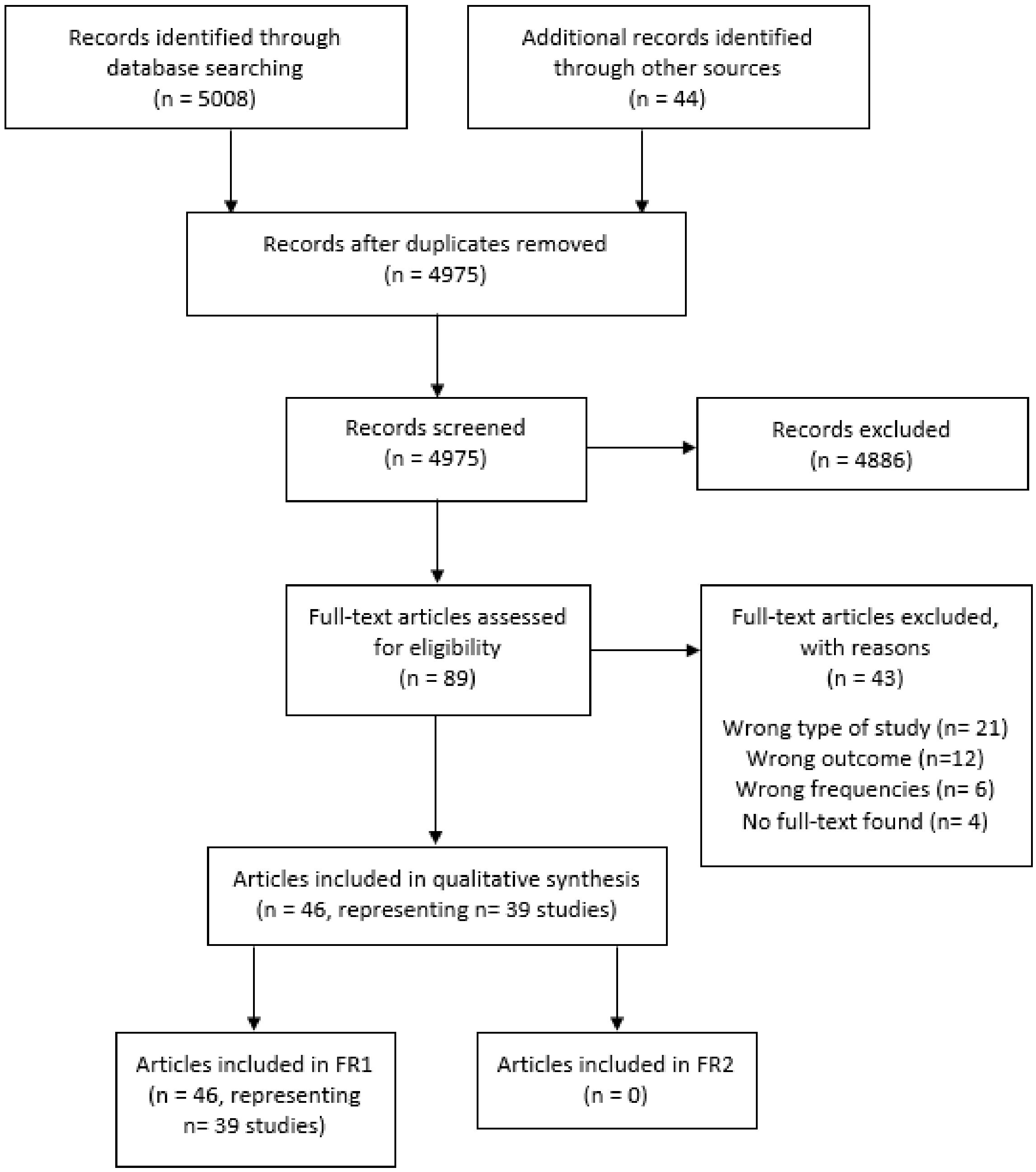
At this stage, a selection based on frequency range was also performed: out of 46 papers/39 studies, all reported exposures to the FR1 range, and none to FR2.

Another selection was based on the guidelines NTP Modified One Generation Study and OECD 443 from 2014 (Foster et al., 2014), which are globally recognised as the gold standard for the planning, conduct and monitoring of experimental bioassays on animals (rodents), aimed at finding effects on developmental pathology, endocrine disruptors, female reproduction, male reproduction, and effects on the reproductive system.

The guideline study design envisages at least 10 animals/sex/group in order to produce statistically robust results. Following this assumption, the papers were distributed by type of study, i.e., male reproduction, female reproduction, developmental pathology.

For each study, the abstract is reported, together with tables summarising the salient information; a senior expert evaluated their adequacy for assessing reproductive and developmental effects (adequate/inadequate), and expressed an overall synthesis of the results (positive/negative/equivocal), following the criteria described in the methodology section.

Figure 15 – Flow diagram. Reproductive/developmental effects in experimental animals FR1



REPRODUCTIVE TOXICITY

Male Mice (Tables 21, a, b)

1. Mugunthan et al., 2012.
India. Mice. Reproductive toxicity.

Mice (n=18) were exposed to 2G ultra-high frequency radiation, 48 minutes per day for a period of 30 to 180 days. The amount of electromagnetic field (EMF) exposed was calculated by the radiation frequency meter. Eighteen mice were exposed to 900-1900 MHz frequency radiation emitted from 2G cell phone and eighteen mice were sham control. The sham control mice (n=18) were exposed to similar conditions without 2G exposure. Each animal's weight was recorded before sacrifice. Three animals each were sacrificed at the end of 30, 60, 90,120,150 and 180 days of exposure in the experimental group after 24 hours of last exposure. Same numbers of control animals were sacrificed on similar period. We collected blood samples to measure plasma testosterone. We measured and analyzed the size, weight and volume of the testis. Testis sections were analysed under the light microscope for structural changes. Results: In 2G exposed group animal weight was lower at first, second and fourth month (p value ≤ 0.05). The mean testis weight of 2G exposed mice was significantly reduced in all months except fourth month (p value <0.05) and the mean testis volume was significantly reduced in the first three months (p value 0.02). The mean seminiferous tubule density per unit area was significantly lower (p value <0.001) in the 2G exposed testis. The mean seminiferous tubule diameter was significantly reduced in 2G exposed testis (p value is highly significant <0.001) except the second month. The mean number of Sertoli cells and Leydig cells were significantly reduced in 2G radiation exposed mice (p value is highly significant <0.001). While compared with control group, mean serum testosterone level of 2G exposed mice were significantly lower (p value 0.004). The following microscopic changes were found in the testis of 2G cell phone radiation exposed mice. 1. The interstitium appeared wide 2. Sertoli cells and spermatogonia were detached from the basal lamina. 3. Vacuolar degeneration and desquamation of seminiferous epithelium. Most of the peripheral tubules showed maturation arrest in the spermatogenesis. Seminiferous tubules scored between 8 and 9 using Johnson testicular biopsy score count. Chronic exposure to ultra-high frequency radiation emitted from a 2G cell phone could cause microscopic changes in the seminiferous tubules, reduction in the number of Sertoli and Leydig cells and decreased serum testosterone level. Long term use of cell phones could cause male infertility.

Comment*: *Adequate/positive.

2. Shahin et al., 2014.
India. Swiss mice (M). Reproductive toxicity.

Twelve-week-old mice were exposed to non-thermal low-level 2.45-GHz MW radiation (CW for 2/day for 30 days, power density = 0.029812 mW/cm2 and SAR = 0.018 W/Kg). Sperm count and sperm viability test were done as well as vital organs were processed to study different stress parameters. Plasma was used for testosterone and testis for 3b HSD assay. Immunohistochemistry of 3b HSD and nitric oxide synthase (i-NOS) was also performed in testis. We observed that MW irradiation induced a significant decrease in sperm count and sperm viability along with the decrease in seminiferous tubule diameter and degeneration of seminiferous tubules. Reduction in testicular 3b HSD activity and plasma testosterone levels was also noted in the exposed group of mice. Increased expression of testicular i-NOS was observed in the MW-irradiated group of mice. Further, these adverse reproductive effects suggest that chronic exposure to non-ionising MW radiation may lead to infertility via free radical species-mediated pathway.

Comment: Adequate/positive.

3. Zhu et al., 2015.

USA. ICR mice (M, SPF). Reproductive toxicity.

Adult male ICR mice were exposed to continuous wave 900 MHz radiofrequency fields (RF) After 7 days quarantine period, the animals were weighed (20 ± 2 gm) and randomized into three sep-arate groups of 10 mice each for different exposures.a. Continuous wave 900 MHzRf at 1.6 mW/cm2power intensity, 4 h/day for 15days. b. Sham exposure withoutRFtransmission (control mice. c. An acute dose of 2 Gy $_{\gamma}$-radiation (GR, positive controls). At the end of exposure, each mouse was caged with 3 mature virgin female mice for mating. After 7days, each male mouse was transferred to a fresh cage and mated with a second batch of 3 females. This process was repeated for a total of 4 consecutive weeks. Sham exposed male mice and those subjected to an acute 2 Gy -irradiation (GR) were handled similarly and used as un-exposed and positive controls,respectively. All females were sacrificed on the 18th day of gestation and presumptive mating and, the contents in their uteri were examined. The overall observations during the 4 weeks of mating indicated that the unexposed female mice mated to RF-exposed male mice showed no significant differences in the percentage of pregnancies, total implants, live implants and dead implants when compared with those mated with sham-exposed mice. In contrast, female mice mated with GR-exposed males showed a consistent pattern of significant differences in the above indices in each and all 4 weeks of mating. Thus, the data indicated an absence of mutagenic potential of RF exposure in the germ cells of male mice.

Comment*: *Adequate/negative.

4. Pandey et al., 2017.

India. Swiss mice (M). Reproductive toxicity.

Swiss albino mice were exposed to RFR (900 MHz) for 4 h and 8 h duration per day for 35 days. One group of animals was terminated after the exposure period, while others were kept for an additional 35 days post-exposure. RFR exposure caused depolarisation of mitochondrial membranes resulting in destabilized cellular redox homeostasis. Statistically significant increases in the damage index in germ cells and sperm head defects were noted in RFR-exposed animals. Flow cytometric estimation of germ cell subtypes in mice testis revealed 2.5-fold increases in spermatogonial populations with significant decreases in spermatids. Almost fourfold reduction in spermatogonia to spermatid turnover (1C:2C) and three times reduction in primary spermatocyte to spermatid turnover (1C:4C) was found indicating arrest in the premeiotic stage of spermatogenesis, which resulted in loss of post-meiotic germ cells apparent from testis histology and low sperm count in RFR-exposed animals. Histological alterations such as sloughing of immature germ cells into the seminiferous tubule lumen, epithelium depletion and maturation arrest were also observed. However, all these changes showed recovery to varied degrees following the post-exposure period indicating that the adverse effects of RFR on mice germ cells are detrimental but reversible. To conclude, RFR exposure-induced oxidative stress causes DNA damage in germ cells, which alters cell cycle progression leading to low sperm count in mice.

Comment: adequate/positive.

5. Pandey et al., 2018.

India. Swiss mice (M). Reproductive toxicity.

The present study investigated the effect of RFR Global System for Mobile communication (GSM) type, 900 MHz and melatonin supplementation on germ cell development during spermatogenesis. Swiss albino mice were divided into four groups. One group received RFR exposure for 3 h twice/day for 35 days and the other group received the same exposure but with melatonin (N-acetyl-5-methoxytryptamine) (MEL; 5 mg/kg bw/day). Two other groups received only MEL or remain unexposed. Sperm head abnormality, total sperm count, biochemical assay for lipid peroxides, reduced glutathione, superoxide dismutase activity and testis histology were evaluated. Additionally, flow cytometric evaluation of germ cell subtypes and comet assay were performed in testis. Extensive DNA damage in germ cells of RFR-exposed animals along with arrest in pre-meiotic stages of spermatogenesis eventually leading to low sperm count and sperm head abnormalities were observed. Furthermore, biochemical assays revealed excess free radical generation resulting in histological and morphological changes in testis and germ cells morphology, respectively. However, these effects were either diminished or absent in RFR-exposed animals supplemented with melatonin. Hence, it can be concluded that melatonin inhibits pre-meiotic spermatogenesis arrest in male germ cells through its anti-oxidative potential and ability to improve DNA reparative pathways, leading to normal sperm count and sperm morphology in RFR-exposed animals.

Comment*: *Adequate/positive (group treated without any supplement of melatonine).

6. Shahin et al., 2018.
India. Swiss mice. Reproductive toxicity.

The aim of present study was to investigate the underlying detailed pathway of the testicular apoptosis induced by free radical load and redox imbalance due to 2.45 GHz MW radiation exposure and the degree of severity along with the increased exposure duration. Twelve-week old male mice were exposed to 2.45 GHz MW radiation [continuous-wave (CW) with overall average Power density of 0.0248 mW/cm2 and overall average whole body SAR value of 0.0146 W/kg] for 2 hr/day over a period of 15, 30, and 60 days. Testicular histology, serum testosterone, ROS, NO, MDA level, activity of antioxidant enzymes, expression of pro-apoptotic proteins (p53 and Bax), anti-apoptotic proteins (Bcl-2 and Bcl-xL), cytochrome-c, inactive/active caspase-3, and uncleaved PARP-1 were evaluated. Findings suggest that 2.45 GHz MW radiation exposure induced testicular redox imbalance not only leads to enhanced testicular apoptosis via p53 dependent Bax-caspase-3 mediated pathway, but also increases the degree of apoptotic severity in a duration dependent manner.

Comment*: *Adequate/positive.

Female mice (Table 22, a)

7. Gul et al., 2009.
Turkey. Rats (F). Reproductive toxicity.

The aim of this study was to investigate whether there were any toxic effects of microwaves of cellular phones on ovaries in rats. In this study, 82 female pups of rats, aged 21 days (43 in the study group and 39 in the control group) were used. Pregnant rats in the study group were exposed to mobile phones that were placed beneath the polypropylene cages during the whole period of pregnancy. The cage was free from all kinds of materials, which could affect electromagnetic fields. A mobile phone in a standby position for 11 h and 45 min was turned on to speech position for 15 min every 12 h and the battery was charged continuously. On the 21st day after the delivery, the female rat pups were killed and the right ovaries were removed. The volumes of the ovaries were measured and the number of follicles in every tenth section was counted. The analysis revealed that in the study group, the number of follicles was lower than that in the control group. The decreased number of follicles in pups exposed to mobile phone microwaves suggest that intrauterine exposure has toxic effects on ovaries. We suggest that the microwaves of mobile phones might decrease the number of follicles in rats by several known and, no doubt, countless unknown mechanisms.

Comment*: *Adequate/equivocal.

8. Shahin et al., 2017.
India. Swiss mice (F). Reproductive toxicity.

The present study investigated the long-term effects of mobile phone (1800 MHz) radiation in stand-by, dialing and receiving modes on the female reproductive function (ovarian and uterine histo-architecture, andsteroidogenesis) and stress responses (oxidative and nitrosative stress). We observed that mobile phone radiation induces significant elevation in ROS, NO, lipid peroxidation, total carbonyl content and serum corticosterone coupled with significant decrease in antioxidant enzymes in hypothalamus, ovary and uterus of mice. Compared to control group, exposed mice exhibited reduced number of developing and mature follicles as well as corpus lutea. Significantly decreased serum levels of pituitary gonadotrophins(LH, FSH), sex steroids (E2 and P4) and expression of SF-1, StAR, P-450scc, 3beta-HSD, 17beta-HSD, cytochromeP-450 aromatase, ER-alfa and ER-beta were observed in all the exposed groups of mice, compared to control.These findings suggest that mobile phone radiation induces oxidative and nitrosative stress, which affects the reproductive performance of female mice.

Comment*: *Adequate/positive.

Male Rats (Tables 23, a-c)

9. Ozguner et al., 2005.

China. Sprague-Dawley rats (M). Reproductive toxicity.

The aim of this experimental study was to determine the biological and morphological effects of 900 MHz radiofrequency (RF) EMF on rat testes. The study was performed in the Physiology and Histology Research Laboratories of Süleyman Demirel University, Faculty of Medicine, Isparta, Turkey in May 2004. Twenty adult male Sprague-Dawley rats weighing 270 - 320 gm were randomized into 2 groups of 10 animals: Group I (control group) was not exposed to EMF and Group II (EMF group) was exposed to 30 minutes per day, 5 days a week for 4 weeks to 900 MHz EMF. Testes tissues were submitted for histologic and morphologic examination. Testicular biopsy score count and the percentage of interstitial tissue to the entire testicular tissue were registered. Serum testosterone, plasma luteinising hormone (LH) and follicle stimulating hormone (FSH) levels were assayed biochemically. Results: The weight of testes, testicular biopsy score count and the percentage of interstitial tissue to the entire testicular tissue were not significantly different in EMF group compared to the control group. However, the diameter of the seminiferous tubules and the mean height of the germinal epithelium were significantly decreased in EMF group ($p<0.05$). There was a significant decrease in serum total testosterone level in EMF group ($p<0.05$). Therefore, there was an insignificant decrease in plasma LH and FSH levels in EMF group compared to the control group ($p>0.05$). The biological and morphological effects resulting from 900 MHz RF EMF exposure lends no support to suggestions of adverse effect on spermatogenesis, and on germinal epithelium. Therefore, testicular morphologic alterations may possibly be due to hormonal changes.

Comment*: *Adequate/positive.

10. Lee et al., 2010.

Korea. Sprague Dawley rats (M). Reproductive toxicity.

We examined the histological changes by radiofrequency (RF) fields on rat testis, specifically with respect to sensitive processes such as spermatogenesis. Male rats (20 x group) were exposed to 848.5 MHz RF for 12 weeks. The RF exposure schedule consisted of two 45-min RF exposure periods, separated by a 15-min interval. The whole-body average specific absorption rate (SAR) of RF was 2.0 W/kg. We then investigated correlates of testicular function such as sperm counts in the cauda epididymis, malondialdehyde concentrations in the testes and epididymis, frequency of spermatogenesis stages, germ cell counts, and appearance of apoptotic cells in the testes. We also performed p53, bcl-2, caspase 3, p21, and PARP immunoblotting of the testes in sham- and RF-exposed animals. Based on these results, we concluded that subchronic exposure to 848.5 MHz with 2.0 W/kg SAR RF did not have any observable adverse effects on rat spermatogenesis.

Comment*: *Adequate/negative.

11. Imai et al., 2011.

Japan. Sprague-Dawley rats (M). Reproductive toxicity.

In recent years concern has arisen whether carrying a cellular phone near the reproductive organs such as the testes may cause dysfunction and particularly decrease in sperm development and production, and thus fertility in men. The present study was performed to investigate the effects of a 1.95 GHz electromagnetic field on testicular function in male Sprague-Dawley rats. Five week old animals were divided into 3 groups of 24 each and a 1.95-GHz wide-band code division multiple access (W-CDMA) signal, which is used for the freedom of mobile multimedia access (FOMA), was employed for whole body exposure for 5 hours per day, 7 days a week for 5 weeks (the period from the age of 5 to 10 weeks, corresponding to reproductive maturation in the rat). Whole-body average specific absorption rates (SAR) for individuals were designed to be 0.4 and 0.08 W/kg respectively. The control group received sham exposure. There were no differences in body weight gain or weights of the testis, epididymis, seminal vesicles, and prostate among the groups. The number of sperm in the testis and epididymis were not decreased in the electromagnetic field (EMF) exposed groups, and, in fact, the testicular sperm count was significantly increased with the 0.4 SAR. Abnormalities of sperm motility or morphology and the histological appearance of seminiferous tubules, including the stage of the spermatogenic cycle, were not observed. Thus, under the present exposure conditions, no testicular toxicity was evident.

Comment*: *Adequate/negative.

12. Meo et al., 2011.
    Saudi Arabia. Wistar rats. Reproductive toxicity.

Forty male Wistar albino rats were divided in three groups. First group of eight served as the control. The second group [group B, n=16] was exposed to mobile phone radiation for 30 minutes/day and the third group [group C, n=16] was exposed to mobile phone radiation for 60 minutes/day for a total period of 3 months. Morphological changes in the testes induced by mobile phone radiations were observed under a light microscope. Exposure to mobile phone radiation for 60 minutes/day caused 18.75% hypospermatogenesis and 18.75% maturation arrest in the testis of albino rats compared to matched controls. However, no abnormal findings were observed in albino rats that were exposed to mobile phone radiation for 30 minutes/day for a total period of 3 months. Long-term exposure to mobile phone radiation can cause hypospermatogenesis and maturation arrest in the spermatozoa in the testis of Wistar albino rats.

Comment*: *Adequate (smaller no. of animals as controls)/equivocal.

13. Al-Damegh, 2012.
    Saudi Arabia. Wistar rats (M). Reproductive toxicity.

The aim of this study was to investigate the possible effects of electromagnetic radiation from conventional cellular phone use on the oxidant and antioxidant status in rat blood and testicular tissue and determine the possible protective role of vitamins C and E in preventing the detrimental effects of electromagnetic radiation on the testes. The study population comprised 120 male Wistar albino rats, distributed at least 10xgroup. The treatment groups were exposed to an electromagnetic field, electromagnetic field plus vitamin C (40 mg/kg/day) or electromagnetic field plus vitamin E (2.7 mg/kg/day). All groups were exposed to the same electromagnetic frequency for 15, 30, and 60 min daily for two weeks. There was a significant increase in the diameter of the seminiferous tubules with a disorganized seminiferous tubule sperm cycle interruption in the electromagnetism-exposed group. The serum and testicular tissue conjugated diene, lipid hydroperoxide, and catalase activities increased 3-fold, whereas the total serum and testicular tissue glutathione and glutathione peroxidase levels decreased 3-5 fold in the electromagnetism-exposed animals. Results indicate that the adverse effect of the generated electromagnetic frequency had a negative impact on testicular architecture and enzymatic activity. This finding also indicated the possible role of vitamins C and E in mitigating the oxidative stress imposed on the testes and restoring normality to the testes.

Comment*: *Adequate/positive.

14. Celik et al., 2012.
    Turkey. Wistar rats (M). Reproductive toxicity.

Wistar-Kyoto male rats were placed into either a control group or a group that was exposed to an electromagnetic field (EMF). Two cell phones with Specific Absorbation Rate values of 1.58 were placed and left off in cages that housed 15 rats included in the control group, and four cell phones were placed and left on in cages that housed 30 rats included in the experimental group. After 3 months, weights, seminiferous tubule diameters, and spermatogenic cell conditions of all testes of the rats were evaluated. One half of each testis was examined also under an electron microscope. No significant differences were observed between the testis weights, seminiferous tubule diameters, and histopathological evaluations between rats that had and had not been exposed to EMF. Electron microscope analysis revealed that the membrana propria thickness and the collagen fiber contents were increased and the capillary veins extended in the experimental group. Common vacuolisation in the cytoplasm of the Sertoli cells, growth of electron-dense structures, and existence of large lipid droplets were noted as the remarkable findings of this study. Although the cells that had been exposed to long-term, low-dose EMF did not present any findings that were contrary to the control conditions, the changes observed during ultrastructural examination gave the impression that significant changes may occur if the study period were to be extended. Longer studies are needed to better understand the effects of EMFs on testis tissue.

Comment: Adequate/negative.

15. Lee et al., 2012.

Korea. Sprague Dawley rats (M). Reproductive toxicity.

The effects of combined exposure to radiofrequency electromagnetic fields (RF-EMF) on rat testicular function, specifically with respect to sensitive processes such as spermatogenesis were examined. Male rats (20 x group) were exposed to single code division multiple access (CDMA) and wideband code division multiple access (WCDMA) RF signals for 12 weeks. The RF exposure schedule comprised 45 min/day, 5 days/week for a total of 12 weeks. The whole-body average specific absorption rate (SAR) of CDMA and WCDMA was 2.0 W/kg each or 4.0 W/kg in total. The correlates of testicular function such as sperm count in the cauda epididymis, testosterone concentration in the blood serum, malondialdehyde concentrations in the testes and epididymis, frequency of spermatogenesis stages, and appearance of apoptotic cells in the testes were investigated. Immunoblot for p53, bcl2, GADD45, cyclin G, and HSP70 in the testes of sham- and combined RF-exposed animals were performed. Based on the results, we concluded that simultaneous exposure to CDMA and WCDMA RF-EMFs at 4.0 W/kg SAR did not have any observable adverse effects on rat spermatogenesis.

Comment: Adequate/negative.

16. Ozlem-Nisbet et al., 2012.

Turkey. Wistar rats (M). Reproductive toxicity.

Male albino Wistar rats (2 days old) were exposed toexposure on reproduction in growing male rats. Male albino Wistar rats (2 days old) were exposed to EMF 1800 and 900 MHz for 2 h continuously per day for 90 days. Sham control was kept under similar conditions except that the field was not applied for the same period. After blood samples were collected, the animals were sacrificed 24 h after the last exposure and the tissues of interest were harvested. The mean plasma total testosterone showed similarity among the two study groups and was significantly higher than the sham control rats. The percentage of epididymal sperm motility was significantly higher in the 1800 MHz group ($P < 0.05$). The morphologically normal spermatozoa rates were higher and the tail abnormality and total percentage abnormalities were lower in the 900 MHz group ($P < 0.05$). Histopathologic parameters in the 1800 MHz group were significantly higher ($P < 0.05$). In conclusion, the present study indicated that exposure to electromagnetic wave caused an increase in testosterone level, epididymal sperm motility (forward), and normal sperm morphology of rats. As a consequences, 1800 and 900 MHz EMF could be considered to be a cause of precocious puberty in growing rats.

Comment: Adequate/positive.

17. Bin-Meferijand El-kott, 2015.

Saudi Arabia. Sprague Dawley rats (M). Reproductive toxicity.

The purpose of this study was to explore the capability of polyphenolic-rich Moringa oleifera leaf extract inprotecting rat testis against EMR-induced impairments based on evaluation of sperm count, viability, motility, sperm cell morphology, anti-oxidants (SOD and CAT), oxidative stress marker, testis tissue histopathology and PCNA immunohistochemistry. The sample consisted of sixty male Wistar rats which were divided into four equal groups. The first group (the control) received only standard diet while the second group was supplemented daily and for eight weeks with 200 mg/kg aqueous extract of Moringa leaves. The third group was exposed to 900 MHz fields for one hour a day and for (7) days a week. As for the fourth group, it was exposed to mobile phone radiation and received the Moringa extract. The results showed that the EMR treated group exhibited a significantly decrease sperm parameters. Furthermore, concurrent exposure to EMR and treated with MOE significantly enhanced the sperm parameters. However, histological results in EMR group showed irregular seminiferous tubules, few spermatogonia, giant multinucleated cells, degenerated spermatozoa and the number of Leydig cells was significantly reduced. PCNA labelling indices were significant in EMR group versus the control group. Also, EMR affects spermatogenesis and causes to apoptosis due to the heat and other stress-related EMR in testis tissue. This study concludes that chronic exposure to EMR marked testicular injury which can be prevented by Moringa oleifera leaf extract.

Comment*: *Adequate/positive.

18. Liu et al., 2015.

China. Sprague-Dawley rats (M) .Reproductive toxicity.

Twenty four rats were exposed to 900 MHz electromagnetic radiation with a special absorption rate of 0.66 ± 0.01 W/kg for 2 h/d. After 50d, the sperm count, morphology, apoptosis, reactive oxygen species (ROS), and total antioxidant capacity (TAC), representing the sum of enzymatic and nonenzymatic antioxidants, were investigated. Western blotting and reverse transcriptase PCR were used to determine the expression levels of apoptosis-related proteins and genes, including bcl-2, bax, cytochrome c, and capase-3. Results: In the present study, the percentage of apoptotic sperm cells in the exposure group was significantly increased by 91.42 % compared with the control group. Moreover, the ROS concentration in exposure group was increased by 46.21 %, while the TAC was decreased by 28.01 %. Radiation also dramatically decreased the protein and mRNA expression of bcl-2 and increased that of bax, cytochrome c, and capase-3. Conclusion: RF-EMR increases the ROS level and decreases TAC in rat sperm. Excessive oxidative stress alters the expression levels of apoptosis-related genes and triggers sperm apoptosis through bcl-2, bax, cytochrome c and caspase-3 signaling pathways.

Comment*: *Adequate/positive.

19. Saygin et al., 2015.

Turkey. Sprague Dawley rats. Reproductive toxicity.

The aim of this study was to investigate electromagnetic radiation (EMR) transmitted by wireless devices (2.45 GHz), which may cause physiopathological or ultrastructural changes, in the testes of rats. We addressed if the supplemental gallic acid (GA) may reduce these adverse effects. Six-week-old male Sprague Dawley rats were used in this study. Forty eight rats were equally divided into four groups, which were named: Sham, EMR only (EMR, 3 h day21 for 30 days), EMR1GA (30 mg/kg/daily), and GA (30 mg/kg/daily) groups. Malondialdehyde (MDA) and total oxidant status (TOS) levels increased (p50.001 for both) in EMR only group. TOS and oxidative stress index (OSI) levels decreased in GA treated group significantly (p50.001 and p50.045, respectively). Total antioxidant status (TAS) activities decreased in EMR only group and increased in GA treatment group (p50.001 and p50.029, respectively). Testosterone and vascular endothelial growth factor (VEGF) levels decreased in EMR only group, but this was not statistically significant. Testosterone and VEGF levels increased in EMR1GA group, compared with EMR only group (p50.002), and also increased in GA group compared with the control and EMR only group (p50.044 and p50.032, respectively). Prostaglandin E2 (PGE2) and calcitonin gene releated peptide (CGRP) staining increased in tubules of the testes in EMR only group (p<0.001 for both) and decreased in tubules of the testes in EMR1GA group (p<0.001 for all parameters). In EMR only group, most of the tubules contained less spermatozoa, and the spermatozoon counts decreased in tubules of the testes. All these findings and the regenerative reaction, characterized by mitotic activity, increased in seminiferous tubules cells of the testes in EMR1GA group (p<0.001). Long term EMR exposure resulted in testicular physiopathology via oxidative damage and inflammation. GA may have ameliorative effects on the prepubertal rat testes physiopathology.

Comment*: *Adequate/positive.

20. Bilgici et al., 2018.

Turkey. Wistar rats (M). Reproductive toxicity.

Inflammatory effect and testicular damage on rats exposed to low level of electromagnetic fields (EMF) at 2.45GHz microwave radiation were investigated. Twenty two Wistar rats were divided into two groups. Group 1 was the control group and not exposed to EMF. Group 2 was exposed to low level EMF (average E-field 3.68 ± 0.36 V/m, whole body average SAR, 0.0233 W/kg, in 10 g tissue) at 2.45GHz for 1 hour/day for 30 consecutive days. At the end of the study, interleukin-6 (IL-6), interleukin-10 (IL-10), interleukin-32 (IL-32), C-reactive protein (CRP) were measured in rat serum and IL-6, IL-10, IL-32 were measured in rat testis tissue.Furthermore, testicular tissues were evaluated histopathologically in terms of spermatogenesis and coagulation necrosis. Serum IL-6 and CRP levels were found to be significantly different in the study group compared to the control group (p<.05), but no significant difference was found in serum IL-10, IL-32 levels and testis tissue IL-6, IL-10, IL-32 levels compared to the control group (p>.05). On the other hand, histopathological evaluation of testicular tissue revealed a significant difference in necrosis and spermatogenesis when compared with the control group (p<.05). It may be concluded that low level EMF at 2.45GHz increases inflammation and testicular damage and negative impact on male reproductive system function.

Comment*: *Adequate/positive.

21. Guo et al., 2019.

China.Sprague-Dawlwy rats. Reproductive toxicity.

Under some occupational conditions, workers are inevitably exposed to high-intensityradiofrequency (RF) fields. In this study, we investigated the effects of one-month exposure to a220 MHz pulsed modulated RF field at the power density of 50 W/m2on the sperm quality in maleadult rats. The sperm quality was evaluated by measuring the number, abnormality and survivalrate of sperm cells. The morphology of testis was examined by hematoxylin–eosin (HE) staining. Thelevels of secreting factors by Sertoli cells (SCs) and Leydig cells (LCs) were determined by enzymelinked immunosorbent assay (ELISA). The level of cleaved caspase 3 in the testis was detected byimmunofluorescence staining. Finally, the expression levels of the apoptosis-related protein (caspase 3,BAX and BCL2) in the testis were assessed by Western blotting. Compared with the sham group, thesperm quality in the RF group decreased significantly. The levels of secreting factors of SCs and themorphology of the testis showed an obvious change after RF exposure. The level of the secretingfactor of LCs decreased significantly after RF exposure. The levels of cleaved caspase 3, caspase 3,and the BAX/BCL2 ratio in the testis increased markedly after RF exposure. These data collectivelysuggested that under the present experimental conditions, 220 MHz pulsed modulated RF exposure could impair sperm quality in rats, and the disruption of the secreting function of LCs and increased apoptosis of testis cells induced by the RF field might be accounted for by this damaging effect.

Comment*: *Adequate/positive.

22. Yu et al., 2020.

China. Sprague Dawley rats. Reproductive toxicity (exp.1 and 2).

The correlation between long-term exposure to SRF-EMR and the decline in male fertility is gradually receiving increasing attention fromthe medical society.While male reproductive organs are often exposed to SRF-EMR, little is currently known about the direct effects of long-termSRF-EMR exposure on the testes and its involvement in the suppression of male reproductive potential. The present study was designed to investigate this issue by using 4G SRF-EMR in rats. A unique exposure model using a 4G smartphone achieved localized exposure to the scrotum of the rats for 6 h each day (the smartphone was kept on active talk mode and received an external call for 1 min over 10min intervals). Results showed that SRF-EMR exposure for 150 days decreased spermquality and pupweight, accompanied by testicular injury. However, these adverse effectswere not evident in rats exposed to SRF-EMR for 50 days or 100 days. Sequencing analysis and western blotting suggested Spock3 overexpression in the testes of rats exposed to SRF-EMR for 150 days. Inhibition of Spock3 overexpression improved sperm quality decline and alleviated testicular injury and BTB disorder in the exposed rats. Additionally, SRF-EMR exposure suppressed MMP2 activity, while increasing the activity of the MMP14–Spock3 complexes and decreasing MMP14–MMP2 complexes; these results were reversed by Spock3 inhibition. Thus, long-term exposure to 4G SRF-EMR diminished male fertility by directly disrupting the Spock3–MMP2–BTB axis in the testes of adult rats. To our knowledge, this is the first study to show direct toxicity of SRF-EMR on the testes emerging after long-term exposure.

***Comment*: *Adequate/positive*.**

DEVELOPMENTAL TOXICITY

Hamsters (Table 24, a)

23. Lerchl 2008a, 2008b, 2008c.

Germany. Djiungarian Hamsters. Developmental toxicity.

In three experiments, adult male Djungarian hamsters (Phodopus sungorus) were exposed 24 hr/day for 60 days to radio frequency electromagnetic fields (RF-EMF) at 383, 900, and 1800 MHz, modulated according to the TETRA (383 MHz) and GSM standards (900 and 1800 MHz), respectively. A radial waveguide system ensured a well defined and uniform exposure at whole-body averaged specific absorption rates of 80 -mW/kg, which is equal to the upper limit of whole-body exposure of the general population in Germany and other countries. For each experiment, using two identical waveguides, hamsters were exposed (n = 120) and sham-exposed (n = 120) in a blind fashion. In all experiments, pineal and serum melatonin levels as well as the weights of testes, brain, kidneys, and liver were not affected. At 383 MHz, exposure resulted in a significant transient increase in body weight up to 4%, while at 900 MHz this body weight increase was more pronounced (up to 6%) and not transient. At 1800 MHz, no effect on body weight was seen. The results corroborate earlier findings which have shown no effects of RF EMF on melatonin levels in vivo and in vitro. The data are in accordance with the hypothesis that absorbed RF energy may result in metabolic changes which eventually cause body weight increases in exposed animals. The data support the notion that metabolic effects of RF-EMFs need to be investigated in more detail in future studies.

Comment: Adequate/negative.

Mice (Table 25, a-c)

24. Finnie et al. a, b (2006, 2009)
    BALB/c mice. Developmental toxicity.

To determine whether whole of gestation exposure of fetal mouse brain to mobile telephone radiofrequency fields produces a stress response detectable by induction of heat shock proteins (HSPs). Using a purpose-designed exposure system at 900 MHz, pregnant mice were given a single, far-field, whole body exposure at a specific absorption rate of 4 W/kg for 60 min/day from day 1 to day 19 of gestation. Control mice were sham-exposed or freely mobile in a cage to control for any stress caused by restraint in the exposure module. Immediately prior to parturition on day 19, fetal brains were collected, fixed in 4% paraformaldehyde and paraffin-embedded. Three coronal sections encompassing a wide range of anatomical regions were cut from each brain and any stress response detected by immunostaining for HSP25, 32 and 70. Results There was no induction of HSP32 or 70 in any brains, while HSP25 expression was limited to two brainstem nuclei and occurred consistently in exposed and non-exposed brains.

Comment*: *Adequate/negative.

25. Lee et al., 2009.

    Korea. ICR mice. Developmental toxicity (teratogenesis).

The murine fetus is a very sensitiveindicator of the effects of stress or stimuli in the environment.Therefore, we investigated the teratogenic effects of multi-signal radiofrequency electromagnetic fields (RF EMFs) on mouse fetuses. Pregnant mice were simultaneously exposed to two types of RF signals, single code division multiple access (CDMA) and wideband code division multiple access (WCDMA). Mice received two 45-min RF-field exposures, separated by a 15-min interval, daily throughout the entire gestation period. The whole-body average specific absorption rate (SAR) of CDMA or WCDMA was 2.0 W/kg. The animals were killed humanely on the 18th day of gestation and fetuses were examined for mortality, growth retardation, changes in head size and other morphological abnormalities. From the results, we report for the first time that simultaneous experimental exposure to CDMA and WCDMA RF EMFs did not cause any observable adverse effects on mouse fetuses.

Comment*: *Adequate (short daily exposure)/negative.

26. Fragopoulou et al., 2010.
    Greece. Balb/c mice. Developmental toxicity.

This study focuses on foetal development following mild daily exposure of pregnant mice to near field electromagnetic radiation emitted by a mobile phone.The investigation was motivated by the fact that the potentially hazardous electromagnetic radiation emitted by mobile phones is currently of tremendous public interest. Physically comparable pregnant mice were exposed to radiofrequency radiation GSM 900MHz emitted by a mobile phone.Within 5 h after birth most cubs were fixed followed by double staining in toto, and conventional paraffin histology. Other cubs remained with their mothers until teeth eruption. Structural development was assessed by examining newborns for the presence of anomalies and/or variations in soft tissues and skeletal anatomy. Electromagnetic radiofrequency exposed newborns, externally examined, displayed a normal phenotype. Histochemical and histological studies, however, revealed variations in the exposed foetuses with respect to control ones concerning the ossification of cranial bones and thoracic cage ribs, as well as displacement of Meckelian cartilage. Littermates examined after teeth eruption displayed normal phenotypes. It is concluded that mild exposure to mobile phone radiation may affect, although transiently, mouse foetal development at the ossification level. The developmental variations observed could be explained by considering the different embryonic origin and mode of ossification of the affected skeletal elements.

Comment*: *Adequate/positive.

27. Sambucci et al., 2011.
Italy. C57BL/6 newborns mice (M and F). Developmental toxicity (immunotoxicology).

The development of the immune system begins during embryogenesis, continues throughout fetal life, and completes its maturation during infancy. Exposure to immune-toxic compounds at levels producing limited/transient effects in adults, results in long-lasting or permanent immune deficits when it occurs during perinatal life. Potentially harmful radiofrequency (RF) exposure has been investigated mainly in adult animals or with cells from adult subjects, with most of the studies showing no effects. Is the developing immune system more susceptible to the effects of RF exposure? To address this question, newborn mice were exposed to WiFi signals at constant specific absorption rates (SAR) of 0.08 or 4 W/kg, 2 h/day, 5 days/week, for 5 consecutive weeks, starting the day after birth. The experiments were performed with a blind procedure using sham-exposed groups as controls. No differences in body weight and development among the groups were found in mice of both sexes. For the immunological analyses, results on female and male newborn mice exposed during early post-natal life did not show any effects on all the investigated parameters with one exception: a reduced IFN-g production in spleen cells from microwaves (MW)-exposed (SAR 4 W/kg) male (not in female) mice compared with sham-exposed mice. Altogether our findings do not support the hypothesis that early post-natal life exposure to WiFi signals induces detrimental effects on the developing immune system.

***Comment**: Adequate/negative, except for reduced IFN-g production in spleen cells from microwaves exposed (SAR 4 W/kg) male (not in female) mice compared with sham-exposed mice.*

28. Zhang et al., 2015.
China. CD1 mice. Developmental toxicity (behavioral study).

The recent rapid development of electronic communication techniques is resulting in a marked increase in exposure of humans to electromagnetic fields (EMFs). This has raised public concerns about the health hazards of long-term environmental EMF exposure for fetuses and children. Some studies have suggested EMF exposure in children could induce nervous system disorders. However, gender-dependent effects of microwave radiation exposure on cognitive dysfunction have not previously been reported. Here we investigated whether in utero exposure to 9.417-GHz microwave throughout gestation (Days 3.5–18) affected behavior, using the open field test (OFT), elevated-plus maze (EPM), tail suspension test (TST), forced swimming test (FST) and Morris water maze (MWM). We found that mice showed less movement in the center of an open field (using the OFT) and in an open arm (using the EPM) after in utero exposure to 9.417-GHz radiation, which suggested that the mice had increased anxiety-related behavior. Mice demonstrated reduced immobility in TST and FST after in utero exposure to 9.417-GHz radiation, which suggested that the mice had decreased depression related behavior. From the MWM test, we observed that male offspring demonstrated decreased learning and memory, while females were not affected in learning and memory, which suggested that microwaves had gender-dependent effects. In summary, we have provided the first experimental evidence of microwaves inducing gender-dependent effects.

***Comment**: Adequate/ positive (gender dependent effects).*

29. Fatehi et al., 2018.
Iran. NMRI-mice. Developmental toxicity.

Two hundred male and female NMRI-mice were used. One hundred males divided in five groups (n = 20) as control and exposed groups. Those irradiated with cell-phone RF in "Standby-mode" 1, 5 and 10 h daily named groups II, III and IV; respectively. Group V irradiated with cell-phone on "Active-mode" one hour daily. After 30 days irradiation, 50 males and 50 females were kept 24 h to assess their embryos. Fifty males were scarified to evaluate both in vitro and in vivo parameters, and 50 females received PMSG and HCG for both quantitative and qualitative evaluation. Comparing groups III, IV and V with control-group showed significantly decreased in the number of two-cell embryos (p = .000); however, a significant increase was found in the number of dead embryos (p = .000). Furthermore, 5 h daily irradiation significantly decreased grade-A embryos (p = .015); while, it significantly increased grade-B, C and D embryos (p-values = 0.026, 0.007, 0.006; respectively). Moreover, comparing groups IV and V to control-group, significant increase was found in pregnancy duration (p = .005, p = .009; respectively). However, in the mentioned groups a significant decrease was seen in number of newborn mice (p = .001, p = .004; respectively). In conclusion, findings showed that the cell-phone radiation can affect development of embryos as well as the number of newborn and pregnancy duration in NMRI-mouse, which might be a significant cause of reproductive failure .

Comment* : *Adequate/positive.

Rats (Table 26, a)

30. Nelson et al., 1991, 1994, 1997, 1997. USA. Sprague-Dawley rats. Developmental toxicity (synergistic effects).

Concurrent exposures to chemical and physical agents occur in the workplace; exposed workers include those involved with microelectronics industry, plastic sealers and electrosurgical units. Previous animal research indicates that hyperthermia induced by an elevation in ambient temperature can potentiate the toxicity and teratogenicity of some chemical agents. We previously demonstrated that combined exposure to radiofrequency (r.f.; 10 MHz) radiation, which also induces hyperthermia and is teratogenic to exposed animals, and the industrial solvent 2-methoxyethanol (2ME) produces enhanced teratogenicity in rats. A subsequent study replicated and extended that research by investigating the interactive dose-related teratogenicity of r.f. radiation (sham exposure or maintaining colonic temperatures at 42.0 degrees C for 0, 10, 20 or 30 min by r.f. radiation absorption) and 2ME (0, 75, 100, 125 or 150 mg/kg) on gestation days 9 or 13 of rats. The purpose of the present research is to determine the effects of r.f. radiation (sufficient to maintain colonic temperatures at 42.0 degrees C for 10 min) on a range of doses of 2ME (0, 20, 40, 60, 80, 100, 120 and 140 mg kg-1) administered on gestation day 13 of rats. Focusing on characterising the dose-response pattern of interactions, this research seeks to determine the lowest interactive effect level. Day 20 fetuses were examined for external and skeletal malformations. The results are consistent with previous observations. Dose-related developmental toxicity was observed for 2ME both in the presence and absence of r.f. radiation. However, concurrent RF radiation exposure changed the shape of the dose-effect curve of 2ME. These data indicate that combined exposure effects should be considered when developing exposure guidelines and intervention strategies.

Comment*: *Inadequate (thermal effects are considered for studying synergistic effects).

31. Nelson et al., 2001.

USA. Sprague-Dawley rats. Developmental toxicity ((synergistic effects).

The purpose of the present research is to investigate if the interactive effects noted for RF radiation and 2ME are unique to these agents, or if similar interactions might be seen with other chemicals. Because methanol is widely used as a solvent as well as fuel additive, and, at high levels, is teratogenic in animals, we selected methanol as a chemical to address generalisability. Based on the literature and our pilot studies, 0, 2, or 3 g/kg methanol (twice, at 6-hour intervals) were administered on gestation day 9 or 13 to groups of 10 Sprague-Dawley rats. Dams treated on day 9 were given methanol and exposed to RF radiation sufficient to maintain colonic temperature at 41 degrees C for 60 minutes (or sham). Those treated on day 13 were given methanol plus either 0 or 100 mg/kg 2ME. Because we observed that methanol produced hypothermia, some groups were given the initial dose of methanol concurrently with the RF or 2ME, and others were given the first dose of methanol 1.5 hours prior to RF or 2ME. Dams were sacrificed on gestation day 20, and the fetuses were examined for external malformations. The results indicate that RF radiation or methanol on day 9 increased the incidence of resorbed fetuses, but no interactive effects were observed. The resorptions were highest in groups given the experimental treatments 1.5 hours apart. The higher dose of methanol also reduced fetal weights. Administration of 2ME or methanol on day 13 increased the rate of malformations, and there was evidence of a positive interaction between 2ME and methanol. Fetal weights were reduced by 2ME and methanol alone, but no interaction was observed. Also, separation of the dosing with the teratogens did not affect the results. These results point out that interactions in developmental toxicology, such as those of RF radiation, 2ME, and methanol that we have studied, are complex, and such interactions cannot be fully understood or predicted without more research. It is important that combined exposure effects be considered when developing both physical agent and chemical agent exposure guidelines and intervention strategies.

Comment*: *Inadequate (thermal effects are considered for studying synergistic effects).

32. Ogawa et al., 2009.

Japan. Sprague-Dawley rats (F), 10 days. Developmental toxicity.

The present study was designed to evaluate whether gestational exposure to an EMF-targeting the head region, similar to that from cellular phones, might affect embryogenesis in rats. A 1.95-GHz wideband code division multiple access (W-CDMA) signal, which is one applied for the International Mobile Telecommunication 2000 (IMT-2000) system and used for the freedom of mobile multimedia access (FOMA), was employed for exposure to the heads of four groups of pregnant CD(SD) IGS rats (20 per group) for gestational days 7–17. The exposure was performed for 90 min/day in the morning. The spatial average specific absorption rate (SAR) for individual brains was designed to be 0.67 and 2.0 W/kg with peak brain SARs of 3.1 and 7.0 W/kg for low (group 3) and high (group 4) exposures, respectively, and a whole-body average SAR less than 0.4 W/kg so as not to cause thermal effects due to temperature elevation. Control and sham exposure groups were also included. At gestational day 20, all dams were killed and fetuses were taken out by cesarean section. There were no differences in maternal body weight gain. No adverse effects of EMF exposure were observed on any reproductive and embryotoxic parameters such as number of live (243–271 fetuses), dead or resorbed embryos, placental weights, sex ratios, weights or external, visceral or skeletal abnormalities of live fetuses.

Comment*: *Adequate/negative.

33. Sommer et al., 2009.

Germany, C57BL mice (M, F). Multi-generation study. Developmental toxicity.

Male and female mice (C57BL) were chronically exposed (life-long, 24 h/day) to mobile phone communication electromagnetic fields at approximately 1966 MHz (UMTS). Their development and fertility were monitored over four generations by investigating histological, physiological, reproductive and behavioral functions. Exposure of 24 h/day, 7 days/week, using 128 M and 256 F over four generations. The mean whole-body SARs, calculated for adult animals at the time of mating, were 0 (sham), 0.08, 0.4 and 1.3 W/kg. Power densities were kept constant for each group (0, 1.35, 6.8 and 22 W/m(2)), resulting in varying SARs due to the different numbers of adults and pups over the course of the experiment. The experiment was done in a blind fashion. The results show no harmful effects of exposure on the fertility and development of the animals. The number and the development of pups were not affected by exposure. Some data, albeit without a clear dose-response relationship, indicate effects of exposure on food consumption that is in accordance with some data published previously. In summary, the results of this study do not indicate harmful effects of long-term exposure of mice to UMTS over several generations.

Comment*: *Adequate/negative.

34. Ozorak et al., 2013.

Turkey. Wistar rats. Developmental toxicity.

The present study was designed to determine the effects of both Wi-Fi (2.45 GHz)- and mobile phone (900 and 1800 MHz)-induced electromagnetic radiation (EMR) on oxidative stress and trace element levels in the kidney and testis of growing rats from pregnancy to 6 weeks of age. Thirty-two rats and their 96 newborn offspring were equally divided into four different groups, namely, control, 2.45 GHz, 900 MHz, and 1800 MHz groups. The 2.45 GHz, 900 MHz, and 1, 800MHz groups were exposed to EMRfor 60min/day during pregnancy and growth. During the fourth, fifth, and sixth weeks of the experiment, kidney and testis samples were taken from decapitated rats. Results from the fourth week showed that the level of lipid peroxidation in the kidney and testis and the copper, zinc, reduced glutathione (GSH), glutathione peroxidase (GSH-Px), and total antioxidant status (TAS) values in the kidney decreased in the EMR groups, while iron concentrations in the kidney as well as vitamin A and vitamin E concentrations in the testis increased in the EMR groups. Results for fifth-week samples showed that iron, vitamin A, and β-carotene concentrations in the kidney increased in the EMR groups, while the GSH and TAS levels decreased. The sixth week results showed that iron concentrations in the kidney and the extent of lipid peroxidation in the kidney and testis increased in the EMR groups, while copper, TAS, and GSH concentrations decreased. There were no statistically significant differences in kidney chromium, magnesium, and manganese concentrations among the four groups. In conclusion, Wi-Fi- and mobile phone-induced EMR caused oxidative damage by increasing the extent of lipid peroxidation and the iron level, while decreasing total antioxidant status, copper, and GSH values.Wi-Fi- and mobile phone-induced EMR may cause precocious puberty and oxidative kidney and testis injury in growing rats.

Comment: Adequate, positive (testes injuries too).

35. Poulletier de Gannes et al., 2013.

France. Wistar rats (M, F). Developmental toxicity.

For the first time, we evaluated the effects of exposure to the 2450 MHz Wi-Fi signal (1 h/day,6 days/week) on the reproductive system of male and female Wistar rats, pre-exposed to Wi-Fi during sexual maturation. Thirty-six Wistar Han male and female rats were purchased (Janvier, France) at 6 and 7 weeks of age, respectively and exposed 1 h/day, 6 days/week, 12 animals per group Exposure lasted 3 weeks (males) or 2 weeks (females), then animals were mated and couples exposed for 3 more weeks. On the day before delivery, the fetuses were observed for lethality, abnormalities, and clinical signs. In our experiment, no deleterious effects of Wi-Fi exposure on rat male and female reproductive organs and fertility were observed for 1 h per days. No macroscopic abnormalities in fetuses were noted, even at the critical level of 4 W/kg.

Comment: Adequate/negative.

36. Celik et al., 2016.

Turkey. Wistar rats. Developmental toxicity (neuro).

The study investigates the effects of Wi-Fi-induced EMR on the brain and liver antioxidant redox systems in the rat during pregnancy and development. Sixteen pregnant rats and their 48 newborns were equally divided into control and EMR groups. The EMR groups were exposed to 2.45 GHz EMR (1 h/day for 5 days/week) from pregnancy to 3 weeks of age. Brain cortex and liver samples were taken from the newborns between the first and third weeks. In the EMR groups, lipid peroxidation levels in the brain and liver were increased following EMR exposure; however, the glutathione peroxidase (GSH-Px) activity, and vitamin A, vitamin E and b-carotene concentrations were decreased in the brain and liver. Glutathione (GSH) and vitamin C concentrations in the brain were also lower in the EMR groups than in the controls; however, their concentrations did not change in the liver. In conclusion, Wi-Fi-induced oxidative stress in the brain and liver of developing rats was the result of reduced GSH-Px, GSH and antioxidant vitamin concentrations. Moreover, the brain seemed to be more sensitive to oxidative injury compared to the liver in the development of newborns.

Comment: Adequate/positive.

37. Shirai et al., 2016.

Japan. Sprague-Dawley rats. Developmental toxicity.

To evaluate the possible adverse effects of multifrequency RF-EMFs, an experiment in which pregnant rats and their delivered offspring were simultaneously exposed to eight different communication signal EMFs (two of 800 MHz band, two of 2 GHz band, one of 2.4 GHz band, two of 2.5 GHz band and one of 5.2 GHz band) was performed. Thirty six pregnant Sprague-Dawley (SD) 10-week-old rats were divided into three groups of 12 rats: one control (sham exposure) group and two experimental (low- and high-level RF EMF exposure) groups. The whole body of the mother rats was exposed to the RF EMFs for 20 h per day from Gestational Day 7 to weaning, and F1 offspring rats (46–48 F1 pups per group) were then exposed up to 6 weeks of age also for 20 h per day. The parameters evaluated included the growth, gestational condition and organ weights of the dams; the survival rates, development, growth, physical and functional development, memory function, and reproductive ability of the F1 offspring; and the embryotoxicity and teratogenicity in the F2 rats. No abnormal findings were observed in the dams or F1 offspring exposed to the RF EMFs or to the F2 offspring for any of the parameters evaluated. Thus, under the conditions of the present experiment, simultaneous whole-body exposure to eight different communication signal EMFs at frequencies between 800 MHz and 5.2 GHz did not show any adverse effects on pregnancy or on the development of rats.

Comment*: *Adequate/negative.

38. Stasinopouloua et al., 2016.

Greece. Wistar rats. Developmental toxicity (neuro).

In the present study, to evaluate the effects of wireless 1880–1900 MHz Digital Enhanced CommunicationTelephony (DECT) base radiation on fetal and postnatal development, Wistar rats (80 dams in 4 groups) were exposed at an average electric field intensity of 3.7 V/m, 12 h/day, during pregnancy. After parturition, a group of dams and offspring were similarly exposed for another 22 days. Controls were sham-exposed. The data showedthat DECT base radiation exposure caused heart rate increase in the embryos on the 17th day of pregnancy.Moreover, significant changes on the newborns' somatometric characteristics were noticed. Pyramidalcell loss and glia fibrilliary acidic protein (GFAP) over-expression were detected in the CA4 region of thehippocampus of the 22-day old pups that were irradiated either during prenatal life or both pre- and postnatally. Changes in the integrity of the brain in the 22-day old pups could potentially be related to developmental behavioral changes during the fetal period.

Comment*: *Adequate/positive.

39. Othman et al., 2017.

Tunisia. Wistar rats. Developmental toxicity (neuro).

The present work investigated the effects of prenatal exposure to radiofrequency waves of conventional WiFi devices on postnatal development and behavior of rat offspring. Ten Wistar albino pregnant rats were randomly assigned to two groups (n =5). The experimental group was exposed to a 2.45 GHz WiFi signal for 2 h a day throughout gestation period. Control females were subjected to the same conditions as treated group without applying WiFi radiations. After delivery, the offspring was tested for physical and neurodevelopment during its 17 postnatal days (PND), then for anxiety (PND 28) and motricity (PND 40-43), as well as for cerebral oxidative stress response and cholinesterase activity in brain and serum (PND 28 and 43). Our main results showed that the in-utero WiFi exposure impaired offspring neurodevelopment during the first seventeen postnatal days without altering emotional and motor behavior at adult age. Besides, prenatal WiFi exposure induced cerebral oxidative stress imbalance (increase in malondialdehyde level (MDA) and hydrogen peroxide (H2O2) levels and decrease in catalase (CAT) and superoxide dismutase (SOD) activities) at 28 but not 43 days old, also the exposure affected acethylcolinesterase activity at both cerebral and seric levels. Thus, the current study revealed that maternal exposure to WiFi radiofrequencies led to various adverse neurological effects in the offspring by affecting neurodevelopment, cerebral stress equilibrium and cholinesterase activity.

Comment*: *Adequate/positive.

Table 21 – Reproductive/developmental effects in experimental animals: reproductive toxicity in male mice (450-6000 MHz) (a)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
1. Mugunthan et al., 2012, Swiss albino mice (M), 30 to 180 days	2G ultra-high frequency radiation (900 - 1900 MHz); the highest SAR value for this standard handset was 1.69W/Kg	48 minutes/day; 18 mice/group	Exposed animal weight was lower at first, second and fourth month ($p<0.05$). The mean testis weight of exposed mice was significantly reduced in all months except fourth month ($p<0.05$) and the mean testis volume was significantly reduced in the first three months ($p < 0.05$). Mean seminiferous tubule density per unit area was significantly lower in exposed testis ($p< 0.01$). The mean seminiferous tubule diameter was significantly reduced in exposed testis ($p < 0.01$) except the second month. The mean number of Sertoli cells and Leydig cells were significantly reduced in exposed mice ($p < 0.01$). Mean serum testosterone level of exposed mice were significantly lower ($p < 0.01$). The following microscopic changes were found in the testis of RFR exposed mice. 1. The interstitium appeared wide 2. Sertoli cells and spermatogonia were detached from the basal lamina. 3. Vacuolar degeneration and desquamation of seminiferous epithelium. Most of the peripheral tubules showed maturation arrest in the spermatogenesis. Seminiferous tubules scored between 8 and 9 using Johnson testicular biopsy score count.	**Adequate/positive**
2.Shahin et al., 2014, Swiss mice (M), 30 days	2.45-GHz; SAR: 0.018 W/Kg	2 h/day; 20 mice group, 40 in total	RFR induced a significant decrease in sperm count and sperm viability along with the decrease in seminiferous tubule diameter and degeneration of seminiferous tubules. Reduction in testicular 3ß HSD activity and plasma testosterone levels was also observed in the exposed group of mice. Increased expression of testicular i-NOS was observed in the MW-irradiated group of mice ($p < 0.01$)	**Adequate/positive**
3. Zhu et al., 2015, ICR mice (SPF) (M adult), [12 virgin females per each male were used for mating], 15 days	900 MHz; 1.6 mW/cm2, whole body average SAR 0.731 W/kg; acute 2 Gy irradiation from Co60 source, at a dose rate of 1 Gy per minute, as positive control	4 h/day; 10 male mices per exposure group. After exposures, each male mouse was kept in a separate cage with 3 virgin females for mating. After 7 days, each male was separated from the females and transferred to a fresh cage with a new batch of 3 virgin females for mating in the second, third and fourth weeks (in total: 12 females per each male).	Not any statistically significant effect on average body weight, testes weight in male mice exposed to RFR. Comparison between the females mated to RF- and sham-exposed mice: non-significant differences in percentages of pregnancies, live and dead implants. There were no significant differences in calculated total implants, live and dead implants per pregnant female ($p > 0.05$).	**Adequate/negative**

Table 21 – Reproductive/developmental effects in experimental animals: reproductive toxicity in male mice (450-6000 MHz) (continue b)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
4. Pandey et al., 2017, Swiss albino mice (M), 35 days	900 MHz (GSM), 0.0054 - 0.0516 W/kg	4 or 8 h/day, 7 days/week, 15/group	Increased damage index in germ cells, sperm head defects, decreased sperm count, arrest in pre-meiotic stage of spermatogenesis, loss of immature germ cells into the seminiferous tubule lumen, epithelium depletion and maturation arrest ($p<0.05$)	**Adequate/positive**
5.Pandey et al., 2018, Swiss albino mice (M), 35 days	900 MHz (GSM), (Melatonin 5 mg/kg bw/day), 0.0054 - 0.0516 W/kg	6 h/day, 7 days/week, 15/group	Decreased sperm count, sperm head abnormalities, extensive DNA damage in germ cells, arrest in pre-meiotic stages of spermatogenesis, excess free radical generation resulting in histological and morphological changes in testis and germ cells morphology ($p<0.05$)	**Adequate/positive** **(group treated without any supplement of melatonine)**
6. Shahin et al., 2018, Swiss albino mice (M), 15, 30, and 60 days	2.45 GHz MW, whole body SAR 0.0146 W/kg	2 h/day; 10 mice/group	Exposure to 2.45 GHz MW leads to altered testicular histoarchitecture, decreased seminiferous tubule diameter, sperm count, sperm viability, and serum testosterone level. Duration dependent increment in total ROS, NO, and MDA level was observed in the testes of exposed animals. Exposure to RFR leads to altered expression of p53, Bax, Bcl-xL, Bcl-2, pro-caspase-3, active-caspase-3, and PARP-1. The expression of cytochrome c was found to be increased significantly in duration dependent manner in the testes of all RFR exposed mice as compared with controls. ($p < 0.05$)	**Adequate/positive**

Table 22 – Reproductive/developmental effects in experimental animals: reproductive toxicity in female mice (450-6000 MHz) (a)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
7. Gul et al., 2009, Swiss mice (F), 21 days	NR (mobile phone in standby position for 11 h and 45 min, and in call position for 15 min), NR	12 h/day, 7 days/week, 30/group	Decreased number of follicles in mice ovaries, decreased ovarian volume ($p<0.01$)	**Adequate/equivocal**
8.Shahin et al., 2017, Swiss albino mice (F), 4 months (120 days)	1800 MHz, Nokia 100 (2G, GSM) dual-band mobile phones, in different operative modes (dialing, receiving, stand-by and switched-off)	3 h/day; 24 mice/group, 2 experiments of 12mice/group, 48 female mice in total each.	Exposure caused significant elevation in ROS, NO, lipid peroxidation, total carbonyl content and serum corticosterone coupled with significant decrease in antioxidant enzymes in hypothalamus, ovary and uterus of mice. Compared to controls, exposed mice exhibited reduced number of developing and mature follicles as well as corpus lutea. Significantly decreased serum levels of pituitary gonadotrophins (LH, FSH), sex steroids (E2 and P4) and expression of SF-1, StAR, P-450scc, 3ß-HSD, 17ß-HSD, cytochrome P-450 aromatase, ER-α and ER-α were observed in all the exposed groups of mice, compared to control ($p < 0.01$)	**Adequate/positive**

Table 23 – Reproductive/developmental effects in experimental animals: reproductive toxicity in male rats (450-6000 MHz) (a)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
9. Ozguner et al., 2015, Sprague-Dawley rats (M), 4 weeks	900 MHz, 2 watts peak power, average power density 1 ± 04 mW/cm^2	30 minutes/day, 5 days/week; 10 rats/group, 20 in total	The weight of testes, testicular biopsy score count and the percentage of interstitial tissue to the entire testicular tissue were not significantly different in RFF group compared to the controls. The diameter of the seminiferous tubules and the mean height of the germinal epithelium were significantly decreased in RFF group (p<0.05). There was a significant decrease in serum total testosterone level in RFR group (p<0.05). Therefore, there was an insignificant decrease in plasma LH and FSH levels in RFF group compared to the control group (p>0.05).	**Adequate/positive**
10.Lee et al., 2010, Sprague-Dawley rats, 12 weeks	848.5 MHz, 2.0 W/kg (CDMA)	90 min/day, 5 days/week, 20/group	Not any statistically significant alteration (NS) for testicular function and spermatogenesis (p>0.05)	**Adequate/ negative**
11. Imai et al., 2011, Sprague-Dawley rats, 5 weeks	1950 MHz (CDMA), 0.4 W/kg, 0.08 W/kg	5 h/day, 7 days/week, 24/group	Not any statistically significant alteration (NS) for testicular function (p>0.05).	**Adequate/negative**
12. Meo et al., 2011, Wistar rats, 12 weeks	900, 1800 GHz (GSM). Intensities: NR	30 minutes/day, 60 minutes/day, 7 days/week 16/group (control group: 8)	Hypospermatogenesis and maturation arrest in the testis (Significance: NR)	**Adequate/equivocal**
13. Al-Damegh, 2012, Wister albino rats (M), 14 consecutive days	900/1800/1900 MHz (GSM), 0.9 W/kg, vitamin C (40 mg/kg/day) or vitamin E (2.7 mg/kg/day)	15, 30, and 60 min/day; 30/group of exposed rats; 10/group of control rats	There was a significant increase in the diameter of the seminiferous tubules with a disorganized seminiferous tubule sperm cycle interruption in RFR-exposed group. The serum and testicular tissue conjugated diene, lipid hydroperoxide, and catalase activities increased 3-fold, whereas the total serum and testicular tissue glutathione and glutathione peroxidase levels decreased 3-5 fold in RFR-exposed animals (p<0.05)	**Adequate/positive**
14. Celik et al., 2012, Wistar-Kyoto rats (M), 3 months	NR, cell phone radiations, SAR 1.58 W/kg	24 h/day (30 M exposed, 15 M controls)	No significant differences in testis weights, seminiferous tubule diameters, and histopathological evaluations (p>0.05). Electron microscope analysis: membrana propria thickness and collagen fiber contents were increased, and the capillary veins extended in exposed animals. Common vacuolisation in the cytoplasm of the Sertoli cells, growth of electron-dense structures, and existence of large lipid droplets are the remarkable findings of this study.	**Inadequate**
15.Lee et al., 2012, Sprague-Dawley rats, 12 weeks	848.5 MHz (CDMA), 1950 MHz (WCDMA), 4.0 W/kg	45 min/day, 5 days/week, 20/group (cage control group: 5)	Not any statistically significant alteration (NS) for testicular function and spermatogenesis (p>0.05)	**Adequate/negative**
16.Ozlem-Nisbet et al., 2012, Albino Wistar rats (M), 90 days	1800 and 900 MHz, SAR: 3.00, 2.7, 2.2, 1.2 mW/kg for 900 MHz for 10, 20, 50, 70 days old rats; 0.053, 0.046, 0.011, 0.011 mW/kg for 1800 MHz for 10, 20, 50, 70 days old rats	2 h/day; 11 rats/group	The mean plasma total testosterone showed similarity among the two study groups and was significantly higher than the sham control rats. The percentage of epididymal sperm motility was significantly higher in the 1800 MHz group (P < 0.05). The morphologically normal spermatozoa rates were higher and the tail abnormality and total percentage abnormalities were lower in the 900 MHz group (P < 0.05). Histopathologic parameters in the 1800 MHz group were significantly higher (P < 0.05).	**Adequate/positive**

Table 23 – Reproductive/developmental effects in experimental animals: reproductive toxicity in male rats (450-6000 MHz) (continued b)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
17. Bin-Meferij El-kott et al., 2015, Sprague-Dawley rats, 8 weeks	900 MHz for GSM, NR intensity, 200 mg/kg aqueous extract of Moringa oleifera leaves	1 h/day (15 M exposed to RF+MO extract; 15 M exposed to RF; 15 M exposed to MO extract; 15 M controls)	Statistically significant decrease of epididymal sperm counts in the exposed group (P < 0.001). Significant decrease of sperm motility. Significant (P < 0.001) increase in the frequency percentage of dead spermatozoa in exposed animals. Overall, hypospermatogenesis and maturation arrest in spermatozoa were observed in the testes of exposed rats compared to their matched control.	**Adequate/ positive**
18. Liu et al., 2015, Sprague-Dawley rats (M), 50 days (from 10 weeks of age)	900 MHz, SAR 0.66 W/kg	2 h/day (24 M exposed; 24 M controls)	Significant increase of the percentage of apoptotic sperm cells by 91.42% in exposed animals; Significant increase of the ROS concentration by 46.21%; Significant decrease of the TAC by 28%; Significant decrease of the protein and mRNA expression of bcl-2 and increase of bax, cytochrome c, and capase-3 (p<0.05)	**Adequate/ positive**
19. Saygin et al., 2015, Sprague-Dawley rats (young M), 30 days	2.45 GHz, whole body SAR 3.21 W/kg, Gallic acid (GA) ,30 mg/kg/daily	3h/day; 12 rats/ group, 48 in total	Malondialdehyde and total oxidant status (TOS) levels increased (p<0.01) in RFR only group. TOS and oxidative stress index levels decreased in GA treated group significantly (p<0.05). Total antioxidant status activities decreased in RFR only group and increased in GA treatment group (p<0.05). Testosterone and vascular endothelial growth factor levels decreased in RFR only group, but this was not statistically significant. Testosterone and VEGF levels increased in RFR+GA group, compared with RFR only group (p<0.01) and also increased in GA group compared with the control and RFR only group (p<0.05). Prostaglandin E2 and calcitonin gene releated peptide staining increased in tubules of the testes in RFR only group (p<0.01) and decreased in tubules of the testes in RFR+GA group (p<0.01). In RFR only group, most of the tubules contained less spermatozoa, and the spermatozoon counts decreased in tubules of the testes. All these findings and the regenerative reaction, characterized by mitotic activity, increased in seminiferous tubules cells of the testes in RFR+GA group (p<0.01).	**Adequate/ positive**
20. Bilgici et al., 2018, Wistar rats (M), 30 days	2.45 GHz, whole body average SAR 0.0233 W/kg	1 h/day (11 M exposed, 11 M controls)	Serum IL-6 and CRP levels were significantly different in in exposed animals (p<0.05). Significant difference in necrosis and spermatogenesis in exposed animals (p<0.05)	**Adequate/ positive**
21. Guo et al., 2019, Sprague-Dawley rats, 1 month	220 MHz (pulsed modulated), 0.030 W/kg	1h/day, 7 days/week, 20/group	Decreased sperm count and survival rate of sperm (p<0.05), increased sperm abnormalities (NS), increased expression in testes of cleaved caspase 3 (p < 0.05), caspase 3 (p<0.01), and the BAX/BCL2 ratio (p<0.01), decreased serum T level (p<0.05)	**Adequate/ positive**

Table 23 – Reproductive/developmental effects in experimental animals: reproductive toxicity in male rats (450-6000 MHz) (continued c)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
22. Yu et al., Experiment 1, 2020, Sprague-Dawley rats (M adults), 50, 100 0r 150 days	smartphone emitting SRF-EMR, 2575–2635 MHz (TD-LTE), 1.05 W/kg.	6 h/day (smartphone was kept on active talk mode and received an external call for 1 min over 10min intervals for 10 cycles); 135 rats (9 groups of 15 rats each).	After 150 days of SRF-EMR exposure, sperm concentration, motility, viability, and normal morphology were comparatively lower in the SRF group than in the control group. Mating experiment in rats exposed to SRF-EMR for 150 days: the pup weight was comparatively lower in the SRF group than in the controls. Testicular morphologic injury: after 150 days, increased disorder in spermatogenesis, as well as significant germ cell loss, and decreased epithelium height were observed, together with lower epithelium height, lower Johnsen score, and higher Cosentino score. Oxidative stress in testes: After 100 days of exposure, only CAT and GSH content was found to be significantly lower in the SRF group. After 150 days, also the levels of MDA, 4-HNE and LPO were comparatively higher, while GSH, SOD and CAT content were lower in the SRF group. Apoptosis in the testes: after 100 days, only cleaved-caspase 8 was significantly upregulated in the SRF group. After 150 days, only the level of Bcl-2 was lower, while the levels of Bax, cleaved-caspase-3, Fas, FasL and cleaved-caspase-8 were significantly higher in the SRF group ($p < 0.01$)	**Adequate/ positive**
Experiment 2, 2020, Sprague-Dawley rats (M adults), 150 days	smartphone emitting SRF-EMR, 2575–2635 MHz (TD-LTE), 1.05 W/kg.	6 h/day (smartphone was kept on active talk mode and received an external call for 1 min over 10min intervals, for 10 cycles); 10 to 15 rats/ group, 91 rats in total (7 groups)	Transcriptional profile changes: 1663 differentially expressed genes including 1446 up-regulated and 217 down-regulated. Spock3 level was higher in rats exposed to SRF-EMR for 150 days. Inhibition of Spock3 overexpression improved sperm quality decline and alleviated testicular injury and BTB disorder in the exposed rats. SRF-EMR exposure suppressed MMP2 activity, while increasing the activity of the MMP14–Spock3 complexes and decreasing MMP14–MMP2 complexes; these results were reversed by Spock3 inhibition ($p < 0.01$).	**Adequate/ positive**

Table 24 – Reproductive/developmental effects in experimental animals: : developmental toxicity in hamster in male rats (450-6000 MHz) (a)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
23. Lerchl et al., 2008 a, b, c, Djungarian hamsters (M), 60 days	a: 383 MHz (TETRA), b: 900 and c: 1800 MHz (GSM), SAR 0.08 W/kg	24 h/day (120 M exposed; 120 M sham)	a: Pineal and serum melatonin levels as well as the weights of testes, brain, kidneys, and liver were not affected; Significant transient increase in body weight up to 4%; b: Pineal and serum melatonin levels as well as the weights of testes, brain, kidneys, and liver were not affected; Significant non transient increase in body weight up to 6%; c: Pineal and serum melatonin levels as well as the weights of testes, brain, kidneys, and liver were not affected; no effect on body weight;	**Adequate/negative**

Table 25 – Reproductive/developmental effects in experimental animals: developmental toxicity in mice (450-6000 MHz) (a)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
24. Finnie et al. a, b (2006), c (2009), BALB/c mice (F)	900 MHz, 4 W/kg	1h/day, 7 days/week, 10/group	Not any statistically significant alteration (NS) in: (a): blood-brain barrier permeability in the immature brain of fetal heads, (b): immediate early gene c-fos expression as a marker of neural stress (c): stress response by induction of heat shock proteins	**Adequate/negative**
25. Lee et al., 2009, ICR mice (F breeders; F and M fetuses), Day 1-17 of gestation	CDMA (849 MHz) and WCDMA (1.95 GHz), SAR 2.0 W/kg for 2 exposure periods (total 4 W/kg)	2 exposures 45-min/day, separated by a 15-min interval (14 F sham; 17 F CDMA-exposed; 20 F sham CDMA+WCDMA controls; 20 F CDMA+WCDMA exposed). Short daily exposure	Simultaneous experimental exposure to CDMA and WCDMA RF EMFs did not cause any observable adverse effects (mortality, growth retardation, changes in head size and other morphological abnormalities) on mouse fetuses.	**Adequate/ negative**
26. Fragopoulou et al., 2010, Balb/c Mus musculus (F breeders; M and F offspring), 5 days before pregnancy; days 1-21 of gestation	GSM 900MHz, SAR 0.6–0.94 W/kg	0 (5 F control breeders, 7 M and F offspring) ; 6 min/day (7 F exposed, 20 M and F offspring); 30 min/day (7 F exposed, 20 M and F offspring)	Statistically significant variations in the ossification of cranial bones and thoracic cage ribs, and displacement of Meckelian cartilage, in exposed animals (both groups). Littermates examined after teeth eruption displayed normal phenotypes.	**Adequate/ positive**

Table 25 – Reproductive/developmental effects in experimental animals: developmental toxicity in mice (450-6000 MHz) (continued b)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
27. Sambucci et al., 2011, C57BL/6 newborns mice (M and F), 5 consecutive weeks, starting the day after birth	Wi-Fi at 2.45 GHz, 0.08 or 4 W/kg SAR	2 h/day, 5 days/week; 16 newborns/group, each with 4 adoptive mothers assigned (48 pups in total)	No differences in body weight and development among the groups were found in mice of both sexes. For the immunological analyses, results on female and male newborn mice exposed during early post-natal life did not show any effects on all the investigated parameters ($p>0.05$), with one exception: a reduced IFN-γ production in spleen cells from microwaves (MW)-exposed (SAR 4 W/kg) male (not in female) mice compared with sham-exposed mice ($p<0.05$).	**Adequate/negative**
28. Zhang et al., 2015, CD1 mice (M and F), in utero exposure, throughout gestation (Days 3.5–18)	9.417 GHz, SAR: 2.0 W/kg	12 h/day; 4 pregnant female mice per group. Previously, to obtain pregnancies: 12 breeding cages were set up, each containing one CD1 female mouse and two CD1 male mice, all aged 6 weeks.	Mice did not differ in motor ability by open field test (OFT); however, frequency of entries into and duration of time spent in the center zone for the treated group were lower compared to controls. Exposed mice had increased anxiety-related behavioral elevated-plus maze test (EPM). Tail suspension test (TST) and forced swimming test (FST) showed that RFR exposure significantly decreased immobility time, demonstrating that the offspring of exposed mice had decreased depression-related behavior. By Morris water maze (MWM), treated mice showed a progressive decline in escape latency. On the fourth and fifth days of MWM, only male mice in Radiation group spent more time trying to find the platform, indicating reduced spatial learning ability ($p < 0.01$).	**Adequate/ positive**
29. Fatehi et al., 2018, NMRI mice (M and F offspring), 30 days	900 MHz, intensity NR	Cell phone in "Standby-mode": 1, 5 and 10 h/day (group 2,3,4); cell-phone on "Active-mode": 1 h/day (group 5); 20 mice/group	Irradiated mice (at any exposure duration) had significant increases in pregnancy duration. Furthermore, when the cellphone changed from off mode to active mode, a significant delay was seen in pregnancy duration. RFR exposure leads to a significant decrease in the number of newborn mice compared to the control group. The results also demonstrated that the increase of the exposure time from 1 h per day (group 2) to 10 h per day (group 4) in the Standby mode caused a significant difference in the number of the newborns ($p < 0.05$).	**Adequate/positive**

Table 25 – Reproductive/developmental effects in experimental animals: developmental toxicity in mice (450-6000 MHz) (continued c)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
30. Nelson et al., 1991, 1994, 1997, 1997; Sprague-Dawley rats (F); 10, 20, 30 minutes	10 MHz (2-methoxyethanol at 20, 40, 60, 75, 80, 100, 120, 125, 140 or 150 mg/kg), 0.8-6.6 W/Kg . Thermal effects (temp. 42C°)	10, 20, 30 minutes; 10-27/group	Synergism between RFR and 2ME administration in the induction of teratogenic effects: increased incidence of external malformation of fetuses ($p<0.05$)	**Inadequate**
31. Nelson et al., 2001, Sprague-Dawley rats (F), 60 minutes	10 MHz (Methanol 2, 3 g/kg); 0.8-6.6 W/Kg Thermal effects (temp. 42C°)	60 minutes; 10/group	Increased incidence of resorbed fetuses ($p<0.05$). No synergistic effects.	**Inadequate**
32. Ogawa et al., 2009, Sprague-Dawley rats (F), 10 days	1950 MHz CDMA, 0.4 W/kg	90 min/day, 7 days/week, 20/group	Not any statistically significant alteration (NS) for: landmarks of sexual maturity, viable litter size/live birth index, neonatal growth, neonatal survival indices, sex ratio in progeny, physiologic endpoints revealing unique toxicities of pregnancy and lactation ($p>0.05$).	**Adequate/negative**
33. Sommer et al., 2009, C57BL mice (M, F), Multi-generation study	1966 MHz (UMTS), 0.08, 0.4, 1.3 W/kg	24 h/day, 7 days/week, 128 M and 256 F over four generations (1M and 2F per cage)	Not any statistically significant alteration (NS) for: viable litter size/live birth index, neonatal growth, neonatal survival indices, prenatal mortality, assessment of sperm quality, weight and morphology of reproductive organs, mating and fertility indices and reproductive outcome, landmarks of sexual maturity, sexual behavior ($p<0.05$)	**Adequate/negative**
34. Ozorak et al., 2013, Wistar albino rat offspring (and F pregnant adult), from pregnancy to 6 weeks of age	Wi-Fi (2.45 GHz) and mobile phone (900 and 1800 MHz) RFR, whole body SAR 0.1 W/kg	1 h/day, 5 days/week; 24 rats/group, 96 in total	Results from the fourth week showed that the level of lipid peroxidation in the kidney and testis and the copper, zinc, reduced glutathione (GSH), glutathione peroxidase, and total antioxidant status (TAS) values in the kidney decreased in the RFR groups, while iron concentrations in the kidney as well as vitamin A and vitamin E concentrations in the testis increased in the RFR groups. Results for fifth-week samples showed that iron, vitamin A, and β-carotene concentrations in the kidney increased in the RFR groups, while the GSH and TAS levels decreased. The sixth week results showed that iron concentrations in the kidney and the extent of lipid peroxidation in the kidney and testis increased in the RFR groups, while copper, TAS, and GSH concentrations decreased ($p<0.05$). There were no statistically significant differences in kidney chromium, magnesium, and manganese concentrations among the four groups ($p>0.05$).	**Adequate/positive**
35. Poulletier de Gannes et al., 2013, Wistar rats (M, F), 5 weeks F, 6 weeks M	2450 MHz (Wi-Fi signal), 0.08, 4 W/kg	1 h/day, 6 days/week, 12/group	Not any statistically significant alteration (NS) for: number of live and dead fetuses per uterine horn, number and location in each uterine horn of early and late resorption sites, distribution of implantation sites on each uterine horn (Significance: NR).	**Adequate/negative**

Table 26 – Reproductive/developmental effects in experimental animals: developmental toxicity in rats (450-6000 MHz) (a)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
36. Celik et al., 2016, Wistar albino rats (F breeders, M offspring), from gestation to 21 days of age	2.45 GHz EMR with 217 Hz pulses, SAR 0.1 W/kg	1 h/day for 5 days/week (8 F exposed breeders, 24 M exposed offspring; 8 F control breeders, 24 M control offspring)	Oxidative stress was observed in the brain and liver of developing rats, due to reduced GSH-Px, GSH and antioxidant vitamin concentrations. Moreover, the brains were more sensitive to oxidative injury compared to the liver in the development of newborns (p<0.05).	**Adequate/positive**
37. Shirai et al., 2016, Sprague–Dawley rats (F adults and their offspring), Mothers: from Gestational Day 7 to weaning; F1 offspring rats from birth up to 6 weeks of age	Eight different communication signal RFR (two of 800 MHz band, two of 2 GHz band, one of 2.4 GHz band, two of 2.5 GHz band and one of 5.2 GHz band), 0.4 W/kg, each frequency contributing for 0.05 W/kg	20 h/day; mothers: 12 rats/group; 46–48 F1 pups per group.	No abnormal findings were observed in the dams or F1 offspring exposed to the RFR or to the F2 offspring for any of the parameters evaluated (p>0.05).	**Adequate/negative**
38. Stasinopoulou et al., 2016, Wistar rats (F adults and their offspring), Pregnant rats throughout the pregnancy, and a group of dams and their offspring for further 22 days	1880–1900 MHz, whole body SAR ranging from 0.016 to 0.020 W/kg	12 h/day; 40 rats/group	RFR exposure caused heart rate increase in the embryos on the 17th day of pregnancy. Significant changes on the newborns' somatometric characteristics were noticed. Pyramidal cell loss and glia fibrilliary acidic protein over-expression were detected in the CA4 region of the hippocampus of the 22-day old pups that were irradiated either during prenatal life or both pre- and postnatally (p>0.05).	**Adequate/positive**
39. Othman et al., 2017, Albino Wistar rats, Gestation period (19–20 days)	2.45 GHz from Wi-Fi, Intensity NR (Wi-Fi: Exposed group was placed at distance of 25 cm from the Antennas. D-Link DWL-3200 AP with 802.11 g mode and WPA2 net-work protection)	2 h/day; 63 control offsprings and 37 treated offspring, 5 adult pregnant exposed rats/group	In-utero WiFi exposure impaired offspring neurodevelopment during the first 17 postnatal days without altering emotional and motor behavior at adult age. Besides, prenatal WiFi exposure induced cerebral oxidative stress imbalance (increase in malondialdehyde level and hydrogen peroxide levels and decrease in catalase and superoxide dismutase activities) at 28 but not 43 days old, also the exposure affected acethylcolinesterase activity at both cerebral and seric levels (p<0.05)	**Adequate/positive**

Table 27 (summary tables 21-26) (a, b) – Collected data for experimental studies on reproductive/developmental effects (FR1: 450-6000 MHz)

Total studies	39								
Adequate studies	37								
Type of study	Mouse					Rat			
	Observed effects	**Total adequate studies***	**Positive results**	**Equivocal results**	**Negative results**	**Total adequate studies***	**Positive results**	**Equivocal results**	**Negative results**
Reproductive-male fertility	Semen quality Histopathological alterations Fertility	9	6		3	14	10	1	3
Reproductive-female fertility	Fertility Gestation period Number of pups Weight of litters	2	1	1					
Development-Female-litters	Neuro/behavioural effects Foetal growth Litter haematochemical characteristics	10	4		6	4	3		1

*Some of the studies include more than one outcome. One study (Ref. 23) was performed on Djungarian hamster, and was considered adequate/negative.

SUMMARY OF THE RESULTS OF REPRODUCTIVE/DEVELOPMENTAL EFFECTS IN EXPERIMENTAL ANIMALS STUDIES (FR1: 450 to 6000 MHZ)(Table 27)

From the present review, 39 studies on reproductive/developmental effects in experimental animals were selected. 20 studies were performed on mice, 18 were performed on rats, 1 on hamsters. Various end points were studied in both mice and rats in adequate studies. Summaries of the results are presented in Table 27.

Out of the 37 adequate studies, the results were:

Reproduction, male fertility (Semen quality, Histopathological alterations, Fertility).

Twentythree adequate studies were performed to investigate possible non-thermal adverse effects on reproduction in male rats and mice. In mice, 6 of 6 adequate studies, showed a positive association between exposure and adverse effects (Ref: 1, 2, 4, 5, 6, 8) and 1 was negative (Ref: 3). In rats, out of 14 studies,10 were positive (Ref: 9, 13, 16, 17, 18, 19, 20, 21, 22, 23), 1 showed equivocal outcomes (Ref: 12), 3 were negative (Ref: 10, 11, 15).

The most convincing evidence regards the statistically significant decline of sperm quality, in both rats and mice. For this outcome there is *sufficient* evidence of association between RF-EMF exposure and the decline of sperm quality.

Reproduction, female fertility (Fertility, gestation period, number of pups, weight of litters).

Only 2 studies on mice were considered adequate for the present review. One of them (Ref. 8) showed positive evidence for the association of adverse effects with RF-EMF exposure, one was equivocal (Ref: 7). Female fertility was not enough investigated, so, although statistically significant effects were found, evidence is *limited* to allow for any conclusive evaluation.

Development - Dams and litters (litter hematochemical characteristics, neuro/behavioural effects, foetal growth, etc)

Fourteen adequate studies were analysed for developmental outcomes. Out of 14, 10 were performed on mice, 4 on rats. In mice, 4 showed a positive association with exposure (Ref: 26, 28, 29, 34) and 6 were negative (Ref: 24, 25, 27, 32, 33, 35). In rats, out of 4 adequate studies, 3 were positive (Ref: 36, 38, 39) and 1 negative.

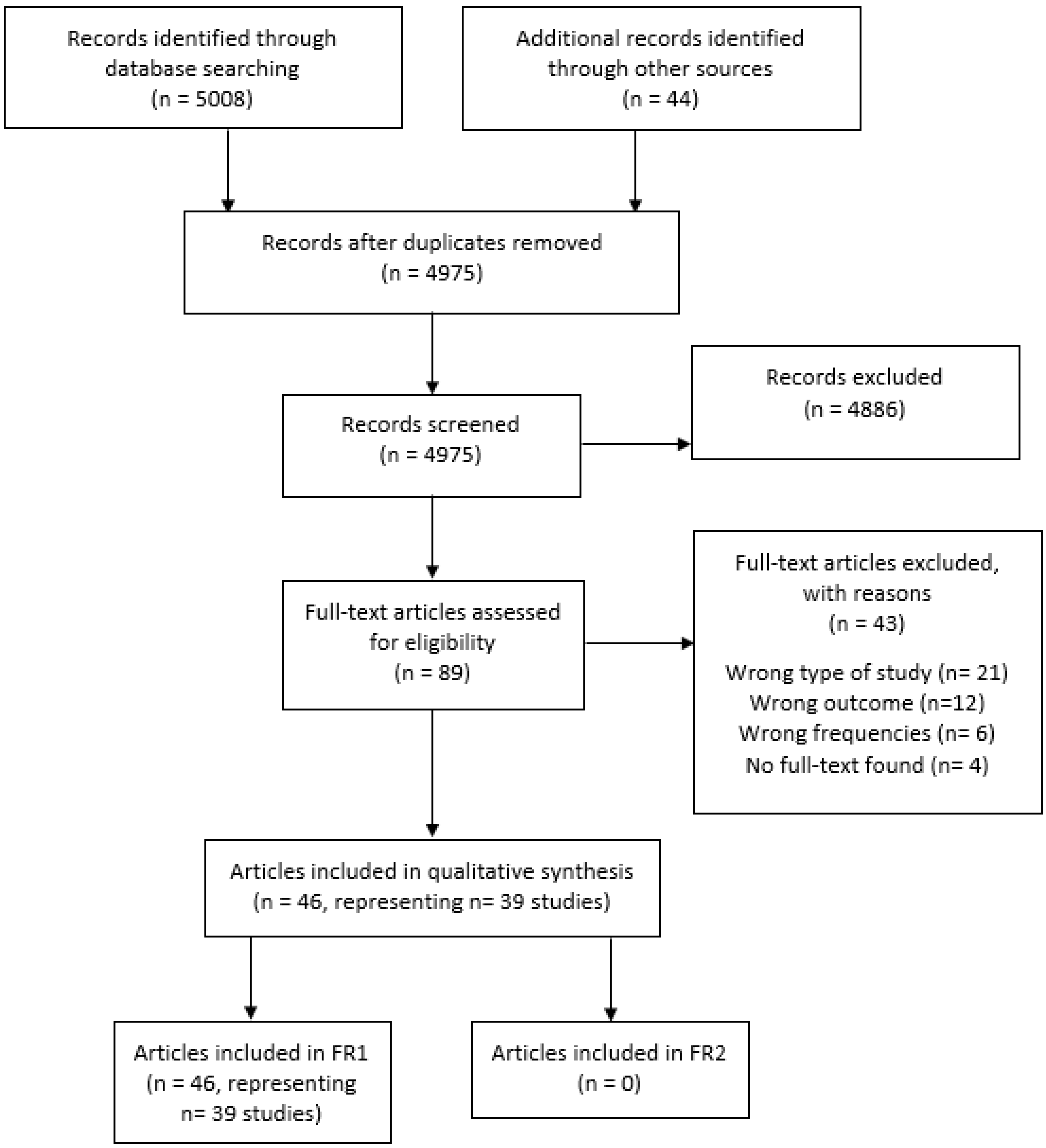
The results on this end point are mixed (conflicting) and the evidence of a possible association of developmental adverse effects with the exposure to RF-EMF is *limited.*

4.2.4 Reproductive/developmental effects in experimental animals: Studies evaluating health effects due to RF at a higher frequency range (FR2: 24 to 100 GHz, MMW) .

The articles identified through database searching and other sources were 5052. After removing duplicates (77) and excluding non-pertinent articles (4886) based on title and abstracts, 89 articles remained. Based on full-text screening, 43 papers were further excluded, so that the published articles with frequencies appropriate for inclusion in this qualitative synthesis were 46, corresponding to 39 studies. In three cases, more than one article was published reporting information on the same study for different reproductive/developmental end points (Fig. 16).

At this stage, a selection based on frequency range was also performed: out of 46 papers/39 studies, all reported exposures to the FR1 range, and none to FR2.

Figure 16 – Flow diagram. Reproductive/developmental effects in experimental animals (FR2)



5. Discussion

In its latest publication ICNIRP states that: "(…) reported adverse effects of RF-EMFs *on health need to be independently verified, be of sufficient scientific quality and consistent with current scientific understanding, in order to be taken as "evidence" and used for setting exposure restrictions. Within the guidelines, "evidence" will be used within this context, and "substantiated effect" used to describe reported effects that satisfy this definition of evidence. The reliance on such evidence in determining adverse health effects is to ensure that the exposure restrictions are based on genuine effects, rather than unsupported claims* (…)*"* (ICNIRP, 2020a).

Both in humans and in animal models, effects that ICNIRP defines as "*unsupported claims*" have been observed; and, some of them represent "*substantiated effects*", i.e. objective and relevant observations from epidemiological and experimental studies, including those on cancer and adverse effects on reproduction and development.

Epidemiological studies, when conducted with adequate information on the exposure scenarios and correct methodology, can provide strong evidence of "substantiated effects" of an agent, factor or situation. However, epidemiological studies can often have several limitations in small sample size, low statistical power, and confounding factors. These limitations include: i) Small exposed or follow up populations which may be insufficient to provide adequate statistical power; ii) The nature, amount and timing of exposures to the hazardous agent may lead to exposure misclassifications and false negative results; iii) Clear results due to confounding factors may be difficult to derive; iv) Methodological factors, such as recall bias, or publication bias, may also prevent clear results; v) The inherent delay in establishing robust epidemiological results due to the long period of tumour latency in humans (ie from first exposure to tumour indentification) on average can be 10-40 years; iv) Wide spread and diffuse exposure to other hazardous agents which may have synergistic or protective effects in combination with the agent being studied; vii) Widespread exposures to EMF creates difficulties in finding a large enough unexposed control group: which then may require the use of lowest exposure groups for comparison as the controls, which can be less robust.

The main direction of bias from many of these methodological and other limitations of human studies tends to produce "false negatives", i.e. results that exonerate the agent from being harmful but which later turn out to be wrong (Grandjean, 2013).

While sufficient evidence of carcinogenicity from RF-EMF was observed in studies on experimental animals, the following reasons suggest that the findings are important/relevant for risk assessment in humans. Animal studies (bioassays) have few limitations, and when adequately conducted to the high standards recommended (OECD, 2018b) can therefore, by comparison to human studies, provide relatively rapid and robust evidence of the association of exposure with the specific outcome.

Since the period of latency is proportional to the average lifespan of an organism, latency is proportionally shorter in the rodents that are commonly used in the laboratories. A latency time of one year in rats is equivalent to slightly more than 30 years of latency in humans, so animal bioassays, even over the rats full life time of approximately 2.5 years, allow cancer identification within a relatively short time compared to human studies.

Animal bioassays can therefore provide important information on the human risk of cancer from exposure to different agents. These data can enhance our confidence in the evidence on human cancer risks from epidemiological data.

Many human carcinogens have first been reliably identified in adequately tested laboratory animals, often many years before the human evidence was established (Huff, 1999; Huff, 2013; Maronpot et al., 2004).

There can also be consistent evidence between well conducted (OECD, 2016) animal and human studies on reproductive and developmental adverse effects.

The importance of experimental bioassays for safeguarding human health also emerges from risk assessments for chemicals as based on well conducted animal studies. Thus, animal studies are used to find the Lowest-Observed-Adverse-Effect Level (LOAEL i.e the lowest concentration of the chemical agent; or sometimes the No-Observed-Adverse-Effect Level- NOAEL) causing adverse alteration of morphology, functional capacity, growth, development, or life span of the target organism distinguishable from unexposed animals/organisms of the same species and strain under the same exposure conditions (Gaylor, 1999).

With RF-EMF, the epidemiological study results have so far only provided "*limited evidence*" of an association with cancer, largely because of the above limitations of epidemiological studies, and the absence of sufficient independent funding of such research.

In studies on laboratory animals, however, where confounding factors and other limitations are minimal, the evidence for RF-EMF having a carcinogenic effect , particularly on peripheral and central nervous system cells, is more robust than in 2011, following publications by the US- NTP and the Ramazzini Institute in 2018/19, and now attains "*sufficiency*" of animal evidence as per IARC evidence evaluation (IARC, 2019).

5.1 Cancer and lower telecommunication frequencies (FR1: 450 to 6000 MHz)

In 2011, in view of the limited evidence in humans and in experimental animals, the Working Group of IARC classified RF-EMF as "possibly carcinogenic to humans" (Group 2B). This evaluation was supported by a large majority of Working Group members. The overall evaluation was: *Radiofrequency electromagnetic fields are possibly carcinogenic to humans* (Group 2B).

Almost 10 years later many new studies have been published and an update is necessary. An Advisory Group of 29 scientists from 18 countries met at the International Agency for Research on Cancer (IARC) in March 2019 to recommend priorities for the IARC Monographs programme during 2020–2024, and among them there are RF-EMF (IARC, 2019).

5.1.1 RF-EMF (FR 1: 450 to 6000 MHz) and cancer in humans

Our review of the literature up to 2020 has found that several new epidemiological studies have been published on the association between RF-EMF and cancer since the publication of IARC Monograph 102 (IARC, 2013), yet the evidence remains mixed (conflicting results). In the Million Women Study cohort, there was no evidence of increased risk of glioma or meningioma. There was an increased risk of vestibular Schwannoma (neurinoma of the acoustic nerve) with long-term use and a significant dose–response relationship (Benson et al., 2013).

Updated follow-up in the Danish nationwide subscribers study did not find increased risks of glioma, meningioma, or vestibular schwannoma, even among those with subscriptions of 10 years or longer (Frei et al., 2011; Schüz et al., 2011).

New reports from case–control studies that assessed long-term use also found mixed results; for example, increased risks of glioma and acoustic neuroma were reported by Hardell and Carlberg, (2015) and Hardell et al., (2013 a, b), but no evidence of increased risks for these tumours was reported by Yoon et al., (2015) and Pettersson et al., (2014).

Several large-scale studies are still in progress and should yield results within the next few years. Mobi-Kids is a multicentre case–control study of brain tumours in those aged 10–24 years. Cohort Study of Mobile Phone Use and Health (COSMOS) is a new European cohort of adult cell phone users. There will also be updated results from the Million Women Study (IARC, 2019).

Some authors state that the elevated risk of brain cancer and neurinoma evidenced by various epidemiological studies do not mirror the observed incidence time trends, which are considered informative on this specific topic. This is not what we found in the recent available literature.

Concerning malignant tumours of the central nervous system (CNS), in 2019 the Global Burden of Diseases, Injuries, and Risk Factors (GBD) Study 2016 (GBD 2016, published on Lancet Neurol, 2019) reports a 4.63 per 100 000 person-years global incidence of malignant CNS tumours, which represents a 17.3% increase from 1990 to 2016. The top three countries with the highest number of incident cases were China, the USA, and India.

An increase in the incidence of glioblastoma multiforme in the frontal and temporal lobes and cerebellum was also reported in USA (Little et al., 2012; Zada et al., 2012).

A register based study in Sweden (Hardell and Carlberg, 2017) showed increasing rates of tumours of unknown type in the brain with higher rate during 2007–2015, in both sexes (Fig. 17 and 18).

Figure 17 – The Swedish National Inpatients Registry (source: Hardell and Carlberg, 2017): men

Joinpoint regression analysis of number of patients per 100,000 inhabitants according to the Swedish National Inpatient Register for men, all ages during 1998–2015 diagnosed with D43 = tumour of unknown type in the brain or CNS (http://www.socialstyrelsen.se/statistik/statistikdatabas/diagnoserislutenvard).

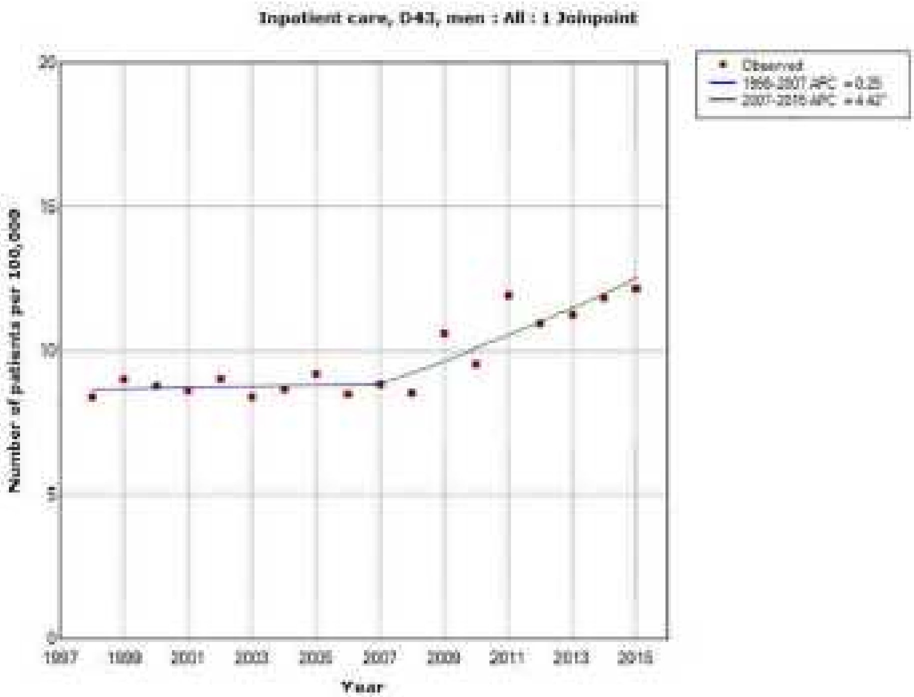
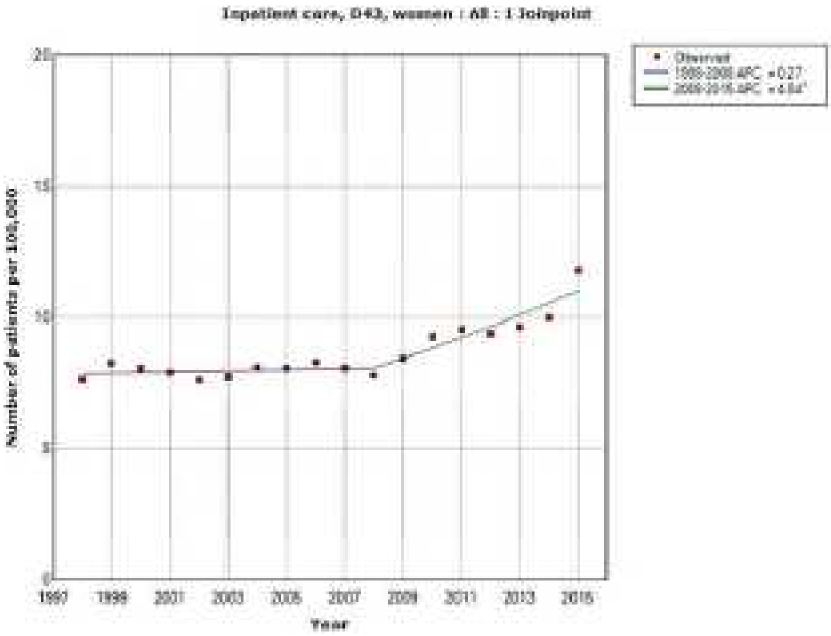


Figure 18 – The Swedish Nnl. Inpatients Registry (source: Hardell and Carlberg, 2017): women

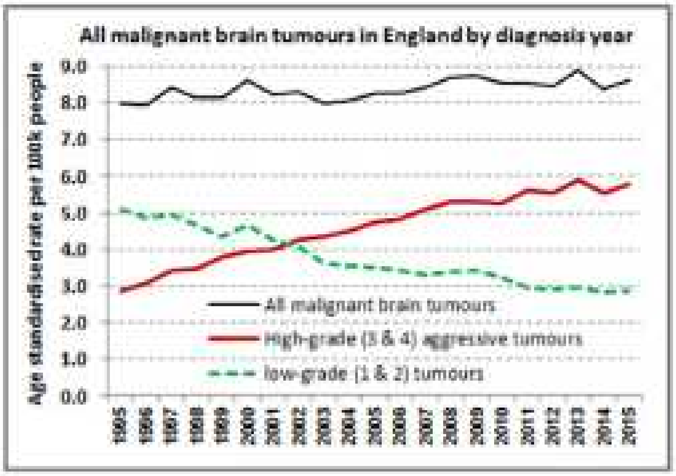
Joinpoint regression analysis of number of patients per 100,000 inhabitants according to the Swedish National Inpatient Register for women, all ages during 1998–2015 diagnosed with D43 = tumour of unknown type in the brain or CNS. (http://www.socialstyrelsen.se/statistik/statistikdatabas/diagnoserislutenvard).



Furthermore, ANSES (2019), in the volume “Estimations nationales de l’incidence et de la mortalité par cancer en France métropolitaine entre 1990 et 2018” reports the trend of the incidence (new cases by year) of glioblastomas (malignant tumours of the brain), histologically confirmed. Between 1990 and 2018 the number of new cases by year, both in men and women, increased: this is essentially attributable to the (environmental, occupational) increase in risks related to this type of cancer (ANSES, 2019)

In a UK study of national incidence data on malignant brain tumours, there was a rise in the rates of the more aggressive type identified in the epidemiological case control studies (Fig. 19). The authors looked at the incidence of brain tumours in three “major cancer registries” over a 15-year period (1992-2006). The study showed “decreased rates of primary brain tumours in all sites with the notable exception of increased incidence of glioblastoma multiforme (GBM) in the frontal lobes, temporal lobes and cerebellum. The increase in GBMs in the temporal lobe (the region of the brain closest to the ear and potentially to a phone) was seen in all three registries, ranging from approximately 1.3% to 2.3% per year, a finding that is statistically significant (Philips et al., 2018).

Figure 19 – Trends in the incidence of of all malignant brain tumours in England
(Philips et al., 2018)



http://www.saferemr.com/2018/03/brain-tumor-incidence-trends.html

In conclusion, referred to our research on FR1, positive *limited* associations have been observed in the literature between exposure to RF-EMF from wireless phones and glioma, and acoustic neuroma in humans.

5.1.2 RF-EMF (FR1: 450 to 6000 MHz) and cancer in experimental animals

New data in experimental animals for exposure to RF-EMF (FR1) have been published since the previous IARC Monographs evaluation in 2011 (IARC, 2013).

The large study by the United States National Toxicology Program (NTP) found an increased risk of malignant schwannomas of the heart in male rats with high exposure to radiofrequency radiation at frequencies used by cell phones, as well as possible increased risks of certain types of tumour in the brain and adrenal glands, and equivocal increased risks in mice or female rats (NTP, 2018a, b).

The Ramazzini Institute (RI) study also found a statistically significant increase in schwannomas of the heart in highly exposed (50 V/m) male rats and an increase in gliomas in female rats (Falcioni et al., 2018). In the Lee et al. study (2011) on Eμ-piml transgenic mice, prone to getting lymphomas, any increase of tumour incidence was observed. Lerchl et al. (2015), in a promotion study found that tumours of the lung and liver in exposed animals were significantly higher than in sham-exposed controls. In addition, lymphomas were also found to be significantly elevated by exposure, suggesting a promotion effect of RF-EMF.

The $30 million NTP study includes both mice and rats. It took more than 10 years to complete and is one of the most comprehensive assessments to date of health effects in animals exposed to RF-EMF, mice and rats. The FDA called for this research in 1999.

In this study, in the far GSM-exposed mice, the NTP found skin tumours and lung tumours in males, and malignant lymphomas in females. Far CDMA-exposed mice showed an increase of liver hepatoblastomas in males and malignant lymphomas in females. The results were labelled as equivocal (a marginal increase of neoplasms that may be test agent related even if the increased incidence of the tumours were statistically significant).

The long term study on rats (NTP, 2018a) found that exposure to high levels of RF-EMF, like that used in 2G and 3G cell phones, was associated with:

- Clear evidence of tumours in the hearts of male rats (malignant schwannomas).

- Some evidence of tumours in the brains of male rats (malignant gliomas).

- Some evidence of tumours in the adrenal glands of male rats (pheochromocytomas).

An expert peer-review panel concluded that the NTP studies were well designed, and that the results demonstrated that both GSM- and CDMA-modulated RFR were carcinogenic to the heart (schwannomas) and brain (gliomas) of male rats (Final evaluation: *Clear evidence of carcinogenicity*) (NTP, 2018c).

The RI in Italy performed a life-span carcinogenicity study on Sprague-Dawley rats to evaluate the carcinogenic effects of RF-EMF in the far field situation, reproducing the environmental exposure to RF-EMF generated by 1.8 GHz GSM antennae at radio-base stations for mobile phones. This is the largest long-term study ever performed in rats on the health effects of RF-EMF, including 2,448 animals. The authors reported the final results regarding brain and heart tumours, confirming and strengthening the same observation as NTP on rats: a statistically significant increase in Schwannomas of the heart in males and an increase in glial malignant tumour in females.

The recent NTP and RI RF-EMF studies presented similar findings in heart schwannomas and brain gliomas, strengthening the reciprocal results. Both NTP and RI studies were well performed, no bias affecting the results. Blinding was applied in both NTP and RI experiments, following their respective Standard Operating Procedures (SOPs) or specifications. It is quite common to have a different response in carcinogenesis for mice and rats, and gender differences in the response to carcinogens are common in both experimental animals and humans. Schwannomas are tumours arising from the Schwann cells, which are peripheral glial cells that cover and protect the surface of all nerves diffused throughout the body; so vestibular (acoustic nerve) and heart schwannomas have the same tissue of origin. In rats, increases in malignant heart schwannomas, malignant glial tumours of the brain and Schwann cell hyperplasia (a pre-malignant lesion) are rare. However, these lesions were observed in exposed animals in two independent laboratories, in a wide range of RF-EMF exposures studied. As a consequence, the findings of the two laboratories could not be interpreted as occurring “by chance”. The NTP and the RI studies show that the assumption that RF radiation is incapable of causing adverse health effects other than by tissue heating is not scientifically based.

It’s noteworthy that both NTP and the RI in the last 40 years strongly contributed with their results to the risk assessment of various chemical and physical agents. Their results were often predictive for human health. The NTP is the world's largest toxicology program; as far as number of agents studied, the RI is second only to NTP. The NTP and RI two-year carcinogenicity studies and their publications are also considered as the "gold standard" of cancer studies due to their high quality, their utility in evaluating human health hazards, and the rigour, transparency, and independency they bring to the evaluation of the data.

In conclusion, for FR1 exposed experimental animals, positive associations, with *sufficient* evidence, have been observed between exposure to RF-EMF and glioma and neuromas (synonymous with shwannoma).

5.2 Cancer and higher telecommunication frequencies (FR2: 24 to 100 GHz)

5.2.1 RF-EMF (FR2: 24 to 100 GHz) and cancer in humans

Very few studies were performed on frequencies between 24 to 100 GHz (FR2). The largest part of them regarded occupational exposure in workers involved in radar telecommunication. The exposure was self-reported or related to job title, and based on the distance from the source of RF emissions. In conclusion, while there are weak suggestions of a possible increase in risk of brain cancers and of lymphomas and leukaemias in workers occupationally exposed, exposure misclassification and insufficient attention to possible confounders limit the interpretation of the findings. In IARC Monograph 102 the conclusion was:

Tumours of the brain*: "exposure misclassification and insufficient attention to possible confounding limit the interpretation of findings. Thus, there is no clear indication of an association of occupational exposure to RF radiation with risk of cancer of the brain"* (IARC, 2013).

"Leukaemia/Lymphoma*: In summary, while there were weak suggestions of a possible increase in risk of leukaemia or lymphoma associated with occupational exposure to RF radiation, the limited exposure assessment and possible confounding make these results difficult to interpret"* (IARC, 2013).

Other kinds of tumour emerged as potentially associated with exposure to high frequencies (uveal melanoma, cancer of the testis, breast, lung, and skin), but many of the studies showed methodological limitations and the results were inconsistent (IARC, 2013).

The present review confirms the IARC remarks, where the highest 5G frequency (FR2) is concerned, there are no adequate epidemiological studies upon which to assess the impact on health.

5.2.2 RF-EMF (FR2: 24 to 100 GHz) and cancer in experimental animals

Seventy six studies were examined for cancer in experimental animals. No available literature regarding the possible association between experimental carcinogenicity and RF radiation, at the range 24 to 100 GHz (FR2), was found.

5.3 Adverse effect on reproduction/development and lower telecommunication frequencies (FR1: 450 to 6000 MHz)

5.3.1 RF-EMF (450 to 6000 MHz) and adverse effects on reproduction /development in humans.

About 2800 studies in this review conformed to pre-set inclusion criterion. Additional records identified through reviewed articles revealed some further eligible articles. However, only a total of 40 articles were used for data extraction, and 26 epidemiological studies were reviewed as being adequate in methodology. The result of the review are presented in Table 18.

- **Man fertility**

In recent years, we have observed a general increasing percentage of male infertility. It has been attributed to an array of environmental, health and lifestyle factors.

Sperm count, motility, DNA integrity, sperm viability and morphology were the most affected parameters when men are exposed to RF-EMF.

FR1 (450 to 6000 MHz): There is sufficient evidence of the association between RF-EMF exposure and adverse effect on fertility in man.

- **Pregnant women exposure**

Miscarriage and pre-term birth among women heavily using mobile-phones during pregnancy was described as possibly associated to the exposure of the embryo/foetus during gestation; the studies are too limited in number and inadequate for exposure assessment in order to reach definitive conclusions. An association can neither be excluded nor confirmed.

FR1 (450 to 6000 MHz): There is limited evidence of the association between RF-EMF exposure and adverse effect on fertility woman.

- **Developmental effects in offspring**

In offspring, behavioural difficulties and motor/cognitive/language delay were examined by epidemiological cross-sectional and cohort studies; the results are mixed (conflicting) and not conclusive. An association can neither be excluded nor confirmed.

FR1 (450 to 6000 MHz): There is limited evidence of the association between RF-EMF exposure and adverse effect on offspring health.

5.3.2 RF-EMF (450 to 6000 MHz) and adverse effects on reproduction /development in experimental animals.

An important aspect of safety assessment of chemical and physical agents is determining their potential reproductive and developmental toxicity. A number of guidelines have outlined a series of separate reproductive and developmental toxicity studies from fertilisation through adulthood and in some cases to second generation.

The OECD Test Guideline 443 is designed to provide an evaluation of reproductive and developmental effects that may occur as a result of pre- and postnatal chemical exposure as well as an evaluation of systemic toxicity in pregnant and lactating females and young and adult offspring. This Test Guideline is designed to provide an evaluation of reproductive and developmental effects that may occur as a result of pre- and postnatal chemical exposure as well as an evaluation of systemic toxicity in pregnant and lactating females and young and adult offspring.

The Extended One-Generation Reproductive Toxicity Study (EOGRTS) is the most recent and comprehensive guideline in this series. EOGRTS determines toxicity during preconception, development of embryo/fetus and newborn, adolescence, and adults, with specific emphasis on the nervous, immunological, and endocrine systems, EOGRTS also assesses maternal and paternal toxicity.

The objective of the prenatal developmental toxicity study is to provide general information concerning the effects of prenatal exposure on the pregnant test animal and on the developing organism. More specifically, the developmental toxicity study aims to identify direct and indirect effects on embryonic and foetal development resulting from exposure to the agent; identify any maternal toxicity; establish the relationship between observed responses and dose in both dam and offspring; establish NOAELs (no observed adverse for maternal toxicity and pup development).

We selected and analysed animal studies considering their compliance with the guidelines mentioned, though our approach tended to be inclusive when the number of animals, exposure assessment and procedure were considered acceptable.

Table 27 summarises the results. Among the different adverse effects of FR1, the most evident was the impairment of sperm quality.

Structural and/or physiological analyses of the testes showed degenerative changes, reduced testosterone level, increased apoptotic cells, and increased production of reactive oxygen species (ROS).

For all other parameters results were limited and they do not allow conclusive evaluation.

- **Male fertility**

As regards RF-EMF exposure, sperm count, motility, DNA integrity, sperm viability and morphology were the most affected parameters when experimental animals are exposed to RF-EMF.

FR1 (450 to 6000 MHz): There is sufficient evidence of the association between RF-EMF exposure and adverse effect on fertility in male experimental animals.

- **Female fertility**

The studies are too limited in number in order to reach definitive conclusions. The two adequate studies examined, show adverse effects, but an association cannot be denied, nor confirmed.

FR1 (450 to 6000 MHz): There is limited evidence of the association between RF-EMF exposure and adverse effect on fertility in female experimental animals.

- **Developmental effects in offspring**

In offspring, gestation duration, foetal growth, litter characteristics, neurobehavioural effects were examined by experimental bioassays in rodents. Some studies were positive, but results are often conflicting for different studies and limitations were observed in exposure assessment. So, results were not conclusive. An association cannot be denied, nor confirmed.

FR1 (450 to 6000 MHz): There is limited evidence of the association between RF-EMF exposure and adverse effect on developmental parameters both in dams and offspring.

5.4 Adverse effect on reproduction/development and higher telecommunication frequencies (FR2: 24 to 100 GHz)

5.4.1 Adverse effect on reproduction/development in humans (FR2: 24 to 100 GHz)

The few available epidemiological studies we have analysed were performed on occupationally exposed men (Table 20). Adverse effects on sperm fertility were reported. However, the two available cross-sectional studies have the limit of self-reported exposure or assessment done by job title. An association cannot be denied, or confirmed. From our search, developmental adverse effects on these higher frequencies were not adequately studied in the human population.

FR2 (24 to 100 GHz): No adequate studies were performed on this band of higher frequencies.

5.4.2 Adverse effect on reproduction/development in experimental animal studies (FR2: 24 to 100 GHz)

In the few studies designed for the higher frequencies, only thermal adverse effects were adequately studied.

FR2 (24 to 100 GHz): No adequate studies were performed on this band of higher frequencies.

6. Conclusions

6.1 Telecommunication frequencies FR1 450 MHz – 6000 MHz

6.1.1 Cancer in humans

There is limited evidence in humans for the carcinogenicity of radiofrequency radiation. Starting from 2011, positive associations have again been observed between exposure to radiofrequency radiation from wireless phones and glioma and acoustic neuroma, but the evidence is not yet sufficiently strong to establish a direct relationship.

6.1.2 Cancer in experimental animals

There is sufficient evidence in experimental animals for the carcinogenicity of radiofrequency radiation.

6.1.3 Reproductive/developmental effects in humans

There is sufficient evidence of adverse effects on the fertility of men. There is *limited* evidence of adverse effects on fertility in women. There is *limited* evidence on developmental effects in offspring of mothers who were heavy users of mobile phones during pregnancy.

6.1.4 Reproductive/developmental effects in experimental animals

There is sufficient evidence of adverse effects on male rat and mouse fertility. There is *limited* evidence of adverse effects on female mouse fertility. There is *limited* evidence of adverse effects on the development in offspring of rats and mice exposed during embryo life.

6.2 Telecommunication frequencies FR2: 24 to 100 GHz

6.2.1 Cancer in humans

The few inadequate data available do not allow any evaluation.

6.2.2 Cancer in experimental animals

No available data.

6.2.3 Reproductive/developmental effects in humans

No available data.

6.2.4 Reproductive/developmental effects in experimental animals

No available data.

6.3 Overall evaluation

6.3.1 Cancer

FR1 (450 to 6000 MHz): As a synthesis of what we have managed to analyse in the available scientific literature, in both human and animal studies, we can say that RF-EMF at FR1 frequencies exposure probably cause cancer, and in particular gliomas and acoustic neuromas in humans.

FR2 (24 to 100 GHz): No adequate studies were performed on non thermal effects of the higher frequencies.

6.3.2 Reproductive developmental effects

FR1(450 to 6000 MHz): These frequencies *clearly* affect male fertility. These frequencies *possibly* affect female fertility. They *possibly* have adverse effects on the development of embryos, foetuses and newborns.

FR2 (24 to 100 GHz): *No adequate* studies were performed on non-thermal effects of the higher frequencies.

7. Policy options

The policy options resulting from the present report – applying to the 5G frequencies (700 MHz, 3600 MHz, 26 GHz) and bearing in mind that the 2G, 3G and 4G frequencies will continue to be used for many years – are reported below.

7.1 Opting for novel technology for mobile phones that enables RF exposures to be reduced

The source of RF emissions that seems at present to pose the greatest threat is the mobile phone. Though transmitting installations (radiobase masts) are perceived by some people as providing the greatest risk, actually the greatest burden of exposure in humans generally derives from their own mobile phones, and epidemiological studies have observed a statistically significant increase in brain tumours and Schwann cell tumours of the peripheral nerves, mainly among heavy cell-phone users.

We accordingly need to ensure that increasingly safer telephone devices are manufactured, emitting low energy and if possible only working when at a certain distance from the body. The cable earpiece solves much of the problem, but is inconvenient and hence puts users off; on the other hand, it is not always possible to use a speakerphone mode.

The option of lowering RF-EMF exposure as much as possible in connection with telephones still applies whatever the frequencies, from 1G to 5G. Countries such as the USA and Canada, which enforced stricter mobile phone SAR limits than Europe, were still able to build efficient 2G, 3G and 4G communications (Madjar, 2016). Since 5G aims to be more energy-efficient than the previous technologies, adopting stricter limits in the EU for mobile phone devices will be simultaneously a sustainable and a precautionary approach.

7.2 Revising the exposure limits for the public and the environment in order to reduce RF exposures from cell towers

Recently European policies (European Commission, 2019) have promoted the sustainability of a new economic and social development model which uses new technologies to constantly monitor the planet's state of health, including climate change, the energy transition, agro-ecology and the preservation of biodiversity. Using the lowest frequencies of 5G and adopting precautionary exposure limits such as those used in Italy, Switzerland, China and Russia, among others, and which are significantly lower than those recommended by ICNIRP, could help achieve these European sustainability objectives.

What epidemiological studies already showed in 2011 (IARC, 2013) has been confirmed by studies on laboratory animals, especially concerning the connection between exposure to RF-EMF and the carcinogenic effect in the nervous system. The safety level currently allowed in Europe is 61 V/m (ICNIRP, 2020a). The lowest dose at which those effects have been experimentally observed for far-field exposure is 50 V/m. In the same experimental study (Falcioni et al, 2018) any carcinogenic effect was observed at 5 V/m.

In light of this result, one policy option might be to revise residential and public exposure maxima throughout Europe. Levels could be reduced by at least 10 times, i.e. to around 6 V/m, which is an exposure level at which no cancer effects in experimental animals have been observed. 6 V/m seems also to be the precautionary limit where no adverse effects on fertility are concerned. It may sound impracticably low if we are to expand telecommunications by 5G, but it is not so.

In Italy, for example, the law sets a top limit of 20V/m, though wherever people are constantly exposed for over four hours (homes, workplaces, schools, centres of congregation, etc.) the critical value is set at 6 V/m. This limit is very close to the 5 V/m we mentioned before as being safe for experimental animals. NOAEL values ("*No Observed Adverse Effect Level*") in experimental studies are commonly used in risk assessments and research (Gaylor, 1999).

In many Italian towns, including Bologna, 5G has already been operating at a frequency of 3600 MHz. Monitoring data show that the mean exposure in the municipality of Bologna was 1.97 V/m for 2019 (peaking at 4.62 V/m in one specific instance). Statistics for 2020 are still being processed, but in no cases have the values prescribed by Italian law been exceeded. For the moment, then, it does seem possible to develop new installations whilst keeping within the legal limit.

Another example is Paris. The city has reached an agreement with France's four main mobile network operators aimed at introducing stricter network radiation norms. The RF-EMF exposure limit was lowered to 5 V/m from the previous 7 V/m for indoor spaces, representing a 30 percent reduction at the frequency reference of 900 MHz, setting a lower limit than the one adopted in Brussels (6 V/m) or Rome (6 V/m). The agreement, approved by the municipality of Paris in 2017, also includes plans for a new monitoring service to help measure EMF levels within buildings. Brussels is a third example of the adoption of a 6 V/m lower limit.

7.3 Adopting measures to incentivise the reduction of RF-EMF exposures

Much of the remarkable performance of new wireless 5G technology can also be achieved by using optic-fibre cables and by adopting engineering and technical measures to reduce exposures from 2-4G systems (Keiser, 2003; CommTech Talks, 2015; Zlatanov, 2017). This would minimise exposure, wherever connections are needed at fixed sites. For example, we could use optic fibre cables to connect schools, libraries, workplaces, houses, public buildings, all new buildings etc. Public gathering places could be 'no RF-EMF' areas (as we have for cigarette smoking) so as to avoid the passive exposure of people not using a mobile phone or long-range transmission technology, thus protecting many vulnerable elderly or immune-compromised people, children, and those who are electro-sensitive.

7.4 Promoting multidisciplinary scientific research to assess the long-term health effects of 5G and to find an adequate method of monitoring exposure to 5G

The literature contains no adequate studies by which to exclude the risk that tumours and adverse effects on reproduction and development may occur upon exposure to 5G MMW, or to exclude the possibility of some synergistic interactions between 5G and other frequencies that are already being used. This makes the introduction of 5G fraught with uncertainty concerning both health issues and forecasting/monitoring the actual exposure of the population: these gaps in knowledge are invoked to justify the call for a moratorium on 5G MMW, pending adequate research being completed.

In light of these uncertainties, one policy option is to promote multidisciplinary team research into various factors concerning exposure assessment and also into the biological effects of 5G MMW, both on humans and on the flora and fauna of the environment, non-human vertebrates, plants, fungi and invertebrates, at frequencies between 6 and 300 GHz. The results of these studies could form the basis for developing evidence-based policies regarding RF-EMF exposure of human and non-human organisms to 5G MMW frequencies. Further studies are needed to better and independently explore the health effects of RF-EMF in general and of MMW in particular.

REACH aims to improve the protection of human health and the environment through better and earlier identification of the intrinsic properties of chemical substances. EU REACH regulates the registration, evaluation, authorisation and restriction of chemicals. It also aims to enhance innovation and competitiveness of the EU chemicals industry. EU REACH is based on the principle, "*no data no market*", placing responsibility on industry to provide safety information on substances. Manufacturers and importers are required to gather information on the properties of their chemical substances, which will allow their safe handling, and to register the information in a central database at the European Chemicals Agency (ECHA) in Helsinki. One policy option can be to apply the same approach used for chemical agents to all types of technological innovation.

7.5 Promoting information campaigns on 5G

Unfortunately, there is a lack of information on the potential harms of RF-EMF. The information gap creates scope for deniers as well as alarmists, giving rise to social and political tension in many EU countries (OECD, 2017). Campaigns to inform the citizens should be therefore a priority.

Information campaigns should be carried out at all levels, beginning with schools. They should show the potential health risks, but also the opportunities for digital development, what infrastructural alternatives exist for 5G transmission, the safety measures (exposure limits) taken by the EU and Member States, and the correct use of the mobile phone. Only by sound and accurate information can we win back citizen trust and reach a shared agreement over a technological choice which, if properly managed, can bring great social and economic benefits.

8. References

8.1 General references

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Recent decades have experienced an unparalleled development in wireless communication technologies (mobile telephony, Wi-Fi). The imminent introduction of 5G technology across the EU is expected to bring new opportunities for citizens and businesses, through faster internet browsing, streaming and downloading, as well as through better connectivity. However, 5G, along with 3G and 4G, with which it will operate in parallel for several years, may also pose threats to human health. This STOA report aim to take stock of our present understanding of health effects of 5G.

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A New Look at Three Potential Mechanisms Proposed for the Carcinogenesis of 5G Radiation

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In telecommunications, the fifth generation (5G) is the new technology standard for cellular networks. However, the potential hazards of this telecommunication technology for human health and the environment have not yet been fully investigated by scientists independent from industry. It is believed that the widespread usage of 5G technology, can lead to significant increases in human exposure to radiofrequency electromagnetic fields (RF-EMF). Given this consideration, in an appeal to the European Union (EU), more than 180 scientists and physicians from 36 countries have warned about the potential dangers of 5G technology [1]. Dr. Lennart Hardell, Professor of Oncology at Örebro University in Sweden and one of the initiators, states: "***The telecom industry is trying to roll out technology that may have very real, unintended harmful consequences….. We are very concerned that the increase in radiation exposure by 5G leads to damage that cannot be reversed***" [1]. While such a large number of experts from different countries have signed this appeal, it is very interesting that an author that is not independent from the telecommunication industry, claims that only a few people believe 5G has adverse health effects "***Beyond this consideration and responding to some unfounded concerns, the paper reaffirms that 5G will not have the negative effect on people's health about which a few individuals have speculated***" [2]. Hardell and Carlberg in their recent publication have addressed their concerns over studies with ties to industry "***Conflicts of interest and ties to the industry seem to have contributed to the biased reports***" [3]. Hardell and Carlberg have also criticized the EU for not acknowledging an appeal to the EU that is currently endorsed by more than 390 scientists and medical doctors requesting a moratorium on 5G deployment until proper scientific eva - uation of potential adverse health effects has been conducted [3]. Exposure to high levels of radiofrequency electromagnetic fields has been proven to be detrimental for humans and the environment. Despite a large body of evidence, there are still scientists [4] who claim that there is no scientific evidence supporting a potential link between 5G and the risk of malignancies such as skin cancer "***Concerns have been raised on online fora and in scientific literature regarding a link between 5G***

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and skin cancer [5], ***despite an absence of scientific evidence***" [6]. It is indeed surprising that Rafferty et al., have cited a report published in the New York Times (NYT) to support their claim about a paper by Mehdizadeh and Mortazavi that addresses the theoretical basis of potential association of 5G and skin cancer. This NYT report has been seriously criticized by Mehdizadeh and Mortazavi, as follows: "***Unfortunately, the approach of New York Times in this report is not scientific. William J. Broad in his report published July 16, 2019 criticized Dr. Bill P Curry for not considering the so-called "protective effect of human skin***". Some recent publications have tried to convince the readers that current concerns about 5G high frequencies are not real. In some cases, such as the paper by Rafferty et al., numerous major shortcomings and the lack of expertise of the authors in physics and biology of RF-EMFs, suggests that these papers, deserve retraction.

Kostoff et al., [7] in their paper published recently, state: "***The common 'wisdom' presented in the literature and media is that, if there are adverse impacts resulting from high-band 5 G, the main impacts will be focused on near-surface phenomena, such as skin cancer, cataracts, and other skin conditions. However, there is evidence that biological responses to millimeter-wave irradiation can be initiated within the skin, and the subsequent systemic signaling in the skin can result in physiological effects on the nervous system, heart, and immune system***" [8].

Current Theories about the Carcinogenesis of 5G

The first model of carcinogenesis of 5G, was developed by Mehdizadeh and Mortazavi and as shown in Figure 1, high-frequency 5G radiation penetrates living skin cells and can damage them severely due to its low penetration and very high energy deposition per unit distance below the skin surface [5]. Given this consideration, absorption of 5G radiation in skin can lead to the generation of high levels of free radicals, which in turn increases the risk of skin cancer. Yakymenko et al., have reported that among 100 peer-reviewed publications on oxidative effects of low-intensity radiofrequency radiation included in their review, 93 studies showed that radiofrequency radiation induced oxidative effects in biological systems [9].

Oxidative stress that is caused by the increase in free radicals including reactive oxygen species (ROS) can play a basic role in pathological conditions of diseases such as cancer [10-12]. As reported by Singh et al., free radicals are involved in the pathogenesis of a multistage process of car-

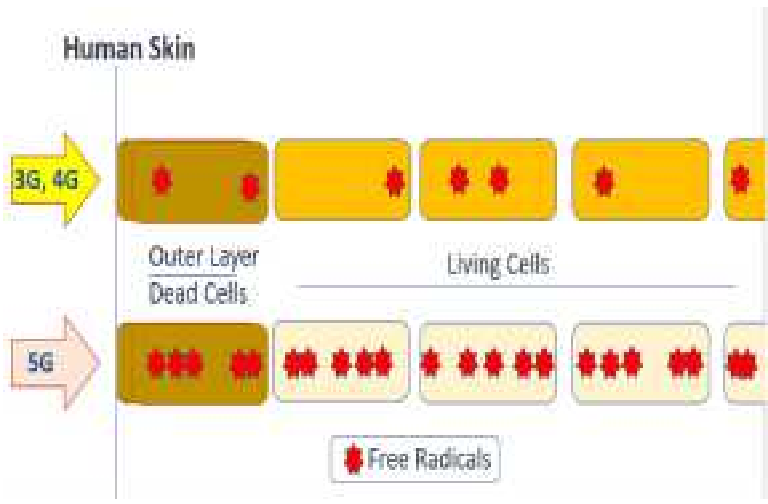

Figure 1: Due to its low penetration and very high energy deposition per unit distance below the skin surface, high-frequency 5G radiation penetrates and severely damages living skin cells.

cinogenesis [13]. Free radicals are believed to cause DNA base damages, strand breaks, damage to the tumor suppressor genes, and an increased expression of the protooncogenes. Moreover, DNA damages induced by reactive oxygen species (ROS) may contribute to higher rates of mutation, genome instability, apoptosis, associated tissue regeneration, and cell proliferation [13]. Lobo et al., introduce cancer as a "free radical" disease "***Cancer and atherosclerosis, two major causes of death, are salient "free radical" diseases***" [14]. Although oxidative stress and potential DNA damages do not necessarily increase the chance of cancer, as addressed by Kostoff et al., a rise in near-surface phenomena, such as skin cancer and cataracts, can be expected [7].

Furthermore, Betzalel et al., have previously developed a simulation model of human skin. It focuses on the multi-layer structure of skin, and especially on the helical segment of the sweat duct that serves as an antenna leading to high specific absorption rate (SAR) of the skin at extremely high frequencies, where resonances of the sweat duct-short wavelength radiation occur. Based on their modeling results, they state: "***There is enough evidence to suggest that the combination of the helical sweat duct and wavelengths approaching the dimensions of skin layers could lead to non-thermal biological effects. Such fears should be investigated and these concerns should also [a]ffect the definition of standards for the application of 5G communications***" [15]. A paper by Tripathi et al., [16] examined in detail the morphology of human sweat ducts observed by optical coherence tomography. Ref. 16 noted that their frequency of resonance lies in the terahertz region. Given the range of duct sizes and wavelength of the 5G radiation, the importance of the shorter 5G wavelengths becomes apparent. This is supported by Tripathi et al., suggesting that resonances occur in the sweat ducts at THz frequencies. As the wavelength of the nonionizing radiation decreases, the resonance coupling and energy deposition will increase. This phenomenon is illustrated in Figure 1.

The importance of the coupling and 5G energy deposition is a complex process. It depends on the incident power density, particular 5G frequency, and the absorption coefficien for the biological medium. Determination of the absorption coefficien is also complex and depends on a number of factors including the angular frequency of the 5G radiation, the conductivity of the tissue of interest, permittivity of the medium, relative dielectric constant, and permeability of the medium [17].

As noted in our discussion the detriment caused by 5G radiation cannot be dismissed without a thorough evaluation of the tissue at risk as well as the energy absorption. This uncertainty suggests that further study is warranted and should consider the mechanisms proposed in this paper.

Conflict of Interest

None

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Title:

Physiological effects of millimeter-waves on skin and skin cells: An overview of the to-date published studies

Short Title:

Effect of mm-waves on skin

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ABSTRACT

The currently ongoing deployment if the 5th generation of the wireless communication technology, the 5G technology, has reignited the health debate around the new kind of radiation that will be used/emitted by the 5G devices and networks – the millimeter-waves. The new aspect of the 5G technology, that is of concern to some of the future users, is that both, antennas and devices will be continuously in a very close proximity of the users' bodies. Skin is the only organ of the human body, besides the eyes, that will be directly exposed to the mm-waves of the 5G technology. However, the whole scientific evidence on the possible effects of millimeter-waves on skin and skin cells, currently consists of only some 99 studies. This clearly indicates that the scientific evidence concerning the possible effects of millimeter-waves on humans is insufficient to devise science-based exposure limits and to develop science-based human health policies. The sufficient research has not been done and, therefore, precautionary measures should be considered for the deployment of the 5G, before the sufficient number of quality research studies will be executed and health risk, or lack of it, scientifically established.

KEYWORDS

5G technology; millimeter-waves; skin; precautionary approach; limited deployment;

INTRODUCTION

The currently ongoing deployment of the 5th generation of the wireless communication technology (5G) is being met with a great enthusiasm by the telecommunication industry, national governments and portion of the general public. However, there is also some resistance from the part of the population in various locations around the globe.

The opposition towards the deployment of the 5G is caused by the uncertainty whether radiation emitted by the 5G networks and devices will have any effects on human health and environmental impact on fauna and flora.

The 5G wireless communication technology that is being deployed comprises of parts of the used already 3G and 4G technologies. The radiation emitted by the predecessors of the 5G, the radiation frequencies emitted by the 3G and 4G technologies, has been classified by the International Agency for Research on Cancer (IARC), as possible human carcinogen. The IARC evaluation did not concern the frequencies above 6 GHz, especially the currently prepared for use 26 GHz and 28 GHz bands and the whole spectrum of 30 – 300 GHz frequencies that will be used in coming years. The currently deployed 5G will be supplemented with a new technology that uses the millimeter-waves (mm-waves) for the fast transfer of large amounts of data. Right now, the 5G technology expands into the frequencies below the 6 GHz. Later on, the 5G will use also the frequencies of 6 – 30 GHz and, still later on, frequencies of mm-waves (30 – 300 GHz). Currently, in Europe, the spectrum of 26 GHz (range 24.25 – 27.5 GHz) and 28 GHz (range 26.5 – 29.5 GHz), is being freed for the 5G use.

It is well established that the 26 GHz and 28 GHz frequencies and mm-waves penetrate only few millimeters inside the human body and are efficiently absorbed by the water content of dermis layer of the skin. This fact has been used to misleadingly portray mm-waves as unlikely affecting the physiology and health of human body because the depth of penetration is only skin deep and does not reach any internal organs.

THE QUESTION

Do we know enough about the interactions between skin and skin cells with mm-waves to determine what health impact, if any, will have the acute and the long-term (life-time) exposure of skin to mm-waves?

In order to answer the question, literature search was performed to find studies where skin and skin cells were examined following exposure to mm-waves and affected functions and properties of skin and skin cells were evaluated in the context of the possible impact, or lack of it, on human health.

In this brief opinion review is presented evidence on the physiological effects of mm-waves exposures on human volunteers, on laboratory animals and on human and animal cells grown in the laboratory.

THE SKIN

In the research examining the effects of mm-waves, skin is simplified into three major components, the stratum corneum consisting of mostly dead cells, the epidermis consisting of few layers of cells where the bottom layer is made of dividing cells that continuously regenerate the epidermis and the underlying dermis layer. The water content of the skin is what determines the depth of penetration of the mm-waves into human body, limiting it to just couple of millimeters.

From the point of view of water content of the skin, the top layer of the skin, the stratum corneum, has low water content 15–40%), whereas the water content the rest of the skin, epidermis and dermis, is ca. 70–80%. Thus, mm-waves energy penetrates the stratum corneum but is efficiently and effectively absorbed by the water in epidermis and dermis layers [1].

Skin is the largest organ of human body that not only functions as kind of "overcoat" but is involved in regulation of physiological processes that impact the functioning of the whole body.

Skin has different thickness, color, and texture in different locations over the body and performs number of important functions. Skin (i) regulates immune response by both mechanically preventing entry of microorganisms and biochemically by generation of molecular mediators that are distributed with blood circulation to internal organs (ii) regulates body temperature, (ii) stores water and fat and prevents water loss, (iii) functions as sensory organ, and (vii) helps to make vitamin D when exposed to the sunlight.

Skin is composed of a variety of cell types that perform various functions. In epidermis reside keratinocytes, melanocytes, Merkel cells, and Langerhans cells. The dermis consists of connective tissue cells and extracellular matrix and there are located numerous nerve endings that provide the sense of touch and heat, the hair follicles, sweat glands, sebaceous glands, apocrine glands, lymphatic vessels and blood vessels. Furthermore, the skin surface provides an environment for over thousand identified species of microbes.

Different pathological conditions affecting skin might have impact on how the skin and skin cells perform their functions and how they might react/respond to mm-waves exposure. These skin ailments, that will affect levels of water in the skin, include dermatitis, eczema, psoriasis, dandruff, acne, cellulitis, skin abscess (boil or furuncle), rosacea, warts, melanoma, basal cell carcinoma, seborrheic keratosis, actinic keratosis, squamous cell carcinoma, herpes blisters, hives, tinea versicolor, viral exantham, shingles, herpes zoster, scabies, or ringworm [2].

Therefore, skin is not just a thin overcoat on the surface of the human body but it is an aggregate of numerous cells and microorganisms living together and playing a crucial role in regulating of the health and wellbeing of human body. As Sanford and Gallo [3] pointed out in their review article:

> "...*The skin, the human body's largest organ, is home to a diverse and complex variety of innate and adaptive immune functions […] the skin immune system should be considered a collective mixture of elements from the host and microbes acting in a mutualistic relationship*..."

LITERATURE SEARCH

Databases search: Articles have been selected from the following science databases: PubMed (www.ncbi.nlm.nih.gov/pubmed), EMF-Portal (https://www.emf-portal.org/) and ORSAA (https://www.orsaa.org/orsaa-database.html). The following keywords or combinations of keywords were used: “millimeter waves”, “skin”, “human”, “mice”, and “rats”. Studies presenting effects of mm-waves on skin physiology and on skin-dependent and skin-induced whole body physiology were analyzed. Peer reviewed original experimental studies published in the English language until September 2019 were considered.

Conflict of interest: Author state no conflict of interest.

Ethical approval: The conducted research is not related to either human or animals use.

BRIEF REVIEW OF THE PUBLISHED STUDIES

The to date published studies examining the effects of millimeter waves on the skin and skin cells provide very haphazard and lacking consistency picture of the possible/probable effects. However, the lack of replications and small size of the studies hamper the efforts to determine whether the skin exposures to millimeter-waves will, or will not, have any physiologically meaningful effects on human health.

I. HUMAN VOLUNTEER STUDIES

Table 1 lists 11 studies performed on human volunteers. There are suggestions that the mm-waves might affect skin and several skin properties that might play a role in how the skin responds to mm-waves’ exposures:

- Hydration level of the skin, as water efficiently absorbs mm-waves [4, 5]
- Thickness of the skin regulates penetration of the mm-waves, in part due to the mm-waves absorbing content of the water in dermis layer [5]
- Distribution and density of distribution of the sweat glands that were proposed to act as structural antennae for the mm-waves [6, 7, 8]
- Distribution of the acupuncture sites and pain/pressure sensing sites that appear to respond to mm-waves [9, 10, 11, 12]
- Health status of the skin that compromises normal functioning of the skin, e.g. psoriasis or skin cancer [5]

This very limited evidence provided in just an 11 human volunteer studies suggests possibility of differences in skin responses depending on the anatomical location of the exposed skin on the individual’s body as well as differences between individuals due to differences in individuals’ skin properties. Also, there is a suggestion that the health status of the skin might affect responses of the skin to mm-waves exposure.

There is a single study where the authors claim to, in their own words, “rule out” any effects of skin exposure to mm-waves on the heart rate, EKG, blood pressure on respiration [13]. However, the scientific significance of the evidence of this single study appears to be overstated by the authors and further experiments are necessary to determine the potential effects of skin exposure to mm-waves on cardiovascular system in humans. Execution of such studies, examining effects of human skin exposure to mm-waves on the functioning of the cardiovascular system, is justified because some of the experimental studies in animals indicate that skin-exposure-derived effects on cardiovascular system might be possible (for details see later in animal studies section).

II. ANIMAL IN VIVO STUDIES

Tables 2A and 2B list in vivo animal studies performed in rats and mice, respectively. The majority of studies on effects of mm-waves on skin and skin cells was published in in vivo animal studies, using rat and mice models. Exposure of hairless areas (naturally or shaven) of the skin of mice and rats was able to induce effects in distant internal organs that were not in any way exposed to mm-waves. This was likely through secretion of yet to be identified molecular mediators that were generated and secreted by the skin cells exposed to mm-waves and transported to distant internal organs with e.g. blood circulation or via nerve endings of the skin.

<u>RAT MODEL</u>

Skin morphology and gene expression

- Morphology: aggregation of neutrophils in vessels, degeneration of stromal cells, and breakdown of collagen [15]
- Gene expression: affected genes associated with regulation of transcription, protein folding, oxidative stress, immune response, tissue matrix turnover and chemokine activity [15]

Rat brain and nervous tissue

- Prevention of epileptic attacks, suggested to be resulting from absorption of mm-waves in skin [16]
- Molecular effects in rat brain, resulting from the absorption of mm-waves in hairless areas of the skin. Decline in activity of protein kinase C, superoxide dismutase and glutathione peroxidase but an increase in catalase activity. Simultaneously occurred an increase in DNA double-strand breaks [17]
- Effect of heated-skin-mediated impact on whole body stress and brain EEG [18]
- Acceleration of nerve regeneration following surgically-induced injury [19]
- Painful electrical stimulation-induced decline in splenic NK cell activity was prevented by co-exposure of skin to mm-waves [20]

Rat sperm

- Molecular effects of oxidative stress were observed in sperm of rats, decline in histone kinase, and catalase activity but increase in superoxide dismutase and glutathione peroxidase. Concomitantly occurred increase in apoptosis and decline in S/G2/M phase in spermatocytes, suggesting possible impact on male fertility [21]

- Degeneration and polymorphism of spermatozoa, deformation of the head and filaments. Number of progeny of irradiated rats increased and was associated with the presence of abnormal spermatozoa [22]

Rat skin overheating impact on circulatory system

- Rapidly elevated temperature of skin, even when the rectal temperature appears normal, may cause circulatory failure [23, 24]
- Histopathological changes in the skin (hemorrhage, congestion of skin blood vessels) and molecular changes serum glucose, creatinine and uric acid. Rapid heating of skin led to circulatory failure and death [25, 26, 27, 28]
- Circulatory effects were not mediated by the levels of nitric oxide, regulated using L-NAME inhibitor of nitric oxide synthesis [29, 30]

Right- and left-polarized mm-waves

- Both, left-handed and right-handed-polarized mm-waves induced small changes in bone-marrow derived leukocytes, erythrocytes and their hemoglobin content. Effects of the right-handed-polarized, but not the left-handed-polarized, mm-waves were diminished by shielding with schungite (mineral rock with C_{60} structure similar to fullerens) [31]
- Both polarizations exerted different effects on stomachs of rats. Right-handed-polarization increased activity of pepsin and suppressed production of mucin and caused hypertrophy of secreting structures in stomach mucosa. Left-handed-polarization caused decline in pepsin production, secretory activity was suppressed, gastric mucosa was covered with mucus occurred necrotic changes, hemorrhaging and occlusion of small blood vessels and epithelium lost microvilli [32]

Rat tissue oxidative stress

- mm-waves exposure that elevates colonic temperature but does not cause hypotension, was associated with increase expression of oxidative stress marker, 3-nitrotyrosine, in lung, liver and blood plasma, leukocytes, intestine and kidney [33]
- Increase/decrease in antioxidant enzymes activity (superoxide dismutase, glutathione peroxidase, catalase) observed in blood leukocytes and blood serum, in brain tissue and in sperm, what suggests defensive response to increased levels of reactive oxygen species [17, 21, 34]

Skin-secreted molecular mediators of macrophages

- Plasma from mm-waves-exposed rats increased expression of 11 proteins, and levels of 3-nitrotyrosine in seven proteins (associated with inflammation, oxidative stress, and energy metabolism) [35]

<u>MICE MODEL</u>

Regulatory impact on immune processes

- Cancer-related effects
    - Regulates (inhibition/enhancement) growth of transplanted tumor cells [36]
    - Does not co-promote, with TPA, development of papilloma in DMBA-induced mice [37]
    - Inhibition of the sub-cutaneous growth of injected B16 melanoma cells [38]
- Impact of mm-waves on cyclophosphamide-related effects
    - Inhibition of cyclophosphamide-induced activation of anti-apoptotic mediator NF-kB [39]
    - No genotoxic effect (no generation of micronuclei) and no effect on cyclophosphamide-induced micronuclei [40]
    - Lack of effect on cyclophosphamide-induced toxic effect on catalase activity [41]
    - Lack of effect on cyclophosphamide-induced toxic effects on leukocytes and bone marrow [42]
    - Restoration of cyclophosphamide-inhibited activity of NK cells [43]
    - Inhibition of cyclophosphamide-induced metastasis due to prevention of cyclophosphamide-induced inhibition of NK cell activity [44]
    - No impact on therapeutic (anti-cancer) properties of cyclophosphamide [45]
    - Restores CD25 expression on CD4+ T cells and increases generation of IFNγ but not IL-10. Effector function of CD4+ T cells is enhanced via Th1 type of immune response (IFNγ). Inhibit effects of CPA by augmenting the proliferation of splenocytes, and altering the activation and effector functions of CD4+ T cells [46]
    - Restores cyclophosphamide-inhibited generation of TNFα, increases generation of IFNγ and T-cell proliferation. No effect on IL10 or B-cell proliferation [47]
    - Restores cyclophosphamide-inhibited generation of Th1 cytokines TNF-α, IFN-γ, and IL-2 and shifts balance of T cells from Th2 towards the pre-cyclophosphamide treatment Th1 [48]
    - Restores phagocytic activity and proliferation of T-cells that were inhibited by cyclophosphamide [49]
    - Inhibits scratching activity of mice induced by pruritogenic agent (compound 48/80) and naloxone suppresses this effect suggesting involvement of endogenous opioids [50]

Regulation of inflammation

- Anti-inflammatory effects by affecting generation of arachidonic acid metabolites and histamine [51, 52]
- Induction/restores changes in composition of fatty acids in thymic cells [53, 54, 55]
- In mice with ongoing inflammation, reduces inflammation and inhibits generation of reactive oxygen species [56]
- Changes in content of CD4+ and CD8+ T-cells in thymus and spleen and changes in expression of cytokines: of IL-1β, IFNγ in thymus and IL-1β, IL-10, and TNFα in spleen [57]

Whole-body well being

- Enhances survival/development of mouse-embryos in vitro [58]
- Had no effect on several health-related parameters: body mass, body temperature, peripheral blood, and mass and cellularity of several important organs like spleen, thymus, adrenal glands, skin, cornea [59]

Effects on muscles and nerves

- Inhibited spontaneous electric activity of sural nerve. Cessation of mm-waves exposure briefly increased nerve firing rate. Depletion of mast cells abolished the mm-waves-effect [60]
- Induces contraction of muscle without temperature increase (non-thermal effect) [61]

Hypoalgesisa and anesthesia

- Induction of hypoalgesic effect due to release of endogenous opioids [62] and lack of effect on small intestinal or colonic transit [63]
- Hypoaglesic effect was stronger when exposed skin is more densely innervated (nose, footpad) [64] but unilateral transection of sciatic nerve abolishes hypoaglesic effect [65]
- Suppresses chronic non-neuropathic pain. Hypoalgesic effect was not mimicked by temperature increase what might suggest non-thermal effect [66]
- Extend the length of anesthesia and opioid antagonist, naloxone, abolishes the effect [67]
- Extends tail-flick period and the effect is blocked by naloxone, what suggests involvement of endogenous opioids [68]

III. HUMAN CELLS IN VITRO STUDIES

Table 3 lists human in vitro studies. There are some 26 studies that examined effects of mm-waves on human skin-residing cells such as: buccal cells, fibroblasts, glial cells, primary keratinocytes and keratinocyte cell line, lymphocytes and melanoma cells. Results obtained by different research groups vary, showing both, some effects or lack of effects of MMW exposure.

Buccal cells

- Shckorbatow et al. [69, 70] have observed changes in chromatin condensation that may suggest effect on activity of genes and on gene transcription process

Fibroblasts

- Shckorbatow et al. [71] observed an increase in granularity of the chromatin in fibroblasts, occurring in a radiation dose dependent manner. Furthermore, the effect was radiation polarization-dependent, where right-handed polarization had stronger effect than the left-hand polarization
- On the other hand, Yakeshiwa et al. [72] has shown lack of effects on proliferation and toxicity of fibroblasts
- Also Gallerano et al. [73] have shown lack of effects on a variety of cytogenetic markers in fibroblasts

Glial cells

- Nicolaz et al. [74, 75] and Zhadobov et al. [76] have shown lack of effect on cellular stress markers and on protein folding, secretion and maturation in endoplasmic reticulum

Primary cultures of keratinocytes

- Bourne et al. [77] did not detect any effect on stress response by monitoring expression of glutathione and Hsp70
- Le Quement et al. [78] analyzed expression of 41000 genes using microarray assay. Depending on the statistical analysis applied to the data, the result was either no effect at all (Benjamini-Hochberg procedure) or effect on some 130 transcripts (t-test). Further analysis of these t-test-indicated potentially affected transcripts by RT-PCR has shown that 24 proteins were indeed affected by the MMW exposure. This observation points out that some of the statistical analyses may incorrectly dismiss changes in expression of genes, especially when the changes are small in magnitude.
- Habauzit et al. [79] observed an effect on gene expression that, according to the authors, suggests a specific electromagnetic effect of mm-waves as the effects was not possible to mimic solely by altering temperature of the cells
- Soubere Mahmoud et al. [80], similarly to Habauzit et al. [79], also did not observe any direct effect of MMW exposure on the transcriptome. However, they observed that mm-waves exposure might affect cells that are under metabolic stress

Keratinocyte cell line HaCaT

- Chen et al. [81] observed lack of effect of MMW exposure on cell-cell communication via gap junctions. However, mm-waves exposures appeared to reverse suppression of gap junction communication induced by phorbol ester. Similarly, lack of effect on gap junction communication was observed by Szabo et al. [82]

- Szabo et al. [82, 83] observed lack of exposure on cell viability, proliferation, adhesion, chemotaxis, interleukin production, expression of stress protein Hsp70. Similarly, Zhadobov et al. [84] did not observe effect of MMW exposure on cell proliferation, gene expression of the conformation of proteins
- Using HaCaT keratinocytes as well as mouse melanoma cells B16F10 and Jurkat cells, Szabo et al. [85] observed the mm-waves-exposure-induced externalization of phosphatydylserine residues on cell membranes, occurring without visible cell membrane damage. Expression of phosphatydyl serine, an early marker of apoptosis, in combination with the observed lack of damage to cell membrane, suggests that biological processes induced by mm-waves exposures could be initiated by the molecular changes induced in cell membranes. Similarly, Le Pogam et al. [86] have observed effect of mm-waves exposures on the permeability of cell membranes
- Le Quement et al. [87] have shown that while mm-waves exposure does not induce endoplasmic reticulum stress markers of BIP and ORP150, it is able to prevent expression of these markers that was induced by thapsigargin. This points out to potential co-exposure effects of mm-waves exposures
- An important marker of the potentially detrimental effect of radiation exposure is a damage to chromosomes and chromatin. Hintzsche et al. [88] examined effects of mm-waves exposure on DNA strand breaks and presence of micronuclei and observed lack of an effect

Lymphocytes

- Using primary dividing lymphocytes, Korenstein-Ilan et al. [89] observed mm-waves-exposure-induced changes in several chromosomes number and replication and suggested that exposures induce genomic instability, a cancer risk factor
- Beneducci et al. [90] using stable leukemia cell line have observed very extensive changes in leukaemia cell morphology and in glucose metabolism

Melanoma cells

- In two separate studies by Beneduci et al. [91, 92], the effects of mm-waves exposure differed from each other. Using the same melanoma cell line RPMI 7932, in the first study, there was observed an anti-proliferative effect of mm-waves exposure whereas in the second study mm-waves exposure did not affect cell proliferation or cell cycle distribution of cells

IV. ANIMAL CELLS IN VITRO STUDIES

Table 4 lists animal in vitro studies.

In rat, neuron-like cells were examined in studies by Haas et al and the non-thermal mm-waves exposures did not affect:

- Expression of expression of neuronal phenotype marker β3-Tubulin nor ubiquitous β-Tubulin [93]
- Dopamine turnover or expression of dopamine transporter DAT protein [94]
- Expression of HSP70, Transient Receptor Potential cation channel subfamily Vanilloid, members 1 and 2 (TRPV1, TRPV2), and purinergic receptor P2X, ligand-gated ion channel, 3 (P2x3) [95]

In rat bone marrow stem cells, Tong et al [96] observed enhancement of the differentiatio by co-exposures to mm-waves and β-mercaptoethanol.

In mice, studies on co-cultures of carcinoma cells with keratinocytes and studies using various kind of leukocytes examined effects of mm-waves exposures.

- In mouse embryonal stem-cell-derived neuronal cells (P-19) mm-waves exposure induced calcium spiking that was dependent of the N-type calcium channels, phospholipase C enzyme. Exposure to mm-waves-induced reorganization of actin-fiber cytoskeleton played a role in regulation of calcium spiking and in regulation of cell size and shape (biomechanics of the cell) [97]
- In co-cultures of mouse embryonal stem-cell-derived neuronal cells (P-19) with keratinocytes, exposures to mm-waves induced increased calcium spiking and ATP secretion in keratinocytes. And the changes were dependent on the input power of the mm-waves [98]
- In neutrophils, mm-waves exposures inhibited or interfered with the process of generation of the reactive oxygen species [99, 100]. In peripheral blood leukocytes, mm-waves exposure had protective effect against DNA damage induced by e.g. X-rays, hydrogen peroxide or methylation agents [101]
- In neutrophils, mm-waves exposure enhanced response to N-formylmethionyl-leucyl-phenylalanine (fMLP) and the effect was modified by various kinase inhibitors [102]

DISCUSSION

The current use of the 3G and 4G technologies and the ongoing deployment of the 5G technology, where the number of base stations will increase dramatically, has reignited the health debate around the radiation emitted by these wireless communication technologies.

The new aspect of the 5G technology that will differ dramatically from the earlier technologies will be the use of mm-waves, where both, antennas and devices will be in very close proximity of the users, affecting the exposure patterns. In some countries, deployment of the 5G technology, using mm-waves for public use, has already begun what adds to the health-related stress of uncertainty in some part of the to-be exposed population.

When evaluating the health risk of any agent, the scientific evidence taken into consideration by the health regulatory authorities consists, in order of importance, of the following types of research studies:

- Epidemiology studies
- Human volunteer studies
- Animal in vivo studies
- Laboratory in vitro studies

The epidemiology studies are possible to execute only after the technology has been deployed and sizable parts of the population are being exposed to the examined agent, in this case the mm-waves radiation emitted by the 5G technology. Thus, this considered to be the most important and relevant scientific evidence is currently not available and will not be available for several years.

However, the remaining three types of studies are possible to execute, and should be executed, before the deployment of the 5G technology, in order to determine whether any risk of health effects exists.

Skin is the only organ of the human body, besides the eyes, that will be directly exposed to the mm-waves of the 5G technology. As presented in this review, the whole scientific evidence on the possible effects of mm-waves on skin and skin cells consists of only some 99 studies, where 11 are human volunteer studies, 54 are animal in vivo studies (rats & mice) and 34 are in vitro laboratory studies using human and animal cell cultures.

These studies examined only short-term acute effects of the exposure that do not provide any information about the possible delayed or long-term-exposure effects. Furthermore, the effects of mm-waves were examined in separation from other frequencies used by the wireless communication technologies and in separation from other environmental stressors. Possibility of any co-effects and/or synergistic effects, between mm-waves and other environmental stressors, were not examined at all.

This clearly indicates that the scientific evidence concerning the mm-waves effects on skin is extremely very limited. The evidence from the 99 studies is insufficient to make any reliable, science based evaluation of whether the mm-waves will have or will not have any health effects.

Besides the sheer number of executed studies, of importance in the analysis of the available scientific data are the types and number of performed studies, the size of the studies, the following of the good laboratory practices used when performing studies, whether the results obtained in one laboratory were possible to replicate by other research groups, and, finally, the number of the research groups that were involved in generation of the data. Scientific data from a single research group, no matter how extensive and well executed, need corroboration from other researchers. The research on mm-waves has been dominated by the research teams in Reims, France and in Philadelphia, USA, and their findings require replication studies from other research groups.

The very limited evidence, stemming from the 99 presented studies, suggests that some biological and physiologically relevant effects might be induced in skin and skin cells by exposures to mm-waves. However, this evidence is currently insufficient to claim that any effects have been proven or disproven.

Therefore, the usefulness of the to-date executed research on mm-waves effects on skin is of a very limited use because for developing protective measures for the users because:

- Firstly, as mentioned above, only a small number of studies examined mm-effects on skin and skin cells.
- Secondly, there is only a very few human volunteer studies.
- Thirdly, the majority of research are small experimental studies performed on animals (rats, mice) or cells grown in laboratory. While such studies are important, they are predominantly used to corroborate the evidence obtained in epidemiological and human volunteer studies. Results of animal and in vitro studies alone are not sufficient to formulate basis for human health policy and for human exposure limits.

Therefore, the recently published guidelines by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [103], stating that the ICNIRP proposed mm-waves radiation exposure limits are protecting users form health effects of mm-waves are only an assumption that is not sufficiently based on scientific evidence because the research on effects of mm-waves on skin has not been performed. This is why any claims, including ICNIRP's, that the current safety limits protect all users, no matter of their age or their health status, have no sufficient scientific basis. The safety limits that are suggested to protect from health effects of mm-waves are based on scientifically unsupported assumptions as seen from the evidence presented in Tables 1-4.

Another serious problem of how the 5G mm-waves employing technology is being presented to the future users is the misrepresentation of the role the skin plays in regulation of the whole body's physiology. The notion, often presented in the news media, that mm-waves will not be of health concern because mm-waves are entirely absorbed by epidermis and dermis layers, is misleading. Indeed, mm-waves are absorbed in the skin and do not penetrate deep enough to reach any internal organs. However, the skin is not just a "physiologically inert overcoat" shielding body from the environment. Skin is involved in regulation of the immune response as well as other body functions (cardiovascular functions, neurological functions) through release of a variety of molecular mediators generated by the skin cells in response to environmental stressors, like e.g. mm-waves.

Considering the very limited research on the effects of mm-waves on skin, there is an urgent need for research on effects of mm-waves on humans. Some of the studies is possible to execute, in ethical manner, using human volunteers. Toxicology studies, on mice and rats, using standardized protocols, like those used by the National Toxicology Program in USA, are urgently needed. In vitro laboratory studies should, preferably, use primary human cells or human cell lines. Studies using high-throughput screening techniques of transcriptomics, proteomics and metabolomics should be used to analyze the ethically available tissue samples obtained from human volunteers to determine the molecular level responses of human body to the mm-waves. Data obtained from the molecular high-throughput screenings can then be used to formulate research hypotheses for testing. Epidemiological studies might not be possible to execute as long as the 5G networks are not deployed and people are not exposed as a population.

Because of the lack of sufficiently robust scientific data on mm-waves effects on human skin, precautionary measures should be recommended, whenever possible and feasible when dealing with the mm-waves exposures. These precautionary measures can be e.g. postponing or limiting the 5G deployment in residential areas. It should be considered that not everything and not everywhere needs to be 5G wirelessly connected. Use of fiber optics connections, that will be used to connect 5G base stations, should be used as extensively as possible to limit the deployment of radiation-emitting devices, especially those in close proximity to people and within people dwellings. Deployment for industrial use should be the first but the further, broader deployment for the non-industrial use, should preferably await for the results of the bio-medical research.

Finally, as stated in recent opinions/reviews, the research on the possible effects of mm-waves on humans is scarce and inadequate for developing reliable, health protecting human health policies:

Foster, Ziskin & Balzano [104]

> "…*The frequency range above 3–10 GHz through the top of the RF band (300 GHz) has heretofore received relatively little attention by the committees that develop the guidelines, despite a large number of (generally low-powered) devices that already operate in this wide band […] However, this broad frequency band is about to gain much wider use with the introduction of a new generation (5G) of wireless communications […] and the development of high-powered millimeter wave devices (30–300 GHz) for industrial and military applications*…"

Wu, Rappaport & Collins [105]

> "...*Compared with lower frequency bands, relatively little careful research has been conducted evaluating the potential of more subtle long-term effects than tissue damage due directly to heating at mmWave frequencies*..."

CONCLUSION

In conclusion, there is an urgent need for research on the biological and health effects of mm-waves because, using the currently available evidence on skin effects, the claims that "*we know skin and human health will not be affected*" as well as the claims that "*we know skin and human health will be affected*" are premature assumptions that lack sufficient scientific basis.

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Adverse health effects of 5G mobile networking technology under real-life conditions

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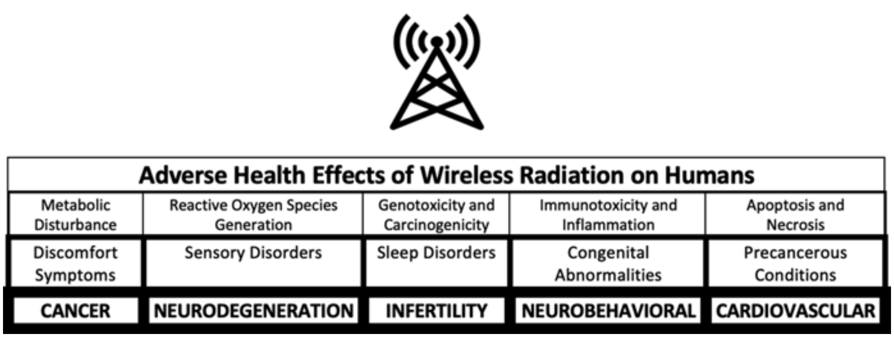
GRAPHICAL ABSTRACT



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Real-life simulation

ABSTRACT

This article identifies adverse effects of non-ionizing non-visible radiation (hereafter called wireless radiation) reported in the premier biomedical literature. It emphasizes that most of the laboratory experiments conducted to date are not designed to identify the more severe adverse effects reflective of the real-life operating environment in which wireless radiation systems operate. Many experiments do not include pulsing and modulation of the carrier signal. The vast majority do not account for synergistic adverse effects of other toxic stimuli (such as chemical and biological) acting in concert with the wireless radiation. This article also presents evidence that the nascent 5G mobile networking technology will affect not only the skin and eyes, as commonly believed, but will have adverse systemic effects as well.

1. Introduction

Wireless communications have been expanding globally at an exponential rate. The latest imbedded version of mobile networking technology is called 4G (fourth generation), and the next version (called 5G- fifth generation) is in the early implementation stage. Neither 4G

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nor 5G have been tested for safety in credible real-life scenarios. Alarmingly, many of the studies conducted in more benign environments show harmful effects from this radiation. The present article overviews the medical and biological studies that have been performed to date relative to effects from wireless radiation, and shows why these studies are deficient relative to safety. However, even in the absence of the missing real-life components such as toxic chemicals and biotoxins (which tend to exacerbate the adverse effects of the wireless radiation), the literature shows there is much valid reason for concern about potential adverse health effects from both 4G and 5G technology. The studies on wireless radiation health effects reported in the literature should be viewed as extremely conservative, substantially underestimating the adverse impacts of this new technology.

2. Wireless radiation/electromagnetic spectrum

This section overviews the electromagnetic spectrum, and delineates the parts of the spectrum on which this article will focus. The electromagnetic spectrum encompasses the entire span of electromagnetic radiation, including:

- ionizing radiation (gamma rays, x-rays, and the extreme ultraviolet, with wavelengths below $\sim 10^{-7}$ m and frequencies above $\sim 3 \times 10^{15}$ Hz);
- non-ionizing visible radiation (wavelengths from $\sim 4 \times 10^{-7}$ m to $\sim 7 \times 10^{-7}$ m and frequencies between $\sim 4.2 \times 10^{14}$ Hz and $\sim 7.7 \times 10^{14}$ Hz);
- non-ionizing non-visible radiation

short wavelength radio waves and microwaves, with wavelengths between $\sim 10^{-3}$ m and $\sim 10^{5}$ m and frequencies between $\sim 3 \times 10^{11}$ to $\sim 3 \times 10^{3}$ Hz;

long wavelengths, ranging between $\sim 10^{5}$ m and $\sim 10^{8}$ m and frequencies ranging between 3×10^{3} and 3 Hz.

How are these frequencies used in practice?

- The low frequencies (3 Hz – 300 KHz) are used for electrical power line transmission (60 Hz in the U.S.) as well as maritime and submarine navigation and communications.
- Medium frequencies (300 KHz–900 MHz) are used for AM/FM/TV broadcasts in North America.
- Lower microwave frequencies (900 MHz – 5 GHz) are used for telecommunications such as microwave devices/communications, radio astronomy, mobile/cell phones, and wireless LANs.
- Higher microwave frequencies (5 GHz – 300 GHz) are used for radar and proposed for microwave WiFi, and will be used for high-performance 5 G.
- Terahertz frequencies (300 GHz – 3000 GHz) are used increasingly for imaging to supplement X-rays in some medical and security scanning applications (Kostoff and Lau, 2017).

In the present study of wireless radiation health effects, the frequency spectrum ranging from 3 Hz to 300 GHz is covered, with particular emphasis on the high frequency communications component ranging from $\sim$1 GHz to $\sim$300 GHz. Why was this part of the spectrum selected? Previous reviews of wireless radiation health effects found that pulsed electromagnetic fields (PEMF) applied for relatively short periods of time could sometimes be used for therapeutic purposes, whereas chronic exposure to electromagnetic fields (EMF) in the power frequency range ($\sim$60 Hz) and microwave frequency range ($\sim$1 GHz-tens GHz) tended to result in detrimental health effects (Kostoff and Lau, 2013, 2017). Given present concerns about the rapid expansion of 5G communications systems (which are projected to use mainly the higher microwave frequencies part of the spectrum in the highest performance (aka high-band) mode) in the absence of adequate and rigorous safety testing, more emphasis will be placed on the communications frequencies in this document.

3. Modern wireless radiation exposures

In ancient times, sunlight and its lunar reflections provided the bulk of the visible spectrum for human beings (with fire a distant second and lightning a more distant third). Now, many varieties of artificial light (incandescent, fluorescent, and light emitting diode) have replaced the sun as the main supplier of visible radiation during waking hours. Additionally, EMF radiations from other parts of the non-ionizing non-visible spectrum have become ubiquitous in daily life, such as from wireless computing and telecommunications. In the last two or three decades, the explosive growth in the cellular telephone industry has placed many residences in metropolitan areas within less than a mile of a cell tower. Future implementation of the next generation of mobile networking technology, 5 G, will increase the cell tower densities by an order of magnitude. Health concerns have been raised about wireless radiation from (1) mobile communication devices, (2) occupational exposure, (3) residential exposure, (4) wireless networks in homes, businesses, and schools, (5) automotive radar, and (6) other non-ionizing EMF radiation sources, such as ‘smart meters’ and ‘Internet of Things’.

4. Demonstrated biological and health effects from prior generations of wireless networking technology

There have been two major types of studies performed to ascertain biological and health effects of wireless radiation: laboratory and epidemiology. The laboratory tests performed provided the best scientific understanding of the effects of wireless radiation, but did not reflect the real-life environment in which wireless radiation systems operate (exposure to toxic chemicals, biotoxins, other forms of toxic radiation, etc). There are three main reasons the laboratory tests failed to reflect real-life exposure conditions for human beings.

First, the laboratory tests have been performed mainly on animals, especially rats and mice. Because of physiological differences between small animals and human beings, there have been continual concerns about extrapolating small animal results to human beings. Additionally, while inhaled or ingested substances can be scaled from laboratory experiments on small animals to human beings relatively straight-forwardly, radiation may be more problematic. For non-ionizing radiation, penetration depth is a function of frequency, tissue, and other parameters. Radiation could penetrate much deeper into a small animal’s interior than similar wavelength radiation in humans, because of the much smaller animal size. Different organs and tissues would be affected, with different levels of power density.

Second, the typical incoming EMF signal for many/most laboratory tests performed in the past consisted of single carrier wave frequency; the lower frequency superimposed signal containing the information was not always included. This omission may be important. As Panagopoulos states: “It is important to note that except for the RF/microwave carrier frequency, Extremely Low Frequencies - ELFs (0–3000 Hz) are always present in all telecommunication EMFs in the form of pulsing and modulation. There is significant evidence indicating that the effects of telecommunication EMFs on living organisms are mainly due to the included ELFs…. While $\sim$50 % of the studies employing simulated exposures do not find any effects, studies employing real-life exposures from commercially available devices display an almost 100 % consistency in showing adverse effects” (Panagopoulos, 2019). These effects may be exacerbated further with 5 G: “with every new generation of telecommunication devices…..the amount of information transmitted each moment…..is increased, resulting in higher variability and complexity of the signals with the living cells/ organisms even more unable to adapt” (Panogopoulos, 2019).

Third, these laboratory experiments typically involved one stressor (toxic stimulus) and were performed under pristine conditions. This contradicts real-life exposures, where humans are exposed to multiple toxic stimuli, in parallel or over time (Tsatsakis et al., 2016, 2017; Docea et al., 2019a). In perhaps five percent of the cases reported in the wireless radiation literature, a second stressor (mainly a biological or chemical toxic stimulus) was added to the wireless radiation stressor, to ascertain whether additive, synergistic, potentiative, or antagonistic effects were generated by the combination (Kostoff and Lau, 2013, 2017; Juutilainen, 2008; Juutilainen et al., 2006).

Combination experiments are extremely important because, when other toxic stimuli are considered in combination either with each other or with wireless radiation, the synergies tend to enhance the adverse effects of each stimulus in isolation. This was shown in several studies that evaluated the cumulative effects of chronic exposure to low doses of xenobiotics in combination (Kostoff et al., 2018; Docea et al., 2018; Tsatsakis et al., 2019a; Docea et al., 2019b; Tsatsakis et al., 2019b, c; Fountoucidou et al., 2019). For those combinations that include wireless radiation, combined exposure to toxic stimuli and wireless radiation translates into much lower levels of tolerance for each toxic stimulus in the combination relative to its exposure levels that produce adverse effects in isolation. Accordingly, the exposure limits for wireless radiation when examined in combination with other potentially toxic stimuli would be far lower for safety purposes than those derived from wireless radiation exposures in isolation.

Thus, almost all of the wireless radiation laboratory experiments that have been performed to date are flawed/limited with respect to showing the full adverse impact of the wireless radiation that would be expected under real-life conditions. Either 1) non-inclusion of signal information or 2) using single stressors only tends to underestimate the seriousness of the adverse effects from wireless radiation. Excluding ***both*** of these phenomena from experiments, as was done in the vast majority of the reported wireless radiation health effects studies, tends to amplify this underestimation substantially. Thus, the results reported in the biomedical literature should be viewed as 1) extremely conservative and 2) the very low 'floor' of the seriousness of the adverse effects from wireless radiation, not the 'ceiling'.

In contrast to the controlled pristine environments that characterize the wireless radiation animal laboratory experiments, the wireless radiation epidemiology studies carried out to date typically involved human beings who had been subjected to myriad known and unknown stressors prior to (and during) the study. The real-life human exposure levels from cell tower studies (reported by Kostoff and Lau (2017)) that showed increased cancer incidence were orders of magnitude lower than those exposure levels generated in the recent highly-funded National Toxicology Program animal laboratory studies (Melnick, 2019). We believe the inclusion of real-world effects in the cell tower studies accounted for the orders of magnitude exposure level decreases that were associated with the increased cancer incidence. The laboratory tests were conducted under controlled conditions not reflective of real-life, while the epidemiology studies were performed in the presence of many stressors, known and unknown, reflective of real-life. The myriad toxic stimuli exposure levels of the epidemiology studies were, for the most part, uncontrolled.

A vast literature published over the past sixty years shows adverse effects from wireless radiation applied in isolation or as part of a combination with other toxic stimuli. Extensive reviews of wireless radiation-induced biological and health effects have been published (Kostoff and Lau, 2013, 2017; Belpomme et al., 2018; Desai et al., 2009; Di Ciaula, 2018; Doyon and Johansson, 2017; Havas, 2017; Kaplan et al., 2016; Lerchl et al., 2015; Levitt and Lai, 2010; Miller et al., 2019; Pall, 2016, 2018; Panagopoulos, 2019; Panagopoulos et al., 2015; Russell, 2018; Sage and Burgio, 2018; van Rongen et al., 2009; Yakymenko et al., 2016; Bioinitiative, 2012). In aggregate, for the high frequency (radiofrequency-RF) part of the spectrum, these reviews show that RF radiation ***below the FCC guidelines*** can result in:

- carcinogenicity (brain tumors/glioma, breast cancer, acoustic neuromas, leukemia, parotid gland tumors),
- genotoxicity (DNA damage, DNA repair inhibition, chromatin structure),
- mutagenicity, teratogenicity,
- neurodegenerative diseases (Alzheimer's Disease, Amyotrophic Lateral Sclerosis),
- neurobehavioral problems, autism, reproductive problems, pregnancy outcomes, excessive reactive oxygen species/oxidative stress, inflammation, apoptosis, blood-brain barrier disruption, pineal gland/melatonin production, sleep disturbance, headache, irritability, fatigue, concentration difficulties, depression, dizziness, tinnitus, burning and flushed skin, digestive disturbance, tremor, cardiac irregularities,
- adverse impacts on the neural, circulatory, immune, endocrine, and skeletal systems.

From this perspective, RF is a highly pervasive cause of disease!

The response from industry has been that no mechanism could explain the biological action of non-thermal and non-ionizing EM fields. Yet, reports of clear perturbations of biological systems at levels near or even below 1000 μW/m^2 (Bioinitiaive, 2019) were explained by perturbations in electron and proton transfers supporting ATP production in mitochondria (Sanders et al., 1980; 1985) exposed to RF or ELF signals (Li and Heroux, 2014).

To obtain another perspective on the full spectrum of adverse effects from wireless radiation, a query was run on Medline to retrieve representative records associated with adverse EMF effects (mainly, but not solely, RF). Over 5400 records were retrieved, and the leading Medical Subject Headings (MeSH) extracted. The categories of adverse impacts from both approaches match quite well. The adverse health effects range from myriad feelings of discomfort to life-threatening diseases.

The full list of MeSH Headings associated with this retrieval is shown in Appendix 1 of (Kostoff, 2019). The interested reader can ascertain what other diseases/symptoms were included. The 5400+ references retrieved are shown in Appendix 2 of (Kostoff, 2019).

5. What types of biological and health effects can be expected from 5G wireless networking technology?

The potential 5G adverse effects derive from the intrinsic nature of the radiation, and its interaction with tissue and target structures. 4G networking technology was associated mainly with carrier frequencies in the range of ~1-2.5 GHz (cell phones, WiFi). The wavelength of 1 GHz radiation is 30 cm, and the penetration depth in human tissue is a few centimeters. In its highest performance (high-band) mode, 5G networking technology is mainly associated with carrier frequencies at least an order of magnitude greater than the 4G frequencies, although, as stated previously, "ELFs (0–3000 Hz) are always present in all telecommunication EMFs in the form of pulsing and modulation". Penetration depths for the carrier frequency component of high-band 5G wireless radiation will be on the order of a few millimeters (Alekseev et al., 2008a, b). At these wavelengths, one can expect resonance phenomena with small-scale human structures (Betzalel et al., 2018). Additionally, numerical simulations of millimeter-wave radiation resonances with insects showed a general increase in absorbed RF power at and above 6 GHz, in comparison to the absorbed RF power below 6 GHz. A shift of 10 % of the incident power density to frequencies above 6 GHz was predicted to lead to an ***increase in absorbed power between 3–***370 % (Thielens et al., 2018).

The common 'wisdom' presented in the literature and media is that, if there are adverse impacts resulting from high-band 5 G, the main impacts will be focused on near-surface phenomena, such as skin cancer, cataracts, and other skin conditions. However, there is evidence that biological responses to millimeter-wave irradiation can be initiated within the skin, and the subsequent systemic signaling in the skin can result in physiological effects on the nervous system, heart, and immune system (Russell, 2018).

Additionally, consider the following reference (Zalyubovskaya, 1977). This is one of many translations of articles produced in the Former Soviet Union on wireless radiation (also, see reviews of Soviet research on this topic by McRee (1979, 1980), Kositsky et al. (2001), and Glaser and Dodge (1976)). On p. 57 of the pdf link, the article by Zalyubovskaya addresses biological effects of millimeter radiowaves. Zalyubovskaya ran experiments using power fluxes of 10,000,000 μW/square meter (the FCC (Federal Communications Commission) guideline limit for the general public today in the USA), and frequencies on the order of 60 GHz. Not only was skin impacted adversely, but also heart, liver, kidney, spleen tissue as well, and blood and bone marrow properties. These results reinforce the conclusion of Russel (quoted above) that ***systemic results may occur from millimeter-wave radiation.*** To re-emphasize, for Zalyubovskaya's experiments, the incoming signal was unmodulated carrier frequency only, and the experiment was single stressor only. Thus, the expected real-world results (when human beings are impacted, the signals are pulsed and modulated, and there is exposure to many toxic stimuli) would be far more serious and would be initiated at lower (perhaps much lower) wireless radiation power fluxes.

The Zalyubovskaya paper was published in 1977. The referenced version was classified in 1977 by USA authorities and declassified in 2012. What national security concerns caused it (and the other papers in the linked pdf reference) to be classified for 35 years, until declassification in 2012? Other papers on this topic with similar findings were published in the USSR (and the USA) at that time, or even earlier, but many never saw the light of day, both in the USSR and the USA. It appears that the potentially damaging effects of millimeter-wave radiation on the skin (and other major systems in the body) have been recognized for well over forty years, yet today's discourse only revolves around the possibility of modest potential effects on the skin and perhaps cataracts from millimeter-wave wireless radiation.

6. What is the consensus on adverse effects from wireless radiation?

Not all studies of wireless radiation have shown adverse effects. For example, consider potential genotoxic effects of mobile phone radiation. A study investigating "the effect of mobile phone use on genomic instability of the human oral cavity's mucosa cells" concluded "Mobile phone use did not lead to a significantly increased frequency of micronuclei" (Hintzsche and Stopper, 2010).

Conversely, a 2017 study investigated buccal cell preparations for genomic instability, and found "The frequency of micronuclei (13.66x), nuclear buds (2.57x), basal (1.34x), karyorrhectic (1.26x), karyolytic (2.44x), pyknotic (1.77x) and condensed chromatin (2.08x) cells were highly significantly ($p = 0.000$) increased in mobile phone users" (Gandhi et al., 2017). Also, a 2017 study to ascertain the "effect of cell phone emitted radiations on the orofacial structures" concluded that "Cell phone emitted radiation causes nuclear abnormalities of the oral mucosal cells" (Mishra et al., 2017). Further, a 2016 study to "explore the effects of mobile phone radiation on the MN frequency in oral mucosal cells" concluded "The number of micronucleated cells/1000 exfoliated buccal mucosal cells was found to be significantly increased in high mobile phone users group than the low mobile phone users group" (Banerjee et al., 2016). Finally, a study aimed at investigating the health effects of WiFi exposure concluded "long term exposure to WiFi may lead to adverse effects such as neurodegenerative diseases as observed by a ***significant alteration on AChE gene expression*** and some neurobehavioral parameters associated with brain damage" (Obajuluwa et al., 2017).

There are many possible reasons to explain this lack of consensus.

1) There may be 'windows' in parameter space where adverse effects occur, and operation outside these windows would show a) no effects or b) hormetic effects or c) therapeutic effects. For example, if information content of the signal is a strong contributor to adverse health effects (Panagopoulus, 2019), then experiments that involve only the carrier frequencies may be outside the window where adverse health effects occur. Alternatively, in this specific example, the carrier signal and the information signal could be viewed as a combination of potentially toxic stimuli, where the adverse effects of each component are enabled because of the synergistic effects of the combination.

As another example, an adverse health impact on one strain of rodent was shown for a combination of 50 Hz EMF and DMBA, while no adverse health impact was shown on another rodent strain for the same toxic stimuli combination (Fedrowitz et al., 2004). From a higher-order combination perspective, if genetic abnormalities/differences are viewed conceptually as potentially equivalent to a toxic stimulus for combination purposes, then a synergistic three-constituent combination of 50 Hz EMF, DMBA, and genetics was required to produce adverse health impacts in the above experiment. If these results can be extrapolated across species, then human beings could exhibit different responses to the same electromagnetic stimuli based on their unique genetic predispositions (Caccamo et al., 2013; De Luca et al., 2014).

1) Research quality could be poor, and adverse effects were overlooked.
2) Or, the research team could have had a preconceived agenda, where finding no adverse effects from wireless radiation was **THE** objective of the study. For example, studies have shown that industry-funded research of wireless radiation adverse health effects is far more likely to show no effects than funding from non-industry sources (Huss et al., 2007; Slesin, 2006; Carpenter, 2019). Studies in disciplines other than wireless radiation have shown that, for products of high military, commercial, and political sensitivity, 'researchers'/organizations are hired to publish articles that conflict with the credible science, and therefore create doubt as to whether the product of interest is harmful (Michaels, 2008; Oreskes and Conway, 2011). Unfortunately, given the strong dependence of the civilian and military economies on wireless radiation, incentives for identifying adverse health effects from wireless radiation are minimal and disincentives are many. These perverse incentives apply not only to the sponsors of research and development, but to the performers as well.

Even the Gold Standard for research credibility - **independent replication of research results** - is questionable in politically, commercially, and militarily sensitive areas like wireless radiation safety, where the accelerated implementation goals of most wireless radiation research sponsors (government and industry) are aligned. It is imperative that highly objective evaluators with minimal conflicts of interest play a central role ensuring that rigorous safety standards for wireless radiation systems are met before widescale implementation is allowed.

7. Conclusions

Wireless radiation offers the promise of improved remote sensing, improved communications and data transfer, and improved connectivity. Unfortunately, there is a large body of data from laboratory and epidemiological studies showing that previous and present generations of wireless networking technology have significant adverse health impacts. Much of this data was obtained under conditions not reflective of real-life. When real-life considerations are added, such as 1) including the information content of signals along with 2) the carrier frequencies, and 3) including other toxic stimuli in combination with the wireless radiation, the adverse effects associated with wireless radiation are increased substantially. Superimposing 5G radiation on an already imbedded toxic wireless radiation environment will exacerbate the adverse health effects shown to exist. Far more research and testing of potential 5G health effects under real-life conditions is required before further rollout can be justified.

Transparency document

The Transparency document associated with this article can be found in the online version.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Arabidopsis cryptochrome is responsive to Radiofrequency (RF) electromagnetic fields

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How living systems respond to weak electromagnetic fields represents one of the major unsolved challenges in sensory biology. Recent evidence has implicated cryptochrome, an evolutionarily conserved flavoprotein receptor, in magnetic field responses of organisms ranging from plants to migratory birds. However, whether cryptochromes fulfill the criteria to function as biological magnetosensors remains to be established. Currently, theoretical predictions on the underlying mechanism of chemical magnetoreception have been supported by experimental observations that exposure to radiofrequency (RF) in the MHz range disrupt bird orientation and mammalian cellular respiration. Here we show that, in keeping with certain quantum physical hypotheses, a weak 7 MHz radiofrequency magnetic field significantly reduces the biological responsivity to blue light of the cryptochrome receptor cry1 in *Arabidopsis* seedlings. Using an *in vivo* phosphorylation assay that specifically detects activated cryptochrome, we demonstrate that RF exposure reduces conformational changes associated with biological activity. RF exposure furthermore alters cryptochrome-dependent plant growth responses and gene expression to a degree consistent with theoretical predictions. To our knowledge this represents the first demonstration of a biological receptor responding to RF exposure, providing important new implications for magnetosensing as well as possible future applications in biotechnology and medicine.

Static magnetic fi lds have profound and diverse effects on living organisms ranging from prokaryotes to man[1–9]. One of the best characterized involves orientation behaviour in migratory birds, which use the magnetic fi ld for directional sensing by a process that requires light[1,7]. Bird magnetosensing has been proposed to occur by the so-called radical pair mechanism, whereby weak magnetic fi lds can alter the spin characteristics of radical pairs generated by a biological magnetoreceptor[10]. An evolutionarily conserved flavoprotein photoreceptor known as cryptochrome, which forms radical pairs and is localized to the bird retina[1,11,12], has been proposed as such a possible magnetoreceptor.

An intriguing feature of the radical pair hypothesis in birds is the theoretical prediction that RF signals in the 1–10 MHz range should elicit the disruption of bird directional responses to the Earth's magnetic field[13–15]. Such disruptive effects were indeed found experimentally for RF fi lds, remarkably even of intensities below 10 nT[9] and, in the case of broad-band fi lds, below 1 nT[16]. Many of these effects can in principle be rationalized with the radical-pair mechanism[14,17]. Therefore since cryptochromes have been implicated in responses to static magnetic fi lds in organisms ranging from plants to humans, a prediction of the radical pair hypothesis is that RF magnetic fi lds could also affect cryptochrome responses. In this work, we explored the intriguing possibility that such fi lds could trigger a biological response involving *Arabidopsis* cryptochrome

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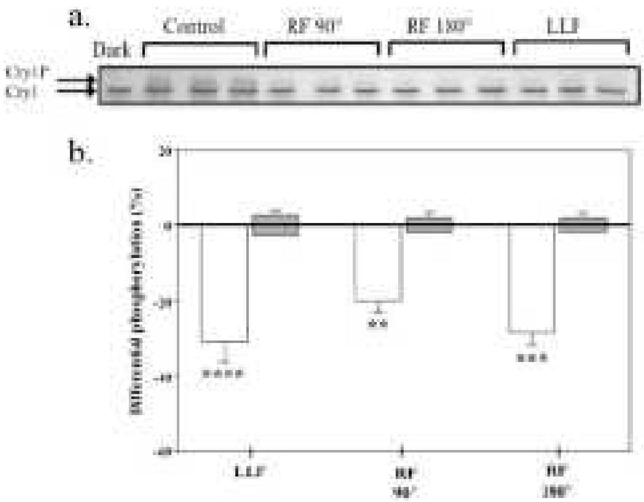

Figure 1. Phosphorylation of cry1 in response to 7 MHz RF fi lds. Four-day old dark-grown etiolated seedlings were subjected to 60 µmol m^{-2} s^{-1} blue light/dark cycles for 90 min as previously described[3] and exposed to LLF (Low Level Field of less than 200nT) or to RF (7 MHz RadioFrequency fi ld) applied either perpendicular (90°) or parallell (180°) to the static GMF (geomagnetic fi ld) – see Fig. 5 in Methods. (**a**) Western blot of nonphosphorylated (Cry1) and phosphorylated (Cry1p) of bands detected by anti-cry1 antibody; triplicate samples were run for each exposure condition. Dark = seedlings before the onset of illumination; Control = seedlings were subjected to 60 µmol m^{-2} s^{-1} blue light/dark cycles for 90 min; RF and LLF exposure conditions are as described in the text. (**b**) Quantitation and statistical analysis of results from at least five independent experiments per exposure condition. Phosphorylation of cry1 is represented as the % difference between exposed seedlings as compared to seedlings maintained in the static GMF control condition. The results of sham experiments for each exposure condition (grey bars) represent differential phosphorylation between the seedlings in mock-treated LLF or RF (see Methods) and control GMF condition. The asterisks indicate a signifi ance level of the differences: ***p*-value <0.01; ****p*-value <0.001; *****p*-value <0.0001. The effect of LLF (*p*-value <0.0001; N = 7), RF 90° (*p*-value = 0.008; N = 9) and RF 180° (*p*-value <0.001; N = 9); white bars; was in all cases to reduce cry1 phosphorylation. The sham treatments (N = 5) for each exposure condition yielded no signifi ant difference compared to the control (GMF).

Results

A rapid, quantitative, and direct assay for magnetic sensitivity is the *in vivo* phosphorylation of *Arabidopsis* cryptochrome in blue light[10,18]. Phosphorylation results from conformational changes triggered in the receptor, whereby the cryptochrome C-terminal domain unfolds from the protein surface and becomes accessible to cellular kinases. Cryptochrome phosphorylation can be visualized on Western blots by an upward mobility shift of the phosphorylated protein. Prior studies have shown that cryptochrome phosphorylation in plant seedlings is altered as a function of the static magnetic fi ld[3,19], and is reduced at near null LLF (low -level fi lds). We therefore tested whether phosphorylation of the *Arabidopsis* cry1 receptor was also responsive to an applied weak 7 MHz RF magnetic fi ld. Th s frequency was chosen as it had been previously reported to interfere both with bird navigation[13,20] and with oxidative metabolic processes in mammalian cultured cells[6] that have been postulated to involve flavoprotein radicals.

The experimental setup is described in detail in Methods. Briefly, a triaxial Helmholtz coil providing current along each of the three axes (x, y, z) was adjusted to set the static magnetic fi ld parallel to the plane of growth of the seedlings, at 40 µT intensity to approximate the local geomagnetic fi ld. Blue light LEDs were used to illuminate the sample. To generate the RF fi ld, a single loop Helmholtz coil was placed around the sample on a rotating axis, such that an RF fi ld could be set in a direction that was either at a parallel or a perpendicular angle to the static magnetic fi ld (see Methods). The RF signal was 7 MHz at 2 µT$_{rms}$. A low - level magnetic fi ld (LLF or Low Level Field) of less than 200nT was generated by layering of sheets of µ-metal shielding around the sample (Methods). All experiments were performed in a dedicated darkroom with temperature at the position of the sample monitored in real time by computer throughout the course of the experiment.

Phosphorylation experiments were performed as described previously[3]. Four-day old dark-grown *Arabidopsis* seedlings on petri plates were illuminated for 90 minutes and simultaneously exposed to RF magnetic fields. These were applied either in parallel or in perpendicular to the geomagnetic fi ld (see Methods). As the control condition, exposure was to the geomagnetic fi ld alone (without applied RF). Finally, a series of sham experiments were conducted at each exposure condition to control for any background variation in the experimental setup (see Methods). Seedlings were then harvested and subjected to Western blot analysis with anti-Cry1 antibody to determine the cryptochrome protein upward mobility shift resulting from phosphorylation (Methods).

The results showed a signifi ant (up to 24%) decline in response to blue light by cryptochrome in seedlings exposed to RF fi lds (Fig. 1). Th s was demonstrated by the reduced intensity of the upward-shifted, phosphorylated band in the Western blot under conditions of applied RF fi lds. Consistent with previous reports[19], exposure to LLF conditions likewise caused a decrease in cryptochrome response (Fig. 1). Thus, an RF magnetic fi ld has a

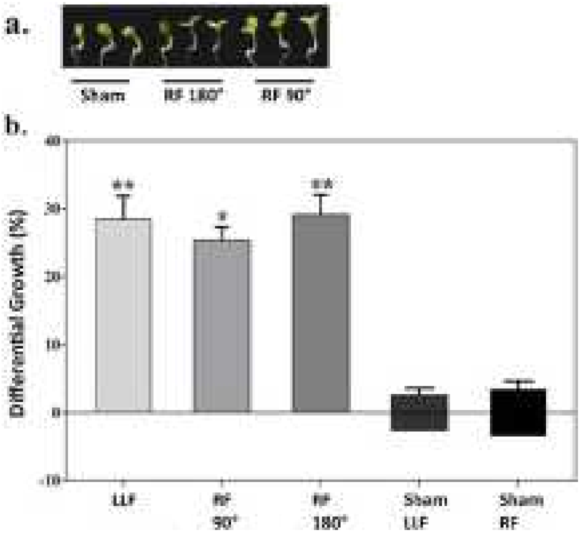

Figure 2. Effect of 7 MHz RF on *Arabidopsis* seedling hypocotyl growth inhibition. Seedlings were germinated and grown in 60 μmol m^{-2} s^{-1} blue light/dark cycles for 5 days as previously described[3]. During this time they were exposed to LLF (Low Level Field of less than 200nT) or to RF (7 MHz RadioFrequency field) applied either perpendicular (90°) or parallell (180°) to the static GMF (geomagnetic field). (**a**). Representative images of seedlings after exposure to RF. (**b**). Hypocotyl lengths averaged from 15 seedlings per exposure condition and compared to seedlings from the reference GMF (geomagnetic field) condition. The results were represented as % difference in hypocotyl length after exposure to LLF or RF as compared to the GMF (geomagnetic field) condition. As a control experiment, sham-exposed (mock treated) LLF and RF seedlings were compared to the reference GMF condition (grey bars). No significant difference between controls and sham-exposed controls was observed. Data are mean ± SE of five independent experiments. The asterisks indicate significance level of the differences: **p*-value <0.05; ** *p*-value <0.01.

similar effect on plant cryptochrome activation as does simply reducing the geomagnetic field to a LLF. Although our results by themselves are not proof that the same underlying mechanism is involved, it is nonetheless intriguing that an analogous effect has been documented in migratory birds[13,20].

To further confirm these findings, two additional assays for cryptochrome biological activity were performed under conditions of RF exposure. These included *Arabidopsis* seedling hypocotyl growth inhibition and qPCR analysis of cryptochrome regulated gene expression, both of which have been reported sensitive to applied static magnetic fields[3,8]. For the plant growth experiments, seedling growth was monitored over 5 days under the identical illumination and magnetic field exposure conditions as for the cryptochrome phosphorylation experiments. Increased seedling growth is an indication of reduced cryptochrome biological activity, since cryptochrome mediates seedling growth inhibition under blue light[3]. The results of the plant growth assay showed that exposure to either parallel or perpendicular RF magnetic fields resulted in significantly increased hypocotyl length (up to 29%), and thereby reduced cryptochrome biological function, as compared to control seedlings (Fig. 2). Exposure to LLF conditions also caused increased hypocotyl length, indicating reduced cryptochrome response. Importantly, comparison of sham RF or sham LLF exposed seedlings to those at the reference geomagnetic field (GMF) condition yielded no statistical difference in phosphorylation.

Expression analysis in response to RF magnetic fields was performed on *PIN1*, *PIN3*, and *AUX1* genes, which had previously been shown to be cryptochrome-regulated and responsive to static magnetic fields[8]. All three of these genes showed statistically significant change in expression in response to LLF exposure (Fig. 3), in this way replicating previously obtained results[8]. Upon exposure to RF fields, gene expression was altered to a similar degree as for LLF (Fig. 3). In summary, altered cryptochrome biological activity has been observed as a result of magnetic field exposure in three independent, unrelated biological assays; one of which (phosphorylation) provides a direct probe of the photoreceptor activation state.

Discussion

Cryptochromes are proposed to be activated through flavin reduction in response to light, hereby conversion of oxidized flavin (FADox) to radical (FADH°) and reduced (FADH-) redox states triggers the conformational change leading to the biologically active form[21] and ref. [22] here (see model in Fig. 4). Reduced flavin is reoxidized back to the inactive (FADox) redox state by a reaction that consumes molecular oxygen; this reaction has the potential to produce radical pair intermediates. Because only the FADH° redox state is correlated with biological activity, the response to light by cryprochrome is determined by the equilibrium concentration of FADH° under a given illumination condition. Intriguingly, prior studies have also shown that cryptochrome-dependent responsivity to magnetic fields occurs exclusively during the reoxidation phase of the photocycle[3,19,23]. Furthermore, a number of possible magnetically sensitive radical pairs may be formed in the course of reoxidation from fully reduced flavin (FADH-), suggesting a change in rate constant k_{2b} as the likely magnetically sensitive step.

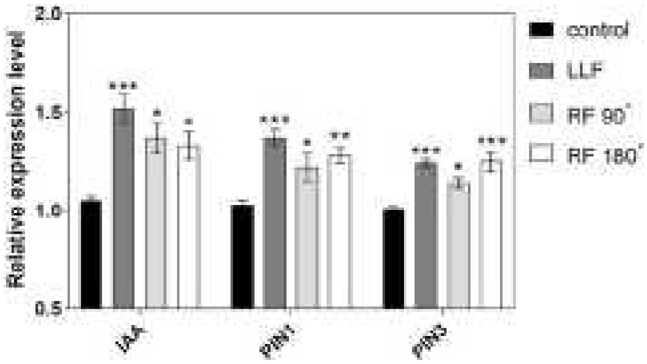

Figure 3. Effect of 7 MHz RF fi ld on *Arabidopsis* gene expression. Four-day old dark-grown etiolated seedlings were subjected to 60 µmol m^{-2} s^{-1} blue light/dark cycles as previously described[3] for 180 min and exposed to LLF (Low Level Field of less than 200nT) or to RF (7 MHz RadioFrequency fi ld) applied either perpendicular (90°) or parallell (180°) to the static GMF (geomagnetic fi ld). Expression levels of IAA, PIN1 and PIN3 genes of *Arabidopsis* was analysed by qPCR analysis as previously described[8] – see also Methods. The results were presented as the relative expression level of the cryptochrome-regulated genes IAA, PIN1 and PIN3 after exposure to LLF, RF perpendicular, and RF parallel condition as compared to the reference GMF (geomagnetic fi ld) condition. Data are mean ± SE of five independent experiments (N = 5). The asterisks indicate signifi ance level of the differences: **p*-value <0.1; ** *p*-value <0.01; ****p*-value <0.001.

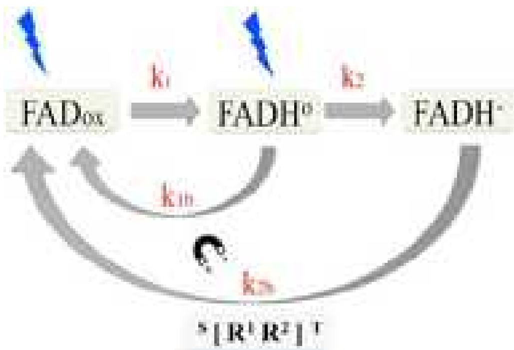

Figure 4. Model for effect of magnetic fi ld on *Arabidopsis* cryptochrome. Please see ref. [21] and ref. [22] for full background. In the ground (dark adapted) state the FAD of cryptochrome exists in the fully oxidized redox state, generally referred to as FADox. Blue light illumination causes the flavin to be photoreduced to the neutral radical redox state, designated as FADH∘. The rate at which the flavin reduction reaction occurs at any given light intensity is defi ed by the rate constant k1, derived from the quantum yield for flavin photoreduction (shown by the blue arrow). The FADH° state is the biologically active signaling state. The radical flavin redox state (FADH∘) is further reduced to the fully reduced redox state (FADH-), with a rate constant k_2. Flavin is reoxidized to the resting state (FADox) via mechanisms involving rate constants (k_{1b} and k_{2b}) that are independent of light (black arrow). Since the FADH° redox state is the only biologically active state of the receptor, cryptochrome biological activity under a given illumination condition results from the equilibrium concentration of the active, FADH°, redox state as determined by the rate constants. *The effect of the magnetic field has been to specifically alter the rate constant* k_{2d}[3,23]. A radical pair involving FADH° and possibly O_2^{o-} (but see also discussion in ref. [8]) formed in a triplet state has been suggested as mediating magnetic sensitivity. Given current uncertainty as to the identity of this radical pair we have labelled it [*R*1*R*2*]* Internal magnetic interactions that coherently interconvert radical-pair singlet and triplet spin states would then affect the rate (k_{2d}) of product (FADox) formation. As a consequence, biological activity would be altered. Th s is because a change in k2d would change the equilibrium concentration of the active FADH° redox state during continuous blue light illumination.

We therefore calculated what magnitude of change in the rate constant k_{2b} could provide the observed magnetic fi ld effect reported in Fig. 3. To model our experimental results in relation to the cryptochrome photocycle, we used a previously reported kinetic model which relates plant seedling growth to the average concentration of the FADH° (active) cry1 redox form[24]. Th s model uses previously deduced estimates of *in vivo* rate constants for cry1 flavin reduction/reoxidation steps (see Supplementary Information for details) in combination with experimental results from this study (Fig. 3). On the assumption that only k_{2b} (formed in the course of FADH- reoxidation) is modified by the magnetic field, we calculated that a modest increase in the rate constant of approximately 20% would result in the observed biological response to LLF. Th s is compatible with a possible radical pair mechanism[13,20].

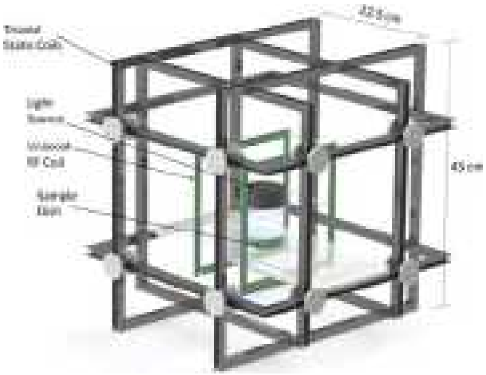

Figure 5. A diagram is shown that represents the experimental apparatus for magnetic fi ld exposure system. Tri-dimensional representation of the tri-axial set used for controlling static and alternating electromagnetic fi lds. Square coil pairs in a Helmholtz configur tion are geometrically aligned to control the static magnetic fi ld (SMF) in the horizontal X-Y direction, and vertical (Z) direction. Th s diagram also depicts the placement of a square coil in Helmholtz configur tion for the generation of RF magnetic fi lds[27]. For further details of exposure system and methodology, please see ref. [27], which used essentially identical apparatus.

In conclusion, this study shows that RF magnetic fi lds alter the biological response characteristics of the *Arabidopsis* cryptochrome receptor itself, similarly to the effects of a near-null magnetic fi ld. These results are consistent with the radical pair mechanism for magnetosensing and cannot be explained by an iron – based magnetosensor[13,20], although we can not exclude that unrelated magnetosensing mechanisms exist in parallel[6,25,26], or that cry may not be the direct RF receptor. Since cryptochromes are found in many organisms in the biological Kingdom including in humans, this study may lead to new biomedical applications developing RF signals to elicit desired cellular responses. Our results also may have more general implications for the capacity of living organisms to respond to man-made electromagnetic noise, by analogy with broad band RF[16] which has been previously shown to disrupt orientation of birds.

Materials and methods

RF magnetic field exposure setup. The setup was essentially as previously described[27]. The initial static magnetic field (SMF) background inside the room varied from 25 to 60 μT as measured with a gauss meter (IDR-321, Integrity Design, VT, USA)[27] in all 3 axes, and therefore required tri-axial compensation to establish a uniform pre-set SMF[27] in the volumes designated for culture plates within the coils[27]. For these experiments, two tri-axial sets of square coils were constructed in a Helmholtz configur tion[27]. The fi st set allowed for the simultaneous exposure of three 100 mm petri dishes as a control to a SMF of 40 μT[27]. The second set served to expose cells to a SMF of 40 μT and to either parallel/perpendicular applied weak 7 MHz magnetic fi lds[27]. In both cases, the 40 μT SMF was oriented perpendicular to the plane of growth of the plants[27]. The experimental exposure included both groups placed within separate tri-axial coils containing a single Helmholtz loop RF loop. The RF coil was not energized for the control SMF and was energized for the RF group[27].

Each square coil (45 cm each side) consisted of 20 turns of 22 AWG enamel-coated copper wire[27]. Each pair of square coils was axially aligned and separated by 22.5 cm in order to achieve the Helmholtz config ration[27]. Each pair of coils in the Helmholtz configur tion was individually driven by a power supply[27]. Resistive circuitry was fed in a twisted pair in order to achieve the necessary compensatory SMF in the desired direction[27]. The SMFs were adjusted accordingly at the isocenter of each tri-axial set as measured by a gauss meter for each axis[27]. A 1-turn square coil (12.5 cm side) in Helmholtz configur tion was built inside one of the tri-axial sets in order to superimpose magnetic fields in the RF band also with 22 AWG enamel-coated copper wires[27]. The geometric center of this RF coil was aligned with that of the triaxial set used for SMF compensation[27]. A function generator (HP33120A, Hewlett-Packard, Palo Alto, CA) established the 7 MHz magnetic signal, and the magnitude recorded in the culture-designated volume was 2±0.5 μT (RMS) after power amplifi ation[27]. The RF signal was measured with a circular search probe sensor composed of 5 turns of 22 AWG enamel-coated copper wires, 1.5 cm in radius, which were connected directly to an oscilloscope via a twisted pair feeding a coaxial cable[27].

The background time-varying magnetic fi ld was measured at the center of the tri-axial sets while inside the room in the location where the experiment was to be performed with a gauss meter (IDR-210, Integrity Design, VT) in all 3 axes[27]. The measurements performed resembled previous observations, where the dominant spectral magnitude was recorded at 50 Hz and was below 2 μT for all cases[27]. The temperature was maintained at 23 °C and verifi d throughout the course of the experiment by computer monitoring via a themocouple placed at the position of the sample[27]. The environmental parameter variance was minimal during the experiments[27]. Th dark room was utilized exclusively for these experiments and were not opened for the duration of the exposures[27].

Near-null magnetic field Exposure System. The near-null magnetic fi ld (LLF) was produced by a double layer μ-metal cylinder. The inner layer was 11.5 cm diameter, and the outer layer was 16 cm diameter, 30 cm of height. We measured the static magnetic fi ld (SMF) at the center of cylinder, which was the position for *Arabidopsis* plate and the SMF intensity was lower than 200nT. The sham LLF was produced by a Helmholtz coil placed within the cylinder. Each coil consisted of 20 windings of 1 mm-diameter copper wire around a[3] plastic circular frame (10 cm diameter, at a separation of 10 cm between coils) at the center[3] of inner μ-metal cylinder (described in ref. [3]). The current was provided to the coils to generate 40 μT static MF, which was local GMF for the sham-control experiments. The temperature was maintained at 23 °C and verifi d throughout the course of the experiment by computer monitoring via a themocouple placed at the position of the sample.

Plant materials and growth conditions. *Arabidopsis thaliana phyA phyB* mutants were used for cry1 phosphorylation and qPCR gene expression experiments, *Arabidopsis thaliana* transgenic over-expressing cry1 seedlings were used in hypocotyl growth tests as previously described[3]. Seeds were sterilized by incubation with 25% bleach for 30 min, washed 3X with sterile water, and plated on 5 mm diameter petri dishes containing 2% (W/V) sucrose, 0.5X MS salts pH 6.0 (MP Biomedicals, INC, Illkirch, France) and 0.9% (W/V) agar. Plates were maintained at 4 °C in the darkness for 48 hours, then illuminated with red light (633 nm) at 23 °C for 24 hours. For phosphorylation and qPCR assay experiments, seedlings were returned to darkness at 23 °C for 4 days. Seedlings for hypocotyl growth assays were transferred after germination to blue light test conditions for 5 days growth. Between 100 and 200 seeds per plate were used for the phosphorylation assay; 15 seeds per plate were measured for the hypocotyl growth assay. Details are as previously described in previous refs. [3,22].

Blue-light exposure system. Please see[3] for complete details. Blue light was produced by LEDs with peak wavelength of 447 nm (Quadica Developments Inc., Alberta, Canada) mounted 4.5 cm above the seedlings at the center of the exposure coil (see above). The LEDs were controlled by custom built automated programmable switches (see ref. [3]. for details) to provide alternating 5 min blue light / 10 min dark pulsed illumination conditions. The photon fluence of blue-light intensity for the experiment was measured by Quantum light meter (LI-185B, LI-COR, Inc., USA).

Phosphorylation assay. Details of this procedure are taken from[3,22]. The phosphorylation assay was performed as described previously[3]. 4-day old dark-grown *Arabidopsis* seedlings were exposed to treatment conditions as follows: 7 MHz RF oriented perpendicular or parallel to the Static Magnetic Field; or LLF (low level field). The control condition was the geomagnetic fi ld at 40 μT. Illumination at all exposure conditions was identical, consisting of repeated pulses of blue-light at 60 μmolm^{-2}s^{-1} for 5 min followed by 10 min darkness. Th s cycle was repeated 6 times for a total time of 90 min. The temperature was maintained at 23 °C and verifi d throughout the course of the experiment by computer monitoring via a themocouple placed at the position of the sample. Seedlings were then quick-frozen in liquid nitrogen and total protein extracted and assayed for the presence of the cryptochrome phosphorylated band by Western blotting as previously described[3].

Experimental design and controls. The experimental design to demonstrate the effect of RF and LLF on cry1 phosphorylation was as previously described[3]. To eliminate any possibility of artifact between experiment (test) and control comparisons, the experiments were performed in duplicate sets of at least five independent trials each. The two experimental groups were designated *treatment*, and *control group*, respectively, each of which were replicated in at least five independent biological repeats.

To determine the extent of phosphorylation, the intensity of the upper, phosphorylated band from each lane of the Western blot (cry1(Pi)) (see example gel Fig. 1, upper panel) was determined using imaging software ImageJ and expressed as a percentage of the intensity of the total cry1 protein (sum of phosphorylated plus unphosphorylated cry1) in the same lane. The formula for obtaining the extent of Cry phosphorylation is thereby [cry1(Pi)]/[cry1 (total)] x 100 yielding the percentage of phosphorylated cryptochrome per lane. Th ee triplicate lanes per individual experimental condition were averaged to yield the percentage of phosphorylation in one harvested sample.

For the *treatment group*, the mean cry1 phosphorylation value of each exposure condition (RF parallel, RF perpendicular, LLF) was compared to the mean cry1 phosphorylation in the reference static 40 μT condition designated as Geomagnetic Field (GMF). Values were expressed as the percent difference between phosphorylation in exposed and reference samples (see Fig. 1). For the *control group*, we compared the mean of cry1 phosphorylation in sham - exposed samples to those of cry1 phosphorylation at the reference GMF condition; (RF perpendicular sham, RF parallel sham, or LLF sham vs. GMF reference). In this *control group*, the experimental setup, position of samples, illumination of samples, etc. were identical to that of the *test experimental group* except that no RF or LLF was applied *in the test* conditions (ie a mock 'test' group).

We then performed statistical analysis to determine the percentage difference of cry1 phosphorylation within the *treatment group* (RF perpendicular, N = 7; RF parallel, N = 9; LLF, N = 7) and within the *control group* (N = 5 for sham - exposed RF perpendicular, RF parallel, and LLF) (see below).

Hypocotyl growth experiments. Seedling growth experiments were performed as in[3]. For each experimental determination, 15 seedlings were measured. All analysis was performed double blind, in that the person performing the measurements did not know under which condition the plates had been grown. For the *treatment group*, the mean value of hypocotyl length from each treatment condition (RF perpendicular, RF parallel, LLF) was compared to the mean value of hypocotyl length in seedlings exposed to the reference GMF condition. For the *control group*, comparisons were made between sham-treated seedlings and the reference GMF condition. Five replicate biological repeats were performed for all experiments in both the *treatment* and *control* groups (N = 5).

For statistical analysis, the significance of differential growth from each condition in the *treatment group* (N = 5; +RF perpendicular vs. GMF, + RF parallel vs. GMF, + LLF vs. GMF) and from each condition of the *control group* (N = 5; -RF perpendicular vs. GMF, -RF parallel vs. GMF, -LLF vs. GMF) was calculated.

Gene	Primer name	Primer sequence (5'-3')	Primer Reference
IAA	IAA-Fw	TGGTCGGTGATGTTCCAT	[15]
	IAA-Rev	CGGATCCTTTCATGATTCTG	
PIN1	PIN1-Fw	AACCACCACGCCGAATTACTC	[30]
	PIN1-Rev	CACCGTCCGTTGCCAATACT	
PIN3	PIN3-Fw	TCTTATCCGGCTCCGAAT	[15]
	PIN3-Rev	GAAGCTCCTTGGCGTCAT	
GADPH	GADPH-Fw	TTGGTGACAACAGGTCAAGCA	[28]
	GADPH-Rev	AAACTTGTCGCTCAATGCAATC	

Table 1. List of primers used in the current study. Data and statistical analysis. For statistical analysis, all data were analyzed by using GraphPad Prism version 7.00 for Windows (GraphPad Software, La Jolla California, USA). Data were analyzed for normality with the Shapiro-Wilk test and Homogeneity of Variances with the Brown-Forsythe test. Results are expressed as means ± standard error of the mean (SEM). The difference between RF or LLF exposed and reference (GMF) samples were compared by using One-way ANOVA followed by Bonferroni's multiple comparisons test. Differences were considered statistically signifi ant with a *p*-value < 0.05 (*), < 0.01 (**), < 0.001 (***) and <0.0001 (****).

Quantitative RT-PCR analysis of altered gene expression. QPCR analysis was performed as described[8]. Dark-grown etiolated *Arabidopsis* seedlings were plated as for the phosphorylation assay, then illuminated at 60 μmolm^{-2}s^{-1} blue-light for 5 min followed by 10 min darkness. Th s cycle was repeated for a total time of 3 h, under the designated electromagnetic exposure conditions (RF, LLF, or the reference GMF). After quick-freezing in liquid nitrogen, total RNA was extracted using the Total RNA Miniprep Kit (New England Biolabs) and cDNA was prepared from 1 mg total RNA using SuperScript fi st-strand synthesis system (Thermo Fisher Scientific). Quantitative RT-PCR was performed using Luna qPCR master mix (New England Biolabs). *Arabidopsis* GADPH was used as the reference gene[28,29]. Five biological replicates were performed for each analysis (N = 5). Primers used for gene expression analysis are listed in Table 1.

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Author contributions
M. Albaqami, M.H., M. Pooam performed experiments, designed experiments and helped write the paper; M. Pooam and M.S. performed statistical analysis; MProcopio performed theoretical calculations and helped write paper; T.R., M. Ahmad, C.M. designed experiments, analysed data and wrote paper.

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Commentary

Aspects on the International Commission on Non-Ionizing Radiation Protection (ICNIRP) 2020 Guidelines on Radiofrequency Radiation

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Abstract

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) published 2020 updated guidelines on radiofrequency (RF) radiation in the frequency range 100 kHz to 300 GHz. Harmful effects on human health and the environment at levels below the guidelines are downplayed although evidence is steadily increasing. Only thermal (heating) effects are acknowledged and therefore form the basis for the guidelines. Despite the increasing scientific evidence of non-thermal effects, the new ICNIRP guidelines are not lower compared with the previous levels. Expert groups from the WHO, the EU Commission and Sweden are to a large extent made up of members from ICNIRP, with no representative from the many scientists who are critical of the ICNIRP standpoint.

Keywords: EU; WHO; ICNIRP; 5G; Microwave radiation

1. Introduction

Wireless technologies, such as mobile phones, cordless phones, base stations, WiFi, 2G, 3G, 4G and 5G emit radiofrequency (RF) radiation, also called microwave radiation. For a long time there has been concern among laymen and a large part of the scientific community that such radiation may be a health hazard and also have a negative effect on the environment including birds [1], insects [2] and plants [3,4].

The seminal first early warning on brain tumor risk associated with exposure to RF radiation from mobile phones was published some 20 years ago [5, 6]. In the following case-control studies by the Hardell group, in addition to mobile phones, also use of cordless phones (DECT) was assessed. These studies confirmed an increased risk for brain tumors, i.e. glioma, for both types of wireless phones [7]. Similar findings were reported for acoustic neuroma [8].

In May 2011 the International Agency for Research on Cancer (IARC) at the World Health Organization (WHO) evaluated RF radiation in the frequency range 30 kHz–300 GHz to be a possible human carcinogen, Group 2B [9, 10].The IARC decision on mobile phones was based mainly on two sets of case-control human studies: the Hardell group studies from Sweden [11-13] and the IARC Interphone study [14, 15]. Both provided supportive evidence of increased risk for brain and head tumors, i.e. glioma and acoustic neuroma. Later published studies by the Hardell group [7, 8] and the French CERENAT (CEREbral tumors: a NATional study) study on glioma and meningioma [16] supported an increased risk for brain tumors and use of mobile and cordless phones. However, risks associated with the use of cordless phones was assessed only by the Hardell group, although cordless phones emit RF radiation of similar type as mobile phones.

The increasing scientific evidence on cancer risks from RF radiation, as well as other health effects, has had little or mostly no effect on preventive measurements. This is due to scientific disagreements and controversies. Some influential organizations are downplaying the health risks, i.e. the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the World Health Organization (WHO), the European Union (EU) and the Swedish Radiation Safety Authority (SSM), see next section. It has been discussed that by now such exposure might be classified as carcinogenic to humans, Group 1, according to the IARC classification [17-19]. However, only an IARC evaluation can make that classification.

Because of the controversies and the lobbying by influential organizations, including the telecom industry, precautionary measures are not taken and the public is not informed about health risks [20, 21]. People in general are, as a consequence, not taking preventive measures when using the handheld wireless phone, WiFi, or when exposed to RF radiation from base stations. Increasing ambient RF radiation gives higher total human exposure [22, 23] in addition to the widespread use of mobile and cordless phones.

During the last decades, the scientific evidence on other health effects than cancer has also increased. By January 2021, 255 scientists from 44 nations and 15 supporting scientists from 11 nations concluded that these effects occur well below most international and national guidelines recommended by ICNIRP, (see next section).

"Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plant and animal life." [24].

The scientific evidence on the carcinogenic potential of RF radiation in laboratory studies has long been accumulating, but has mostly been ignored or dismissed by e.g., ICNIRP, the WHO, the EU and the SSM. The increased cancer risk in humans for RF radiation is clearly supported by recent animal studies [25-27] and mechanistic studies, both induction of reactive oxygen species (ROS) [28], and DNA damage [29-31]. The history on carcinogenic effects in laboratory studies started several decades ago.

Co-carcinogenic effects of RF radiation exposure and benzopyrene in mice were published already in 1982 [32]. The study showed that 2,450 MHz of RF radiation at either 50 or 150 W/m^2 promoted carcinogenesis. These levels exceed the ICNIRP guidelines, see below. The authors concluded that the resulting acceleration of development of spontaneous and chemically induced cancers indicated the carcinogenic potential of RF radiation.

Two studies published in 1990 demonstrated that 2,450 MHz continuous-wave RF radiation exerted a biphasic effect on glioma cells [33] and lymphocytes [34]. Cell proliferation was found at a specific absorption rate (SAR) of ≤50 W/kg, whereas a higher SAR suppressed DNA and RNA synthesis. These effects were reported to be non-thermal, i.e. not caused by heating.

A statistically significant increased incidence of primary malignant diseases was found in exposed animals compared with sham exposure in a study on 200 rats exposed to 2,450 MHz pulsed RF radiation for 21.5 h/day for 25 months compared with 200 controls. SAR ranged between 0.144 and 0.4 W/kg, depending on the rat's weight [35]. This was one of the first large scale studies to be conducted. Consequently the results in the U.S. National Toxicology Program (NTP) [25-26] and the Ramazzini Institute [27] studies are in line with these findings.

A study on mice carrying a lymphomagenic oncogene exposed to RF radiation showed a statistically significant increased risk for malignant lymphoma [36]. A total of 100 mice were sham-exposed and 101 were exposed for two 30-min periods per day for up to eighteen months to 900 MHz pulsed RF radiation with power densities of 2.6-13 W/m^2 (SAR 0.008-4.2 W/kg; mean, 0.13-1.4 W/kg). These results were not confirmed in the study by Utteridge et al. [37] which has been noted not to be a replication study [10, 38].

A co-carcinogenic effect was found in a study on mice exposed to a Universal Mobile Telecommunications System (UMTS) test signal from the fetal period for up to 24 months [39]. Animals were exposed to UMTS fields with intensities of 0 (sham), 4.8 and 48 W/m^2. The low-dose group was subjected to additional prenatal ethylnitrosourea (ENU) treatment. The group that was ENU-treated and UMTS-exposed at 4.8 W/m^2 exhibited an increased rate of lung tumors and an increased incidence of lung carcinomas as compared with the controls treated with ENU alone.
A tumor promoting effect was studied in another study on ENU-treated mice. The exposure levels were 0 (sham), 0.04, 0.4 and 2 W/kg SAR. The numbers of lung and liver tumors

in exposed animals were statistically significant higher compared with those in sham-exposed controls, as were the numbers of malignant lymphoma. A tumor-promoting effect of RF radiation was found at low to moderate levels (0.04 and 0.4 W/kg SAR), which were well below the exposure limits for users of mobile phones, 2 W/kg (of tissue) to the head [40].

Numerous published studies report effects or damage in terms of oxidative stress, damage to DNA, gene and protein expression, breakdown of the blood-brain barrier and damage to the brain and other organs of the body [41, 42]. There is also increasing evidence of adverse (chronic) health effects from long-term exposure. This was already reported as the “microwave syndrome” or “radiofrequency sickness” some fifty years ago. Reported health effects in scientific studies during the last decades from exposure to mobile phone towers, WiFi and mobile phones are consistent with the reported effects from RF radiation (microwaves) half a century ago [43, 44]. Furthermore, repeated studies show harmful effects from prenatal exposure, both in animal studies and in humans [45, 46].

Many countries around the world rely on guidelines for maximum allowed exposure from ICNIRP, supported and recommended by the WHO [47]. In Europe, most countries also follow the recommendations from the EU Commission that are based on ICNIRP and the EU expert group Scientific Committee on Emerging and Newly Identified Health Risk (SCENIHR). In 2020 ICNIRP published updated guidelines [48] based on the reviews and opinions from the WHO 2014 environmental health criteria public consultation report, SCENIHR 2015 [49] and the Scientific Council on Electromagnetic Fields at the Swedish Radiation Safety Authority (SSM) 2015, 2016, 2018 [50-52].

In this article we discuss how these organizations have evaluated the increasing evidence of harmful effects of RF radiation at levels below most national guidelines and limits for RF radiation exposure. The same individuals reappear in several of these organizations’ expert groups, see Table 1, and there are no representatives in these groups from the many scientists that disagree with their conclusions [24]. We discuss primarily cancer risks in Appendix B of the ICNIRP updated guidelines [48].

WHO 2014 core group	**ICNIRP**	**IEEE**	**EU**	**SSM**	**EMF Scientist Appeal**	**The 5G Appeal EU**
Emilie van Deventer, project leader	X	X	-	X	-	-
Simon Mann	X	-	-	-	-	-
Maria Feychting	X	-	-	X	-	-
Gunnhild Oftedal	X	-	-	-	-	-
Eric van Rongen	X	X	X	X	-	-
Maria Rosaria Scarfi	X	-	X	X	-	-
Denis Zmirou	-	-	-	-	-	

SCENIHR 2015	ICNIRP	IEEE	WHO	SSM	EMF Scientist	5G Appeal EU
Theodoros Samaras	-	X	-	-	-	-
Norbert Leitgeb	-	-	-	-	-	-
Anssi Auvinen	X	-	-	-	-	-
Heidi Danker Hopfe	-	-	-	X	-	-
Kjell Hansson Mild	-	-	-	-	-	-
Mats Olof Mattsson	X	X	-	-	-	-
Hannu Norppa	-	-	-	-	-	-
James Rubin	-	-	X	-	-	-
Maria Rosaria Scarfi	X	-	X	X	-	-
Joachim Schüz	-	-	-	-	-	-
Zenon Sienkiewicz	X	-	-	-	-	-
Olga Zeni	-	-	X	-	-	-
SSM 2016	ICNIRP	IEEE	WHO	EU	EMF Scientist	5G Appeal EU
Anke Huss	From 2020	-	-	-	-	-
Clemens Dasenbrock	X	-	-	-	-	-
Emilie van Deventer	X	X	X	-	-	-
Eric van Rongen	X	X	X	X	-	-
Heidi Danker-Hopfe	-	-	-	X	-	-
Lars Klaeboe	-	-	-	-	-	-
Maria Rosaria Scarfi	X	-	X	X	-	-
Martin Röösli	X	-	X	-	-	-

Table 1: Many persons in expert groups at the WHO, the EU commission and in Sweden are current or former members in ICNIRP, and other expert groups, with no representative from the scientific community with opinions as expressed in EMF Scientist Appeal or 5G Appeal. For further details see ICNIRP [72,135,136,140,141,143-146], IEEE [137,145], EU [86,138,145], SSM [71,142], EMF Scientist Appeal [24], the 5G Appeal EU [139].

2. Evaluating Organizations

2.1. ICNIRP

ICNIRP is a non-governmental organization (NGO) based in Germany that has obtained major influence world-wide on health risks from RF radiation through its recommended guidelines for limiting RF radiation exposure [48, 53, 54]. These guidelines are recommended by the EU Commission, the WHO and are adopted by the majority of the countries around the globe.

ICNIRP was started in 1992 as an "independent commission". It is registered in Germany and located in Munich at the same address as the German Federal Office for Radiation Protection [55].

ICNIRP maintains the same attitude to health effects from RF-radiation as the Institute of Electrical and Electronics Engineers (IEEE) and its standards setting committee, the International Committee on Electromagnetic Safety (ICES). This committee and ICNIRP, are both standard setting organizations for frequencies between 0 Hz to 300 GHz.

ICES have many industry and military representatives among its members [56]. ICES within IEEE also sets limits for RF exposure which are in line with the ICNIRP opinion that there are only immediate thermal effects and no effects below those that cause immediate effects due to increased temperature. This perception was established in the 1950's and a decade later used when the first thermal based standard for radiofrequency radiation was set in the USA in 1966 [57]. Several members of ICNIRP are also present or former members of IEEE/ICES [58].

The biophysicist Michael Repacholi from Australia was ICNIRP's first chairman and he is since 1996 an emeritus member [59]. Experts from various countries constitute the "main commission" of ICNIRP; a chair, a vice chair and 11 other members. Further scientists are elected by this commission to the scientific expert group (SEG). New and continuing members to the commission are elected by the members of the main commission. Nominations can be submitted by the members of the Commission itself, the Executive Council of IRPA (the International Radiation Protection Association) or the IRPA Associate Societies. It seems as if no scientist that is critical to the thermal paradigm on RF radiation risks, advocated by ICNIRP, is elected as a member of the Commission.

ICNIRP published its first guidelines on RF radiation in 1998 [53]. These were updated in 2009 with no changes [54]. Only short-term thermal (heating) effects were acknowledged to form the basis for the exposure guidelines. Long-term exposure and non-thermal effects were considered not to be established, thus excluding a large number of peer-reviewed scientific studies on negative health and biological effects from RF-radiation below the ICNIRP guidelines. In 2020 ICNIRP [48] published new guidelines on health risks based on documents from: the WHO 2014 draft, the EU SCENIHR 2015 report and the Swedish SSM reports 2015, 2016 and 2018.

It should be noted that not one of these five reviews has been published after peer-review in a scientific journal. Critique from the scientific community has been expressed against several of these reviews but has been ignored. Furthermore, these older documents do not cover the most recent research. In the following comments are given to these three reviews since the ICNIRP 2020 is based on these older evaluations with no new and further evaluation of its own [48].

2.2 The WHO Public Consultation Environmental Health Criteria Document, 2014

The WHO EMF Project, responsible for the 2014 document, was established in 1996. ICNIRP's chairman Michael Repacholi suggested in 1995 that WHO should start the EMF Project [60]. In 1995, while Repacholi still was chairman of ICNIRP, he became the head of the WHO International Electromagnetic Fields Project, and then head of the WHO EMF Project in 1996 [61], where he remained until 2006 [62]. A close colloboration between WHO and ICNIRP was initiated. In November 1998 the WHO EMF Project commenced a process aimed at the harmonization of EMF standards worldwide according to the ICNIRP guidelines [63]. Benefits to trade was given as one main argument to this specific project. The 100 times lower limits (compared to ICNIRP) in Eastern Europe were described as problematic [63].

The possibility of industry funding to the project was arranged already before the start of the project: "In 1995 WHO reached agreement consistent with these policies with Royal Adelaide Hospital (RAH), Australia to collect funds on behalf of the EMF Project. A memorandum of understanding allowed RAH to collect funds from government, professional associations and industry." [64]. This financial situation was ended in 2006 after disclosure by investigating journalists that showed that approximately half of the funding for the WHO EMF Project came from telecom industry organizations; GSM Association, Mobile Manufacturers Forum (MMF) and Forschungsgemeinschaft Funk e.V. (FGF) [65, 66].

Since 2006 the project leader of the WHO EMF project is Emilie van Deventer, an electrical engineer and longtime member of the industry organization IEEE [67]. She is the founder and former chairperson of the IEEE Joint Chapter on Electromagnetics and Radiation [68]. Her background is in "electromagnetic characterization of high-speed circuits for telecommunications applications, computationa electromagnetics (RF frequency and time domain techniques), electromagnetic compatibility, antenna modelling and design" and does not include medical training [69, 70]. She is the WHO EMF Project observer at the ICNIRP's main commission as well as a member of the SSM expert group from 2010 to 2017 [60, 71, 72].

The WHO EMF Project is in principle synonymous with ICNIRP. The same individuals that propose the ICNIRP guidelines are also acting as experts evaluating hazards from RF radiation on behalf of the WHO. This kind of double position situation is a potential conflict of interest according to the Ethical Board of the Karolinska Institute, Stockholm, Sweden 2008 (Dnr 3753-2008-609).

In 2005-2006 the personnel at the WHO EMF Project were Michael Repacholi, Emilie van Deventer, Chiyoi Ohkubo [62], Richard Saunders [73], Eric van Rongen and Lisa Ravenscroft [60]. All except Ravenscroft are current or former members of ICNIRP. In fact, at a meeting at WHO, Geneva in March 2017, Dr Maria Neira, at that time Director for Public Health and Environment at WHO, stated that ICNIRP is an Non-Governmental organization (NGO) with an official relationship with WHO that "helps us a lot in our analyses" and their members work as WHO's experts [74]. The WHO EMF Project has for many years been criticized for its collaboration with the industry; electrical, military and telecom [75].

A draft of a Monograph on health effects of electromagnetic field (EMF) exposure was released by WHO in 2014 [76]. It was open for public consultation until December 31, 2014, but has never been published as a final version and it is unclear why it was never finalized.

Out of the six experts in the WHO core group responsible for the draft, four were active members and one was a former member of ICNIRP [74], a fact that illustrates that WHO continues to be almost identical with ICNIRP, see Table 1. Many critical comments were sent to the WHO. One example is the "No confidence" letter sent by The BioInitiative Working Group in December 2016 to the WHO EMF Program Manager that concluded that the experts writing the WHO draft were to a large extent ICNIRP members.

"The BioInitiative Working Group urges the World Health Organization to make changes to the WHO RF EHC [Environmental Health Criteria] Core Group membership to more fairly reflect membership and expertise of the 2011 IARC RF Working Group. At present the WHO RF EHC Core Group is indistinguishable from ICNIRP (1, 2) undermining credibility of the process and ensuring doubt about conclusions." [77].

This letter was followed by another letter from the BioInitiative Working Group in January 2017 including suggestion of experts to replace present persons in the Core Group as well as Additional Experts [78].

A call for Protection from Non-ionizing Electromagnetic Field Exposure was made by the International EMF Scientist Appeal.

"By not taking action, the WHO is failing to fulfil its role as the preeminent international public health agency…. The WHO is calling for all nations to adopt the ICNIRP guidelines to encourage international harmonization of standards… It is our opinion that, because the ICNIRP guidelines do not cover long-term exposure and low-intensity effects, they are insufficient to protect public health." [24].

In total forty-seven NGOs also submitted a critical statement regarding the WHO draft on December 15, 2014. The WHO draft was criticized for the absence of pluralism among the selected experts, for biased reporting of scientific results and the "promiscuity between the WHO and ICNIRP." [79].

A press release was furthermore issued on February 24, 2017 by the European coordination of organizations for an EMF exposure regulation which truly protects public health. They stated that "The Conflict of Interest Scandal is repeating itself in the WHO" [80].

In a letter of concern dated March 1, 2017 the Russian National Committee on Non-Ionizing Radiation Protection wrote to the WHO: "It has just come to our attention that the WHO RF Working group consists mainly from present and past ICNIRP members.….the private self-elected organization ICNIRP, similar as majority of the current WHO RF WG [Working Group] members, does not recognize the non-thermal RF effects,…" [81].

In 2016 at a seminar at SSM in Stockholm Emilie van Deventer said that they had received 700 comments on the draft including references to "at least 300 papers that we had missed" [82].

It is unclear how WHO reacted to the critique. The Monograph is still unfinished. Instead the WHO has called for a new systematic review of this topic.

It should be noted that WHO in 2014 issued the following statement: "THIS IS A DRAFT DOCUMENT FOR PUBLIC CONSULTATION. PLEASE DO NOT QUOTE OR CITE." Nevertheless, this WHO Monograph draft from 2014, issued by a group dominated by ICNIRP members, was used as a basis for the ICNIRP guidelines 2020.

2.3. The European Commission SCENIHR opinion 2015

In 2015 the European Commission's expert group on electromagnetic fields, SCENIHR, released its report "Opinion on potential health effects of exposure to electromagnetic fields (EMF)" [49]. It was an update of the previous SCENIHR Opinions of 19 January 2009 "Health effects of exposure to EMF" and 6 July 2009 "Research needs and methodology to address the remaining knowledge gaps on the potential health effects of EMF" [83].

SCENIHR is one of three "Independent Scientific Committees" that provide the EU Commission, and through the Commission the other European institutions, with scientific advice regarding consumer safety, public health and the environment [84]. The Committee is also supposed to "…draw the Commission's attention to the new or emerging problems which may pose an actual or potential threat".

According to the Commission decision 2008, article 15 [85], the experts "…shall undertake to act independently of any external influence" and "shall make a declaration of commitment to act in the public interest and a declaration of interests indicating either the absence or existence of any direct or indirect interest which might be considered prejudicial to their independence". However, this committee has a history of being unbalanced in terms of representation from both sides of the scientific controversy on RF radiation. No representatives from the scientific community that are of the opinion that there is increasing evidence of harmful effects have participated; at least no person has declared other opinion than the ICNIRP view.

The 2007 SCENIHR [86] working group's chair was Anders Ahlbom from Sweden, ICNIRP commission member 1996-2008 and contributing to the ICNIRP guidelines 1998. Mats-Olof Mattsson, from Sweden, was one of the groups' three experts.

The 2009 SCENIHR [87] working group was identical to the 2007 group, but Mats-Olof Mattsson, from 2013 member of ICNIRP SEG, replaced Ahlbom as chair [88]. Eric van Rongen, member of ICNIRP and ICES as well as working with the WHO EMF Project, was now among the external experts [87].

The 2015 SCENIHR working group was made up of Theodoros Samaras and Norbert Leitgeb (retired) and ten additional external experts [89]. Of the ten external experts, four are former or present members of ICNIRP main commission or SEG (Anssi Auvinen, Mats-Olof Mattsson, Maria Rosaria Scarfi and Zenon Sienkiewicz). Both Mattsson and Samaras are members of ICES/ IEEE [56].

2.3.1 Main conclusions 2015

The quotes in this section are from the SCENIHR report 2015 [49]:

"Overall, the epidemiological studies on mobile phone RF EMF exposure do not show an increased risk of brain tumours. Furthermore, they do not indicate an increased risk for other cancers of the head and neck region.…The results of cohort and incidence time trend studies do not support an increased risk for glioma while the possibility of an association with acoustic neuroma remains open."

Other effects from RF-radiation such as different health symptoms, also known as the microwave syndrome [43], neurological diseases and other health outcomes, were also dismissed with various arguments. The conclusion of no brain tumor risks from RF radiation relied upon several studies with methodological shortcomings resulting in underestimated risks, for instance the Danish cohort study [90, 91], the UK Benson study [92] as well as the Cefalo study [93], see below. Joachim Schüz, who was a member of SCENIHR 2015 working group that drafted SCENIHR 2015, was also coauthor of these three studies [94].

Increased cancer risks in other epidemiological studies [7, 8, 14, 15, 16] were downplayed by SCENIHR [49] with reference to a few brain tumor incidence trend reports, the Danish cohort and a UK cohort:

"The fact that incidence rates of glioma and meningioma do not rise in the age groups of highest mobile phone prevalence provides evidence that common use of mobile phones is unlikely to be associated with an increased risk of those brain tumours. This is confirmed by the Danish cohort study that rules out risks that would affect large segments of the population. Evidence against an association also arises from the large-scale UK million women study."

2.3.2. Methodological issues

2.3.2.1. The Danish Cohort (2001, 2006, 2011): This study, funded by Danish telecom operators, first published in 2001 [90] and last updated in 2011 [91], reported no increased risks of tumors in the central nervous system. It was based on 420,095 mobile phone private subscribers. This group's incidence of brain tumors was compared with the incidence within the rest of the Danish population (control group). However, there are severe methodological faults that led to erroneous results:

- Inclusion only of mobile phone private subscribers in Denmark between 1982 and 1995 in the exposure group.
- Exclusion of the most exposed group, consisting of 200,507 corporate users of mobile phones [90]. They were instead included in the unexposed control group if not private subscribers.
- Users with mobile phone subscription after 1995 were not included in the exposed group and were thus treated as unexposed: "individuals with a subscription in 1996 or later were classified as non-users" [91].
- Actual exposure data is unknown and no analysis by laterality (the side were the phone is hold in relation to the position of the tumor) was performed.
- All users of cordless (DECT) phones were treated as unexposed for that exposure although they were also exposed to the same kind of RF radiation as from mobile phone use. The Hardell group has shown that use of cordless phones increases risk of glioma and acoustic neuroma tumors [7, 8].

Professor Michael Kundi of the Medical University of Vienna expressed the opinion that the Danish study is "the most severely biased study among all studies published so far" [95]. Certainly, there were severe methodological flaws. The study [90, 91, 96] was regarded by IARC in the 2011 evaluation [9, 10] to be uninformative regarding cancer risks due to serious exposure misclassification. However, it is included by SCENIHR [49], WHO [76], SSM [97] and ICNIRP as evidence of no risk [98, 99]. The statement by SSM 2013 [97] that: "The Danish cohort studies make an important contribution to the total assessment in the field." is remarkable taking the critique of the study that should have been well known to the SSM expert panel. The many shortcomings in the study were discussed in a peer-reviewed article [100] concluding that: "After reviewing the four publications on the Danish cohort study, one might rightly wonder whether this cohort was initially set up to show no increased risk."

2.3.2.2. The Benson UK study (2013): This cohort study of 791,710 women in the Million Women Study was started during 1996-2001 [92]. Data on mobile phone use was collected at one time between 1999 and 2005, without questions separating heavy users from light users. Mobile phone use was based on the answers to a few questions posed at the time when the women were recruited to the study: "About how often do you use a mobile phone?", "Never, less than once a day, or every day?" Those who did use a mobile phone were also asked "for how long?". At the end of the study in 2009, a random sample of participants were asked two more questions about their mobile phone use, but these answers were never used in the analyses. Use of cordless (DECT) phone was not assessed. Due to limitations in the study design, such as no comprehensive assessment of life-time mobile phone use, the study is uninformative and should not be used as scientific evidence of lack of cancer risk. In fact the authors concluded that:

"The main limitation of the study is that mobile phone use was reported at baseline and may have changed subsequently. Almost all women who reported daily use of mobile phones at baseline were still using a mobile phone at least once a week when asked again 8.8 years later. However, some women who reported not using a mobile phone at baseline began use subsequently; and this might dilute our estimates of relative risk towards the null" [92].

2.3.2.3. The CEFALO Study (2011): The CEFALO study on brain tumor risk for children aged 7-19 using mobile phones [93] is claimed in the SCENIHR 2015 report [49] to have found no increased risk. The children in the study were diagnosed with a brain tumor during 2004-2008. The study showed several statistically non-significant increased odds ratios (ORs). However, a press release issued by one of the authors, Maria Feychting at the Karolinska Institute in Stockholm, stated that "Reassuring results from first study on young mobile users and cancer risk…The so called CEFALO study does not show an increased brain tumor risk for young mobile users." [101]. She was vice chair of ICNIRP 2012-2020, member of ICNIRP SEG 2000-2012, and is currently SEG member since 2020. Maria Feychting was also member of the WHO core group responsible for the WHO 2014 draft. Martin Röösli, member of ICNIRP Commission since 2016, the SSM expert group since 2010, as well as member of the WHO 2014 external expert group, was also coauthor of this study (corresponding author). Martin Röösli also claimed in a press-release that the results were reassuring of no risk [102].

The study has several shortcomings and one major shortcoming is the assessment of RF exposure from cordless phones that was not included in the total RF radiation exposure. Furthermore, the scientists did not assess total exposure from cordless phones (DECT). Instead the authors analyzed "…ever used cordless phones, and the cumulative duration and number of calls with cordless phones in the first 3 years of use." This is a scientifically invalid method to study risk associated with an agent [103]. Thereby four to sixteen years of potential exposure were disregarded in the study age group 7-19 years. It is most questionable since use of the cordless phone increases by age.

This is more startling since no such time limit was made in the questionnaire sent to the Ethical Board at Karolinska Institute, Stockholm (DNR2005/1562-3). There were four questions on use of a cordless phone (summary): 1. When did you first start using a cordless phone? 2. How often did [child] answer the cordless phone? 3. How often does [child] speak on the cordless phone? 4. When [child] talks on the cordless phone, which phrase fits the best? (about 1 min, about 3 min, about 6 min, about 10 min or more).

No doubt even with these few questions it would have been possible to assess lifetime cumulative use of the cordless phones. According to the questions there is no reason or possibility to limit to only the first three years of use. Furthermore, it is not probable that a child would only use the cordless phone for three years and then stop the habit. To note is also an e-mail (personal communication) from Martin Röösli to one of the authors (MN) on August 17, 2011 in which he regarding cordless phones stated that "We also asked about ever using it and we requested the age range that they have used the phone". No doubt with that information, which was not given in the article, it would have been possible to calculate whole lifetime cumulative exposure.
Thus, it is evident that limiting use to only first three years would bias the results towards unity, particularly as children tend to increase their phone use with increasing age, which is also shown in the CEFALO study. In spite of this, SCENIHR [49] gave the impression that all cordless phone use was included by claiming that "Use of cordless phones showed no increased OR (1.09; CI 0.81-1.45), not even in the group of highest cumulative use." This claim is most misleading. Highest group for cumulative use available in the study was only 70+ hours. Further, the authors intentionally omitted the real highest users by limiting the exposure to the first three years of use. It is remarkable that this misleading claim in the SCENIHR report was written by one of the authors of CEFALO (Joachim Schüz), who also was coauthor of the Danish cohort and the Benson study.

In a comment, the Hardell group wrote [103]:

"Further support of a true association was found in the results based on operator-recorded use [of mobile phones] for 62 cases and 101 controls, which for time since first subscription > 2.8 years yielded [odds ratio] OR 2.15 (95% [confidence interval] CI 1.07-4.29) with a statistically significant trend (P = 0.001)….. We consider that the data contain several indications of increased risk, despite low exposure, short latency period, and limitations in the study design, analyses and interpretation".

In fact, all ORs on mobile phone use were >1.0 according to Table 2 in the article [93]. For both ipsilateral and contralateral mobile phone use statistically significant increased risks were obtained for highest group of cumulative numbers of calls; OR = 2.91, 95% CI = 1.09-7.76 and OR = 4.82, 95 % CI = 1.21-19.24, respectively. For central or unknown location a statistically significant decreased risk was found based on low numbers. It should be noted that there are missing numbers of cases and controls in different strata in e.g. Table 5 in the article [93], no explanation is given as we have discussed [103]. The anatomical distribution for brain tumors in children differs from adults [104]. Thus, there are more central and brain stem tumors, facts not considered by Aydin et al. [93] In children the distribution of RF radiation differs from adults with larger part of the brain more exposed due to e.g. smaller head and thinner bone [105]. Thus, the laterality analysis should be interpreted with caution.

2.3.3. Critical comments on SCENIHR [49]

There were in total 186 critical comments submitted to EU by different persons and organizations [106]. Less than 30 percent of these comments were taken into account, a few yielding minor clarifications in the text but without changes of the SCENIHR major conclusions. The BioInitiative Group was among many others that expressed critical comments to the SCENIHR: "In summary, the preliminary SCENIHR conclusion that glioma risk is weaker now is not scientifically justified. The only way that conclusion could be reached by SCENIHR is to exclude critical studies that present evidence to the contrary, i.e. studies that report the risk of glioma (and acoustic neuroma) is stronger now than in 2009" [107].

2.4. The reports from the Swedish Radiation Safety Authority (SSM) 2015, 2016 and 2018 [50-52]

The expert group on electromagnetic fields at SSM was created in June 2002. Between 2003 and 2010 it was called the "Independent Expert Group on Electromagnetic Fields". During that period Anders Ahlbom, member of ICNIRP main commission 1996-2008, and SCENIHR member 2007-2009, was the head of the expert group and his colleague Maria Feychting, longtime member of ICNIRP and member of the WHO 2014 core group, was the group's secretary. From 2013 and until today, the expert group was renamed as the "Scientific Council on Electromagnetic Fields".

Between 2003 and 2019 the SSM group has published thirteen reports in English on its webpage [71]. All reports since 2003 have consistently refuted or ignored evidence of health risks from non-thermal exposure in line with the views by ICNIRP, the WHO and the SCENIHR.

Since the first report in 2003 until today around half of the group's members have also been present or previous ICNIRP members. In consequence the conclusions have generally been that there are no health risks below the limits recommended by ICNIRP. No scientist critical to the ICNIRP view has ever been part of this group. Here are some examples of conclusions from the SSM reports (2015 – 2018) that are included as basis for the present ICNIRP guidelines.

2.4.1. SSM 2015

"In terms of exposure from mobile phone base stations or other RF-EMF transmitters, no new evidence has become available indicating a causal link between exposure and symptoms or Electromagnetic Hypersensitivity (EHS)…. New studies on mobile phone use and tumours in the brain using retrospective exposure assessment are in line with previous research, which means that increased risks were observed in some of the most extreme exposure categories. However, it is not clear to what extent these risk estimates are affected by recall bias… New studies on associations between sperm quality and mobile phone use are of low quality and cannot be used to evaluate a potential association with RF-EMF exposure" [50].

The 2015 SSM report raised the issue that recall bias might have affected brain cancer risk estimates. However the study by Momoli et al. [108] showed that recall bias did not affect the risk of glioma in the Canadian component of the Interphone study [14]. In addition, it should be noted that the 2020 ICNIRP guidelines [48] refer to recall bias in the case-control studies of the Interphone study but do not mention the analysis by Momoli et al. Also, as displayed below, recall bias cannot explain the results in the Hardell group studies.

2.4.2. SSM 2016

"Most research in the past decade has been done into a possible relation between mobile phone use and brain tumours. Epidemiological studies have provided weak indications for an association between frequent and long-term use of a mobile phone and gliomas (malign tumours of the brain tissue) and vestibular schwannomas (also called acoustic neuromas, a benign tumour of the vestibulocochlear nerve that connects the ear to the inner brain). The evidence is not very clear and unequivocal, however. Altogether it provides no or at most little indications for a risk for up to approximately 15 years of mobile phone use" [51].

In a press release, at the time of the publication of the 2016 report, this Swedish authority claimed that the suspicion that mobile phones or wireless networks could be a health risk to humans or to the environment had become weaker during the past 13 years since the first of the group's report [109]. This contrasted with the increasing scientific evidence of the opposite [24]. In Table 2 results for meta-analysis of highest cumulative use in hours of mobile phone use in case-control studies is given and the results for acoustic neuroma are given in Table 3. Clearly these results from the different studies available in 2016 are in contrast to the statement by SSM.

	All			**Ipsilateral**		
	Ca/Co	OR	95 % CI	Ca/Co	OR	95 % CI
Interphone 2010 [14]						
Cumulative use ≥1,640 h	210/154	1.40	1.03 – 1.89	100/62	1.96	1.22 – 3.16
Coureau et al 2014 [16]						
Cumulative use ≥896 h	24/22	2.89	1.41 – 5.93	9/7	2.11	0.73 – 6.08
Hardell, Carlberg 2015 [7]						
Cumulative use ≥1,640 h	211/301	2.13	1.61 – 2.82	138/133	3.11	2.18 – 4.44
Meta-analysis						
Cumulative use ≥1,640 h*	445/477	1.90	1.31 – 2.76	247/202	2.54	1.83 – 3.52

*≥896 h used for Coureau et al.

Table 2: Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95 % confidence interval (CI) for glioma in case-control studies in the highest category of cumulative use in hours for mobile phone use, for further details see [42].

	All			Ipsilateral		
	Ca/Co	OR	95 % CI	Ca/Co	OR	95 % CI
Interphone 2010 [15]						
Cumulative use ≥1,640 h	77/107	1.32	0.88 – 1.97	47/46	2.33	1.23 – 4.40
Hardell et al. 2013 [8]						
Cumulative use ≥1,640 h	27/301	2.40	1.39 – 4.16	19/133	3.18	1.65 – 6.12
Meta-analysis						
Cumulative use ≥1,640 h	104/408	1.73	0.96 – 3.09	66/179	2.71	1.72 – 4.28

Table 3: Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95 % confidence interval (CI) for acoustic neuroma in case-control studies in the highest category of cumulative use in hours for mobile phone use, for further details see [42].

2.4.3. SSM 2018

This annual report was the twelfth in this series and covered studies published from October 2015 up to and including March 2017. Oxidative stress effects reported below ICNIRP guidelines was discussed but the relevance for human "direct health effects" was claimed to be "unclear". The conclusion was that "No new health risks have been identified." [52].

It is clear that the SSM expert group has not made a sound and objective scientific evaluation of health risks associated with RF radiation exposure. We note that SSM in April 2020 published a new report from the SSM expert group which concluded: "The results of the research review give no reason to change any reference levels [ICNIRP's] or recommendations in the field". Of the ten members in the scientific group five were present or past members of ICNIRP [110].

3. ICNIRP 2020 Evaluation

Eric van Rongen, chair of the ICNIRP Commission 2016-2020, claimed in a press release regarding the new ICNIRP guidelines 2020 that the 1998 version was "conservative in most cases" and "still provide adequate protection for current technologies". He also argued that: "The most important thing for people to remember is that 5G technologies will not be able to cause harm when these new guidelines are adhered to" [111].

Many other incorrect statements were made in the recent ICNIRP paper [48] contrary to an objective evaluation of the available scientific evidence. In the following the section on cancer is reviewed. That section claims:

"There is a large body of literature concerning cellular and molecular processes that are of particular relevance to cancer. Although there are reports of effects of radiofrequency EMFs on a number of these endpoints, there is no substantiated evidence of health-relevant effects (Vijayalaxmi and Prihoda 2019)".

Already in the first paragraph in the report evidence on biological effects from RF radiation is dismissed without scientific foundation. This continues regarding cancer risks. Mostly not even references are given to the discussed studies, or with erroneous references. The uninformed reader may take the statements at face value and not understand that they are, in fact, not correct.

3.1. Animal studies

Regarding animal studies yielding a promoting effect from RF radiation [39, 40] ICNIRP states that "…interpretation of these results and their applicability to human health [is] difficult, and, therefore, there is a need for further research to better understand these results". In the next paragraph the recent animal NTP studies [25, 26] and Ramazzini Institute results [27] are disregarded, stating that "…no consistency was seen across these two studies" and "within the context of other animal and human carcinogenicity research (HCN 2014, 2016), their findings do not provide evidence that radiofrequency EMFs are carcinogenic".

On the contrary, as discussed above, animal studies indicate that RF radiation may both promote and initiate cancer. In a review, the Hardell group concluded that:

"There is clear evidence that RF radiation causes cancer/tumor at multiple sites, primarily in the brain (glioma) and head (acoustic neuroma). There is also evidence of an increased risk of developing other tumor types. The results are similar in both the NTP studies (19, 20) and the Ramazzini Institute findings (34). Based on the IARC preamble to the monographs, RF radiation should be classified as Group 1: The agent is carcinogenic to humans" [19].

In a note published by ICNIRP in 2018 it was claimed that the histopathological evaluation in the NTP study was not blinded as to exposure status [112]. This was rebutted by one of those responsible for the NTP study [113]. However, it seems to have had no impact on the ICNIRP evaluation [48]. ICNIRP claims that the animal studies "do not provide evidence that radiofrequency EMFs are carcinogenic," while an independent peer review of the NTP data concluded that this study provided 'clear evidence of carcinogenic activity', see Table 4 in a comment on the NTP study [19]. A comprehensive discussion of the ICNIRP evaluation was published by Melnick as a correspondence with "focuses on ICNIRP's false claims about the methodology, interpretation, and relevance of the National Toxicology Program studies on cell phone radiation" [114]. This included misleading statements by ICNIRP on e.g., the pathology review procedure, rat survival rates, multiple comparisons, but also excluding discussion of other end points such as DNA strand breaks in the brain cells, and increased incidence of cardiomyopathy. Melnick concluded that "ICNIRP should promote precautionary advice for the general public rather than trying to justify their decision to dismiss findings of adverse health effects caused by RF-EMFs and thereby retain their 20+ y-old exposure guidelines that are based on protection against thermal effects from acute exposure". In the response, ICNIRP seemed not to make a serious scientific rebuttal of the statements by Melnick "except for one minor issue", i.e., the description of the NTP study as "whole of life" rather than "most of life" [115].

3.2. Brain tumor risks from mobile phone use

Regarding epidemiological studies first a study by Martin Röösli et al. [116] is cited by ICNIRP. Röösli is, as mentioned earlier, both member of the ICNIRP commission, the WHO 2014 external experts and the SSM experts. The article has several limitations. The results on use of cordless phones as risk factor for brain tumors are not discussed. Regarding glioma risk all results on cumulative use of wireless phones were not discussed and ipsilateral or contralateral use in relation to tumor localization in the brain were omitted from the meta-analyses. These results are important and have shown a consistent pattern of increased risk.

There were several other limitations in the article [116], such as including the Danish cohort study [90] in the meta-analyses. As discussed above, the study has severe errors of exposure classification and was therefore evaluated to be uninformative regarding carcinogenesis in the IARC 2011 evaluation [10] including Martin Röösli as one participating member.

Regarding the thirteen country Interphone study on glioma [14] and acoustic neuroma [15] ICNIRP concludes that the studies do "…not provide evidence of an increased risk", which is not correct [48]. On the contrary regarding glioma cumulative call-time of mobile phones ≥1,640 h resulted in OR = 1.40, 95 % CI = 1.03–1.89, increasing to OR = 1.87, 95% CI = 1.09–3.22 for glioma in the temporal lobe, the most exposed part of the brain. Ipsilateral mobile phone use yielded OR = 1.96, 95% CI = 1.22–3.16 for all glioma, cumulative use ≥1,640 h. Furthermore, a statistically significant increased risk for glioma was seen in the group 2–4 years for regular use, with 1–1.9 years use as reference category, OR = 1.68, 95% CI = 1.16–2.41, see Appendix 2 [14]. The highest OR was seen in the 10+ years category for regular use, OR = 2.18, 95% CI = 1.43–3.31.

In parts of Interphone, RF radiation dose was estimated as total cumulative specific energy (TCSE; J/kg) absorbed at the tumor's estimated center [117]. The risk increased with increasing TCSE 7+ years before diagnosis, OR = 1.91, 95% CI = 1.05 - 3.47 (p-trend = 0.01) in the highest quintile. Comparing with glioma in other parts of the brain, increased ORs were found for tumors in the most exposed part of the brain in those with 10+ years of mobile phone use, OR = 2.80, 95% CI = 1.13 - 6.94.

Similar results were reported by Grell et al. [118]:

"we found a statistically significant association between the intracranial distribution of gliomas and the self-reported location of the phone…Taken together, our results suggest that ever using a mobile phone regularly is associated with glioma localization in the sense that more gliomas occurred closer to the ear on the side of the head where the mobile phone was reported to have been used the most".

Canadian data from the Interphone Study were evaluated separately [108]. For glioma, when comparing those in the highest quartile of use (>558 lifetime hours) to those who were no regular users, the OR was 2.0, 95% CI = 1.2 - 3.4. After adjustment for selection and recall biases somewhat higher OR was found, 2.2, 95 % CI = 95% CI = 1.3 - 4.1, indicating that such bias did not cause the results.

Also for acoustic neuroma, the Interphone study yielded statistically significant increased risk. Thus, ipsilateral cumulative mobile phone use > 1,640 hours gave OR = 2.33, 95 % CI = 1.23-4.40 [15].

Regarding the Hardell group studies ICNIRP [48] writes: "…a set of case-control studies from the Hardell group in Sweden report significantly increased risks of both acoustic neuroma and malignant brain tumors already after less than five years since the start of mobile phone use, and at quite low levels of cumulative call time." No reference is given to the studies, indicating they have not been seriously evaluated. ICNIRP's writing is not consistent with what the studies reported. In the shortest latency time >1- 5 years period overall mobile phone use yielded for glioma OR = 1.2, 95 % CI = 0.98-1.5 increasing to OR = 2.3, 95 % CI = 1.6-3.4 in the latency period > 20 years (p trend = 0.01). Similar results were found for cordless phones although based on low numbers in the longest latency period. The lowest quartile of cumulative wireless phone use gave OR = 1.2, 95 % CI = 0.9-1.4 increasing to OR = 2.0, 95 % CI = 1.6-2.6 in the fourth quartile (p trend < 0.0001) [7]. Thus, as the published results show no statistically significant increased risk was found in total in the shortest latency group contrary to what ICNIRP stated, although somewhat higher risk was found for ipsilateral use.

For acoustic neuroma, the Hardell group reported use of wireless phone (mobile and/or cordless phone) with latency time >1-5 years in total OR = 1.2, 95 % CI = 0.8-1.6 increasing to OR = 4.4, 95 % CI = 2.2-9.0 (p trend = 0.003) for latency > 20 years [8]. The risk increased with cumulative use of wireless phone; first quartile OR = 1.2, 95 % CI = 0.8-1.7 and fourth quartile OR = 2.2, 95 % CI =1.5 – 3.4, p trend = 0.03. Thus, the results were similar as for glioma. These results were dismissed by ICNIRP.

In addition, ICNIRP claims that the Hardell group results may be caused by recall bias. For meningioma no statistically significant increased risk was found in the same study. Using meningioma cases as "controls" (the comparison entity) still yielded statistically significant increased risk for glioma and mobile phone use; ipsilateral use OR = 1.4, 95 % CI = 1.1-1.8, contralateral OR = 1.0, 94 % CI = 0.7-1.4 and for cordless phone use ipsilateral OR = 1.4, 95 % CI = 1.1-1.9, contralateral OR = 1.1, 95 % CI = 0.8-1.6 [7]. Similar results were found for acoustic neuroma using meningioma cases as the comparison group [8]. These results clearly show that the increased risks for glioma and acoustic neuroma were not caused by recall bias.

The CERENAT study by Coureau et al. [16] was omitted by ICNIRP. The study strengthened the evidence of increased risk for glioma associated with mobile phone use. Life-long cumulative duration ≥896 h gave OR=2.89, 95% CI 1.41 - 5.93 for glioma. Number of calls ≥18,360 gave OR=2.10, 95% CI 1.03 - 4.31. Higher risks were obtained for the highest exposed area, (temporal tumor), as well as occupational and urban mobile phone use. The Danish cohort study on mobile phone use with serious methodological limitations was however discussed in ICNIRP 2020, adding to the no-risk paradigm.

Furthermore, ICNIRP claims that "Studies of other types of tumors have also not provided evidence of an increased tumor risk in relation to mobile phone use. Only one study is available on mobile phone use in children and brain tumor risk. No increased risk of brain tumors was observed." This is yet another incorrect statement [93]. The CEFALO study, as discussed previously, showed increased risks in spite of methodological shortcomings.

3.3. Thyroid cancer

In 2016 the Hardell group published increasing incidence of thyroid cancer in the Nordic countries especially during the last two decades [119]. The thyroid gland is a target organ for RF radiation from smartphones, which was discussed as an etiologic factor. A case-control study on mobile phone use suggested an increased risk for thyroid cancer associated with long-term use [120]. The same material was used to study genotype-environment interaction between single nucleotide polymorphism (SNPs) and mobile phone use [121]. The study showed that mobile phone use increased the risk for thyroid cancer when genetic variants were present within some genes. It was concluded that pathways related to DNA repair may be involved in the increased risk. The study was published online 6 December 2019, that is well before the ICNIRP 2020 publication. ICNIRP omitted completely to discuss the increasing incidence of thyroid cancer and the association with mobile phone use. The statement by ICNIRP of no risk for other tumor types is not correct. The increasing incidence of thyroid cancer in the Nordic countries is confirmed in our recent publication [122].

3.4. Brain tumor incidence

Another example by ICNIRP that misguides the reader is the statement "trends in brain cancer incidence rates from a large number of countries or regions…have not found any increase in the incidence since mobile phones were introduced." This is not correct. Philips et al. [123] reported a statistically significant increasing incidence of glioblastoma multiforme in UK during 1995-2015. Similar results were published from USA [124]. In Sweden, the Hardell group published increasing rates of brain tumors based on the Swedish National Inpatient Register and the Causes of Death Register [125]. The same group also published an increasing incidence of brain tumors in the Swedish Cancer Register [126]. ICNIRP seems to have overlooked facts that would contradict their claim that the results showing brain tumor risk are "not consistent with trends in brain cancer trends".

3.5. Transmitters, base stations and cancer

According to ICNIRP, studies on exposure to environmental RF radiation "have not provided evidence of an increased cancer risk either in children or in adults". No references to that statement are given. In a review by Khurana et al. [127] two of three studies reported increased incidence of cancer at a distance < 350 m [128] or < 400 m [129] from a base station. Dode et al. [130] reported increased cancer mortality in an area within 500 m from a base station in Belo Horizonte, Brazil. A study from Taiwan found a statistically significant increased risk of all neoplasms in children with higher-than-median RF radiation exposure to mobile phone base stations [131]. A cause-effect relationship between RF radiation in occupational and military settings, mainly communication equipment and radar, and hematolymphatic malignancies was reported by Peleg et al. [18]. They concluded that available research "make a coherent case for a cause-effect relationship and classifying RFR exposure as a human carcinogen (IARC group 1)". DNA damage and oxidative stress were associated with living in a vicinity of base stations in a study from India which is also of interest in this context [132]. It would have been pertinent for ICNIRP to review the literature.

There are also studies showing increased risk for childhood leukemia from RF transmitters. One of the authors of the ICNIRP 2020 guidelines, commission member Martin Röösli, stated at a seminar organized by SSM in 2016 that until 2003 all but one results on transmitters had shown increased risk for childhood leukemia: "it was quite impressive that [for] almost all the studies for different type of leukemias basically they reported significantly increased risk. So it was not a random sample of risk estimates. All but one risk estimates were above 1" [133]. This is in obvious contrast to the claim in ICNIRP 2020.

4. Conflicts of Interests

The conclusion by ICNIRP is not objective and lacks scientific credibility according to a research report that investigated ICNIRP commissioned by two European Parliament Members published in June 2020 [58]. Industry funding has been found to influence the results on research on RF radiation and health effects. However, ICNIRP does not take this into account although ICNIRP members themselves have reported that industry-funded scientific research seems to influence the results by reporting less findings showing adverse health effects of EMF compared to independent research [134].

The composition of ICNIRP is very one-sided according to the EU report [58]:

"ICNIRP has been, and is still, dominated by physical scientists… ..As one can read in the 45 portraits of the members of the ICNIRP commission and of the Scientific Expert Group (SEG), they all share the same position on the safety issues: non-ionising radiation poses no health threats and the only effects it has are thermal".

The EU report [58] pointed to the fact that ICNIRP's chairman Eric van Rongen, in 2016 invited the industry organization ICES to comment and thereby influence the upcoming ICNIRP 2020 guidelines [48]. The report concludes that it is:

"clear from ICES minutes that ICNIRP worked very closely with IEEE/ICES on the creation of the new RF safety guidelines that were published in March 2020. And this implies that large telecom-companies such as Motorola and others, as well as US military, had a direct influence on the ICNIRP guidelines, which are still the basis for EU-policies in this domain".

The EU report [58] also highlights several ICNIRP experts' financial ties to the industry. As described in that report, it should be noted that for example the European Food and Safety Authority (EFSA) considers conflict of interests as "any situation where an individual has an interest that may compromise or be reasonably perceived to compromise his or her capacity to act independently and in the public interest in relation to the subject of the work performed at EFSA". Apart from the telecom industry funding of the WHO EMF project, while it was led by ICNIRP's first chairman Michael Repacholi [74] (1996-2006), the EU report documents that "the majority of ICNIRP-scientists did perform research partly funded by industry".

As cited in the EU Report [58], Professor David Carpenter, Environmental Health Sciences at the University of Albany, USA, considers the "perversion that can result due to conflicts of interests" to be "one of the greatest problems in scientific discovery…When funding for scientists comes from an organization or corporation with desires to present a clean bill of health to the public, there is strong motivation to give the funder what they want, if only to continue receipt of funding."

To act both on behalf of ICNIRP to set guidelines supposed to protect against harmful health effects of RF radiation, and at the same time evaluate the health risks representing other organizations, may constitute a conflict of interest, i.e. according to the opinion of the Ethical board of the Karolinska Institute, Stockholm, Sweden. Many of the ICNIRP commission and SEG members act on behalf of several organizations thereby evaluating their own ICNIRP guidelines validity on behalf of other organizations. This kind of conflict of interest adds to those in terms of telecom funding and connection to ICES, see Table 1 [24, 71, 72, 86, 135-146].

5. Guidelines for RF Radiation Exposure

The new ICNIRP 2020 guidelines were developed with 5G in mind, especially considering frequencies that are higher to the presently used mobile phone communications. ICNIRP recognizes citizens' concerns regarding safety of 5G, however the new guidelines show no reduction of safety limits. The premise for safeguarding human health has remained the same – to avoid thermal effects. ICNIRP's 2020 guidelines [48] are based, like in 1998 [53], only on thermal effects, i.e. the RF radiation from mobile communications devices can be high as long as it causes no tissue heating. This may be problematic for mm waves as the radiation can cause heating effects on the surface of the skin. A systematic review on 5G safety limits based on thermal dose concluded that: "The results also show that the peak-to-average ratio of 1,000 tolerated by the International Council on Non-Ionizing Radiation Protection guidelines may lead to permanent tissue damage after even short exposures, highlighting the importance of revisiting existing exposure guidelines" [147]. Furthermore, some organs are more susceptible to RF radiation damage so local dosimetry is more appropriate for characterizing organ-specific risk [10].

Currently the mobile communications reside on frequencies up to 2,600 MHz band, with some minor exceptions beyond that frequency. 5G frequencies are expected to be using bands all over the higher radiofrequency spectrum, including previous 2G and 3G bands. Main 5G frequencies, however, will be at 3.4 to 4.2 GHz. Later, millimeter waves will also be deployed to provide 5G services, these are expected to reside at frequencies of 24-28 and 39 GHz. Millimeter wave base stations are expected to cover mainly high public density areas, such as city squares, transportation hubs, business and shopping centers and other public areas.

With the new reference levels [48] ICNIRP differentiates whole body exposure and exposure to small areas of the body introducing two separate classes of reference levels. ICNIRP grants higher exposure when assessing compliance by reference values; basic restrictions however have remained the same. ICNIRP claims, that this is because of better scientific understanding with respect to the 1998 guidelines. In Table 4 we compare ICNIRP reference levels between the 1998 [53] and the 2020 guidelines [48]. The calculated values are for arbitrary frequencies per each designated band; mobile communications frequency bands differ from region to region. Table 4 characterizes bands used in most European countries.

In their 1998 guidelines, at frequencies over 10 MHz, the reference levels are based on electric and magnetic field strengths for the whole-body SAR basic restrictions, derived by computer simulations and experimental data [53]. The 2020 guidelines introduce reference levels for local exposure [48]. In 2020 whole body reference levels, the averaging time has been increased from 6 min to 30 min, which ICNIRP argues is to better match the time taken for body core temperature to rise [48].

Frequency (MHz)	Example usage	ICNIPR 1998 [53] reference level, 6 min	ICNIPR 2020 [48] reference levels, whole body exposure, 30 min	ICNIPR 2020 [48] reference levels, local exposure, 6 min
800	LTE	4	4	18.2
900	GSM, UMTS	4.5	4.5	20.1
1,800	GSM	9	9	36.6
1,900	DECT	9.5	9.5	38.3
2,100	UMTS	10	10	40
2,400	WiFi 2G	10	10	40
2,600	LTE	10	10	40
3,500	5G, WiMax	10	10	40
5,500	WiFi 5G	10	10	40
26,000	5G	10	10	30.9

Table 4: Comparison of ICNIRP 1998 and 2020 reference levels across common mobile communication frequencies, time averaged (W/m²).

The ICNIRP 2020 [48] reference levels are based on time averaged exposure over 6 min or 30 min, see Table 4. However, supra-additive effects between pulses from different RF radiation sources may give much higher peak radiation from short time pulses than the power density average. Using time averaging in reference values, as in the ICNIRP guidelines, definitely underestimates the risk.

Year	Power Density Limit (μW/m²)	Name	Description
1966	100,000,000	ANSI C95.1 [149]	Based on thermal effects and 0.1-hour (or 6 minute) averaging time.
1991	10,000,000	ANSI/IEEE C95.1-1991 [150]	Based on thermal effects.
1996	10,000,000 5,800,000	FCC [151]	USA: 5,800,000 averaged over a 30-minute period (869 MHz), previously recommended in 1986 by NCRP; 10,000,000 for PCS frequencies (1.85-1.99 GHz).
1998	10,000,000 9,000,000 4,500,000	ICNIRP [53]	10,000,000 for 2–300 GHz 9,000,000 for 1800 MHz and 4,500,000 for 900 MHz averaged over 6 min.

2001	1,000	Salzburg Resolution [152]	
2001	100	EU Parliament STOA 2001 [153]	
2002	1	New Salzburg Precautionary Exposure Limit Indoor [154]	Maximum indoor exposure recommendation for GSM base stations proposed by the Public Health Office of the Government of Salzburg.
2009	See 1998	ICNIRP [54]	Confirmation of ICNIRP 1998.
2012	3-6	Bioinitiative 2012 Recommendation [44]	
2016	0,1-100	Europa EM EMF Guidelines [41]	For frequencies between GSM 900 to WiFi 5,6 GHz depending on sensitivity, night time or daytime exposure.
2020	400 MHz: 10,000,000 800 MHz: 18,200,000 1,800 MHz: 36,600,000 2,000 MHz: 40,000,000 6 GHz: 40,000,000 60 GHz: 26,600,000 300 GHz: 20,000,000	ICNIRP 2020 [48]	General public, local exposure, averaged over 6 min. For whole body exposure see Table 4.

Table 5: Guidelines by different organizations for radiofrequency radiation in µW/m^2.

In a recent review, average exposure limit was suggested to be considerably lower, 0.1 V/m; 26.5 µW/m^2 [148]. This guideline is comparable with the BioInitative Report from 2012 [44] with a scientific benchmark of 30-60 µW/m^2, and for chronic exposure to sensitive persons and children 3-6 µW/m^2. The EUROPAEM EMF guidelines published daytime RF radiation exposure to be 10-1,000 µW/m^2, nighttime 1-100 µW/m^2, and for sensitive persons 0.1-10 µW/m^2 [41]. All these guidelines by independent research groups without conflicts of interest are very much lower than the ICNIRP guidelines. These lower guidelines are aimed at preventing health effects and hazards, Table 5 [41, 44, 48, 53, 54, 149-154].

6. Discussion

As a general rule ICNIRP, WHO, SCENIHR and SSM have for many years dismissed available studies showing harmful effects from non-thermal RF exposure and have based their conclusions mainly on studies showing no effects. Results showing risk are criticized, disregarded or not even cited while studies showing no risks are accepted as evidence of no risk in spite of severe methodological problems. Many statements by these agencies are misleading and not correct. They are easily rebutted by reading the relevant publications.

In fact, these activities are not in line with prevention of health hazards. Previously the precautionary principle in cancer prevention was discussed exemplified by e.g. asbestos, certain pesticides and RF radiation [155, 156]. It was noted that cancer prevention is usually very cost-effective. In a recent article we gave historical examples on lost opportunities based on early warnings with RF radiation as one more recent example [157].

In 2018 there was a call to dismantle ICNIRP and replace the organization with independent scientists [158]: "ICNIRP's mandate to issue exposure guidelines needs to be seriously questioned. ICNIRP is not independent of industry ties as it claims… Its opinions are not objective, not representative of the body of scientific evidence, but are biased in favor of industry."

The EU report investigating ICNIRP concluded in June 2020 that "for really independent scientific advice we cannot rely on ICNIRP." [58].

Our review reveals, with focus on cancer risks, an almost systematic downplaying of health risks from RF radiation by a group of persons that dominate the expert evaluations, see Table 1. Many of them reappear in several of these organizations' expert groups and also in other groups not described in this paper. One striking example is ICNIRP's chairman Eric van Rongen who also appeared in the WHO core group of six experts 2014 as well as one of SSM's eight experts and SCENIHR's nine experts in 2009 as well as secretary of the Health Council of the Netherlands expert group [159]. Another example is Maria Feychting, ICNIRP member since 2000, who was one of WHO's six core group experts behind the WHO 2014 draft, secretary of the SSM expert group evaluations 2003-2010, on the AGNIR (UK) expert group from 2009 and a Norwegian expert group in 2012 [160]. A third example is Martin Röösli, member of ICNIRP, the WHO external experts for the WHO draft 2014, the SSM expert group since 2010 and a Swiss expert group [99].

Our review also notes that there is a clear relationship between ICNIRP and ICES, which is dominated by industry representatives. Eric van Rongen, has been a member of ICES since 2000, ICNIRP member since 2001 and elected chair of ICNIRP in 2016, vice chair since 2020. From ICES annual report 2016 it was reported that:

"The new ICNIRP Chairman and one of the new members of the 14 member committee are also ICES members and ICNIRP is now willing to discuss harmonization of the exposure limits found in IEEE Stds C95.1TM-2005 and C95.6TM-2002 and the ICNIRP Guidelines. At a June 2016 Mobile Manufacturers Forum Workshop in Ghent, Belgium, the new ICNIRP Chairman, Dr. van Rongen, presented "ICNIRP's proposed HF guidelines" and extended an invitation to ICES to comment on the proposed guidelines. TC95 formed a 19 member task group to draft a document to comment on the ICNIRP proposed guidelines. The document was circulated to the TC95 membership for comment and a final document submitted to ICNIRP in time for discussion at the ICNIRP September meeting." [56].

The TC 95 committee's objective is "Development of standards for the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz". These standards are based on the same scientifically invalid approach as the ICNIRP guidelines. In this TC95 committee, in which many members come from the military or the telecom industry, or are consultants to them, ICNIRP's chairman Eric van Rongen, Michael Repacholi, ICNIRP's first chairman and leader of the WHO EMF project 1996-2006, Theodoros Samaras (chairman SCENIHR) and Mats-Olof Mattson, Chairman SCENIHR 2009 and member of ICNIRP, are also found.

All these expert groups dominated by ICNIRP consequently reach similar conclusions that there are no health effects below ICNIRP guidelines. No representative from the scientific community that is of the opinion that there is increasing evidence of health risks below the ICNIRP guidelines, e.g. as expressed in the EMF Scientists Appeal [24], has ever been a member of the expert groups at the WHO, the EU, the SSM or ICNIRP. Certainly scientists who do not discount evidence of health effects from exposure to RF radiation that are observed at exposures below guideline levels should be represented.

The resistance to the abundant and growing scientific evidence on health risks is remarkable and not within the realm of public health. This behavior, due to the ICNIRP influence and dominant role in several other expert groups, is detrimental to human health and leads to suffering and even premature death that could have been prevented. Furthermore, it must be stressed that in general there is lack of persons with medical education and competence not only in the evaluating bodies but also in several research teams producing questionable results as exemplified in this text.

ICNIRP is not representative of the scientific community since it does not include representatives from scientists that agree there is evidence of harmful effects at levels well below ICNIRPs limits although these scientists are in majority in the scientific community [24].

7. Conclusion

ICNIRP's conclusion [48] on cancer risks is: "In summary, no effects of radiofrequency EMFs on the induction or development of cancer have been substantiated." This conclusion is not correct and is contradicted by scientific evidence. Abundant and convincing evidence of increased cancer risks and other negative health effects are today available. The ICNIRP 2020 guidelines allow exposure at levels known to be harmful. In the interest of public health, the ICNIRP 2020 guidelines should be immediately replaced by truly protective guidelines produced by independent scientists.

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Association between estimated whole-brain radiofrequency electromagnetic fields dose and cognitive function in preadolescents and adolescents

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ABSTRACT

Objective: To investigate the association between estimated whole-brain radiofrequency electromagnetic fields (RF-EMF) dose, using an improved integrated RF-EMF exposure model, and cognitive function in preadolescents and adolescents.
Methods: Cross-sectional analysis in preadolescents aged 9–11 years and adolescents aged 17–18 years from the Dutch Amsterdam Born Children and their Development Study (n = 1664 preadolescents) and the Spanish INfancia y Medio Ambiente Project (n = 1288 preadolescents and n = 261 adolescents), two population-based birth cohort studies. Overall whole-brain RF-EMF doses (mJ/kg/day) were estimated for several RF-EMF sources together including mobile and Digital Enhanced Cordless Telecommunications phone calls (named phone calls), other mobile phone uses than calling, tablet use, laptop use (named screen activities), and far-field sources. We also estimated whole-brain RF-EMF doses in these three groups separately (i.e. phone calls, screen activities, and far-field) that lead to different patterns of RF-EMF exposure. We assessed non-verbal intelligence in the Dutch and Spanish preadolescents, information processing speed, attentional function, and cognitive flexibility in the Spanish preadolescents, and working memory and semantic fluency in the Spanish preadolescents and adolescents using validated neurocognitive tests.
Results: Estimated overall whole-brain RF-EMF dose was 90.1 mJ/kg/day (interquartile range (IQR) 42.7; 164.0) in the Dutch and Spanish preadolescents and 105.1 mJ/kg/day (IQR 51.0; 295.7) in the Spanish adolescents.

Abbreviations: RF-EMF, radiofrequency electromagnetic fields.

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Higher overall estimated whole-brain RF-EMF doses from all RF-EMF sources together and from phone calls were associated with lower non-verbal intelligence score in the Dutch and Spanish preadolescents (−0.10 points, 95% CI -0.19; −0.02 per 100 mJ/kg/day increase in each exposure). However, none of the whole-brain RF-EMF doses was related to any other cognitive function outcome in the Spanish preadolescents or adolescents.
Conclusions: Our results suggest that higher brain exposure to RF-EMF is related to lower non-verbal intelligence but not to other cognitive function outcomes. Given the cross-sectional nature of the study, the small effect sizes, and the unknown biological mechanisms, we cannot discard that our resultsare due to chance finding or reverse causality. Longitudinal studies on RF-EMF brain exposure and cognitive function are needed.

1. Introduction

Mobile communication devices such as phones and tablets emit electromagnetic fields (EMF) in the radiofrequency (RF) range of 3 kHz–300 GHz. Exposure to RF-EMF has become ubiquitous because of the enormous increase in the use of mobile communication devices in recent years, especially in late childhood (Birks et al., 2018; Crone and Konijn, 2018; IARC, 2013; ICT, 2017; Sage and Burgio, 2018; van Deventer et al., 2011). Adolescents might be more vulnerable to the potential RF-EMF health effects than adults, especially in their cognitive function, because their brain is still developing (Gerber et al., 2009; Kheifets, 2005; Rice and Barone, 2000).

Studies in mice and rats suggest that exposure to RF-EMF increases the permeability of the blood brain barrier, impairs intracellular calcium homeostasis, alters neurotransmitter regulation, and causes neuronal loss. These reports also show that RF-EMF damages brain tissues like the cerebral cortex (Kim et al., 2017). In addition, studies in humans show both positive and negative cognitive effects after or during exposure to RF-EMF (Barth et al., 2012; Valentini et al., 2010; Vecsei et al., 2018; Verrender et al., 2016). Thus currently evidence is not sufficient to draw any definite biological mechanism. Also, several epidemiological studies have investigated the association between RF-EMF exposure and cognitive function in 5 to 18-year-olds, showing mixed results (Abramson et al., 2009; Bhatt et al., 2017; Foerster et al., 2018; Guxens et al., 2016; Heinrich et al., 2010; Redmayne et al., 2016; Schoeni et al., 2015a, 2015b; Thomas et al., 2010; Zheng et al., 2014). Most of these studies assessed brain RF-EMF exposure only taking into consideration proxies of exposure such as maternal- or self-reported phone calls from mobile or Digital Enhanced Cordless Telecommunications (DECT) (Abramson et al., 2009; Bhatt et al., 2017; Guxens et al., 2016; Redmayne et al., 2016; Schoeni et al., 2015a, 2015b; Thomas et al., 2010; Zheng et al., 2014) and only one cohort study estimated the actual whole-brain dose received from some RF-EMF sources (Schoeni et al., 2015a; Roser et al., 2016; Foerster et al., 2018). This cohort study found that higher whole-brain RF-EMF dose was related to lower figural memory (Foerster et al., 2018; Schoeni et al., 2015a) but not to concentration capacity (Roser et al., 2016) in 12 to 17-year-olds. Patterns of mobile communication devices use are different between ages during adolescence (Eeftens et al., 2018). Therefore, a broader assessment of RF-EMF exposure to the brain by integrating all RF-EMF sources according to usage patterns will result in a more accurate and comprehensive dose estimation.

The aim of this study was to investigate the association between estimated overall and source-specific whole-brain RF-EMF dose and cognitive function in two brain development periods: preadolescence (9–11 years of age) and adolescence (17–18 years of age). We used a recently developed method to estimate whole-brain RF-EMF dose with the advantage of integrating a large number of RF-EMF sources resulting in a more accurate and comprehensive estimation.

2. Methods

2.1. Study design and population

This cross-sectional analysis used data from two population-based birth cohort studies, the Dutch Amsterdam Born Children and their Development (ABCD) Study (www.abcd-study.nl) and the Spanish INfancia y Medio Ambiente (INMA) Project (Guxens et al., 2012) for which we included four INMA sub-cohorts (Valencia, Sabadell, Gipuzkoa, and Menorca). Between 1997 and 2004, depending on the cohort, pregnant women were invited to participate. A total number of 8266 pregnant women for ABCD and 2752 for INMA enrolled and their children have been followed through childhood. RF-EMF exposure and cognitive function were assessed in preadolescents at 9–11 years in ABCD (i.e. Dutch preadolescents) and in the Valencia, Sabadell, and Gipuzkoa sub-cohorts of INMA (i.e. Spanish preadolescents), and in adolescents at 17–18 years in the Menorca sub-cohort of INMA (i.e. Spanish adolescents). We included preadolescents and adolescents with information on RF-EMF exposure and with at least one cognitive test available (n = 1664 (20.1%) Dutch preadolescents, n = 1288 (56.7%) Spanish preadolescents, and n = 261 (54.1%) Spanish adolescents) (Supplementary Figure S1). Informed consent was obtained from all participants as part of the original studies and in accordance with each study's institutional review board.

2.2. Estimated whole-brain RF-EMF dose

We applied an integrative RF-EMF exposure model to estimate whole-brain RF-EMF dose from several RF-EMF exposure sources (Liorni et al., 2020; Luuk van Wel, in press). This model is built using information on the use of mobile communication devices (i.e. near-field RF-EMF sources) and estimations of exposure to environmental RF-EMF sources (i.e. far-field RF-EMF sources).

2.2.1. Near-field RF-EMF sources

Information of the use of mobile communication devices close to the body was collected using maternal-reported questionnaires in the Dutch and Spanish preadolescents and self-reported questionnaires in the Spanish adolescents. Duration of i) use of mobile phone for calling, ii) use of DECT phone for calling, iii) mobile phone use for internet browsing, e-mailing, and text messaging (named other mobile phone uses), iv) tablet use while wirelessly connected to internet, and v) laptop use while wirelessly connected to internet was collected in minutes/day.

Information on the proportion of network use for calling, and type of screen activity while other mobile phone uses, laptop use, or tablet use was not collected. Based on the mobile phone use in preadolescents, adolescents, and young adults in Europe collected in the same period of time than in our study, we assumed a proportion of 35% 2G calls, 65% 3G calls, and no hands-free devices use (Langer et al., 2017). During the timeslots where preadolescents and adolescents were using tablet or laptop while wirelessly connected to internet, we assumed that preadolescents and adolescents were 40% of that time playing video games, 40% of that time streaming video, and 20% of that time browsing the internet or checking social media based on expert opinion.

2.2.2. Far-field RF-EMF sources

We estimated RF-EMF exposure to different environmental RF-EMF sources (mobile phone base stations, FM radio and TV broadcast antennas, mobile phones, DECT phones, and WiFi) based on the micro-environments where preadolescents and adolescents spend most of their time such as home, school, commuting, and outdoors.

To estimate RF-EMF exposure from mobile phone base stations at home, a validated 3D geospatial radio wave propagation model NISMap was used (Bürgi et al., 2009; Beekhuizen et al., 2013, 2014; Huss et al., 2015). In brief, NISMap computes the field strengths of mobile phone base stations for any location in 3D-space using detailed characteristics of the antennas and the 3D geometry of the urban environment. The model has been validated with outside, inside, and personal measurements showing reliable rank-order predictions (Beekhuizen et al., 2014, 2013; Martens et al., 2015). We assessed the emission of the three mobile phone communication systems in use at the time of the study (GSM900, GSM1800, and UMTS) using a country-wide mobile phone base stations data set from 2015. These systems operated in the following downlink frequency bands: 925–960 MHz, 1805–1880 MHz, and 2110–2170 MHz, respectively. Using the geo-coded address of each participant and the floor level of his/her bedroom at the time of the cognitive function assessment, we computed the RF-EMF exposure from mobile phone base stations at each participant's bedroom.

RF-EMF exposure from mobile phone base stations in the other microenvironments besides home and from the other far-field RF-EMF sources (FM radio and TV broadcast antennas, mobile phones, DECT phones, and WiFi) in all microenvironments was approximated using the average of the personal RF-EMF measurements done over up to 72 h by 56 preadolescents from the Dutch cohort and by 191 preadolescents and 53 adolescents from the Spanish cohort (Birks et al., 2018).

2.2.3. Integrated RF-EMF exposure model

We applied an integrated RF-EMF exposure model to estimate overall and source-specific whole-brain RF-EMF doses (Liorni et al., 2020; Luuk van Wel, in press). Briefly, the model combines three types of information: i) the estimated ratio of the absorbed power to the mass in which it is absorbed of each specific RF-EMF source which already takes into account the protection role of the head and individual characteristics (e.g. sex, age, height, weight), known as specific absorption rate (SAR, in Watts (W)/kilogram (kg)), normalized to 1 W output power(Liorni et al., 2020), ii) the output power of each RF-EMF source (in W), and iii) the daily duration of use or exposure to each RF-EMF source (in minutes (min)/day). First, the model estimated a specific RF-EMF dose (millijoules (mJ)/kg/day) to each RF-EMF source (mobile phone calls, DECT phone calls, other mobile phone uses, tablet use, laptop use, and far-field RF-EMF sources) as follows:

$$\text{Specific whole-brain RF-EMF dose}_{source} = \left(\mathbf{SAR}_{source} x \ \mathbf{Output\ power}_{source} x \ \mathbf{Duration}_{source}\right) \quad \text{Equation 1}$$

Then, overall whole-brain RF-EMF dose was calculated combining the specific RF-EMF doses of all RF-EMF sources:

$$\text{Overall whole-brain RF-EMF dose} = \sum_{source}\left(\mathbf{SAR}_{source} x \ \mathbf{Output\ power}_{source} x \ \mathbf{Duration}_{source}\right) \quad \text{Equation 2}$$

Moreover, we combined the RF-EMF sources in three groups that lead to different exposure patterns to the brain: i) high RF-EMF doses from peak exposures very close to the head but for short periods of time (i.e. mobile and DECT phone calls, named phone calls), ii) low RF-EMF doses that might mainly represent a variety of social or individual factors related to the use of mobile communication devices (i.e. mobile phone use for internet browsing, e-mailing, and text messaging, tablet use, and laptop use while wirelessly connected to the internet, named screen activities), and iii) low RF-EMF doses received continuously throughout the day (i.e. far-field sources such as mobile phone base stations, FM radio and TV broadcast antennas, and WiFi, named far-field).

The output power depends on the characteristics of the network. We assumed that other mobile phone uses, laptop use, and tablet use while wirelessly connected to the internet occur using WiFi at 2.4 GHz and that WiFi data transfer rates were 54 Megabits per second. Moreover, the brain SAR depends on the relative distance to the device. SAR values were estimated in an previous study (Liorni et al., 2020) and we used averaged SAR values from different available positions of use to obtain one SAR value per device and activity that could be inserted in Equation (1) and Equation (2).

2.3. Cognitive function

Cognitive function measured as non-verbal intelligence, information processing speed, attentional function, cognitive flexibility, working memory, and semantic fluency were assessed at 9–11 years in the Dutch and Spanish preadolescents or at 17–18 years in the Spanish adolescents using a battery of validated neurocognitive tests (Table 1).

2.3.1. Non-verbal intelligence

Non-verbal intelligence describes thinking skills and problem-solving abilities that do not fundamentally require verbal language production and comprehension (Anagnostou et al., 2013). In this study, non-verbal intelligence was assessed using a Raven-like test (Vodegel Matzen et al., 1994) in the Dutch preadolescents and the Raven test (John and Raven, 2003) in the Spanish preadolescents. These tests consist of a matrix of figural patterns in which one pattern is missing. Preadolescents must choose a potential match for the missing pattern from different given options. Over the course of the test, participants were exposed to different matrices, and the task consists on discovering the rules governing the configuration of the patterns and to apply them to select the correct option. The number of correct responses were collected for each cohort, converted into standard deviation units (z-score equals raw score subtracted from mean and divided by the standard deviation) and then standardized to a mean of 100 and a standard deviation of 15 (new score = 100 + 15 x z-score) to homogenize the scores between cohorts. A lower score indicates lower non-verbal intelligence.

2.3.2. Information processing speed

Information processing speed is how quick an individual can identify, discriminate, integrate, make decisions, and respond to visual and verbal information (Holdnack et al., 2016). In this study, information processing speed was measured by the coding and the symbol search subtests of the Wechsler Intelligence Scale for Children IV (WISC-IV) in the Spanish preadolescents (Kaufman et al., 2006). In the coding subtest, a clue in which 9 numbers from 1 to 9 are paired with 9 different symbols is given to the preadolescents. Then, preadolescents had to go through a random list of numbers between 1 and 9 and place the corresponding symbol below each number based on the clue given to them at the beginning. They had to do it as fast as possible during a maximum of 120 s. In the symbol search subtest, several rows of 7 symbols, divided in 2 target symbols on the left and 5 other symbols on the right are given to the preadolescents. The preadolescents had to go through each row and identify if one of the 2 target symbols on the left is repeated in the group of 5 symbols on the right as fast as possible during a maximum of 120 s. Scores of the coding and symbol search subsets were summed to form the processing speed index. The processing speed index was converted into standard deviation units (z-score equals raw score subtracted from mean and divided by the standard deviation) and then standardized to a mean of 100 and a standard deviation of 15 (new score = 100 + 15 x z-score). A lower processing speed index indicates lower information processing speed.

2.3.3. Attentional function

Attentional function is the capacity to focus on a stimulus over a period of time while ignoring other perceivable information (White et al., 2009). In this study, attentional function was assessed in the Spanish preadolescents and adolescents using the Attention Network Task (Fan et al., 2002). The test consists of responding to whether a central fish placed in the screen is pointing to the left or to the right by

Table 1
Details of cognitive function assessment.

Cognitive ability	Test	Outcome of interest name	Outcome of interest calculation	Interpretation	Cohort and age
Non-verbal intelligence	Raven's Test	Non-verbal intelligence score	Number of correct items	↓n of correct items; lower non-verbal intelligence	Spanish preadolescents
	Raven-like test				Dutch preadolescents
Speed of information processing	Coding and symbol search subtests of the WISC -IV	Processing speed index	Coding subtest score + symbol search subtest score	↓index; lower speed of information processing	Spanish preadolescents
Attentional function	Atentional Network Task	Hit Reaction Time	Mean response time for all correct answer (ms)	↑HRT and ↑omission/commission errors; inattention	
		Hit Reaction Time (Standard Error)	Standard error of the reaction time for responses to all correct answers	↓HRT and ↑omission/commission errors; impulsivity	
		Omission errors	Number of times the individual did not respond to a stimuli	↑HRT(SE); inattention	
		Commission errors	Number of times that the individual respond wrongly		
Visual attention	Trail Making Test-part A	Visual attention score	Time to complete the task (ms)	↑time; lower visual attention	
Cognitive flexibility	Trail Making Test-part B	Task switching score	Time to complete the task (ms)	↑time; lower task switching capacity	
	Trail Making Test-part A and Trail Making Test-part B	Task shifting score	(Time to complete the TMTB (ms) – Time to complete the TMTA (ms))/Time to complete the TMTA (ms))	↑score; lower task shifting capacity	
Semantic Verbal Fluency	Semantic Verbal Fluency Test	Semantic verbal fluency score	Number of words of animals that do not repeat	↓n of words; lower semantic fluency	Spanish preadolescents and adolescents
Working memory	N-back	Hit Reaction Time	Mean response time for all correct answer (ms)	↑HRT and ↓d'; lower working memory	
		d'	z (hit rate) – z (false alarm rate)		

ms, milliseconds; TMTA, Trail Making Test Part A; TMTB, Trail Making Test Part B; WISC-IV, Wechsler Intelligence Scale for Children-IV.

pressing the corresponding button on the mouse while ignoring all the flanking fishes (i.e. the other 4 fish located to the left and right of the central fish), which point in either the same or opposite direction than the central fish. Our primary outcomes of interest were the hit reaction time (HRT, the mean response time in milliseconds (ms) for all correct answer), the standard error of the HRT (HRT(SE), the standard error of the reaction time for responses to all correct answers), the number of omission errors (the number of times the individual did not respond to a stimuli), and the number of commission errors (the number of times that the individual respond incorrectly). Higher omission errors reflect poorer orientation and a slower response. Higher omission errors and/or commission errors together with a fast HRT reflect impulsivity while higher omissions and/or commission errors together with a slow HRT indicate inattention. HRT(SE) is a measure of the consistency of the response time, such that higher values indicate inattention.

2.3.4. *Visual attention*

Visual attention mediates the selection of relevant and the filtering out of irrelevant information from cluttered visual scenes (McMains and Kastner, 2009). Visual attention was assessed in the Spanish preadolescents using the part A of the Trail Making Test (TMTA) (Tombaugh, 2004). Preadolescents were instructed to draw lines connecting 25 consecutive encircled numbers distributed on a computer screen as quickly and accurately as possible. Time to complete the task (in ms) was recorded and higher (i.e. slower) time to complete the task indicates a lower visual attention (Gaudino et al., 1995).

2.3.5. *Cognitive flexibility*

Cognitive flexibility is the ability to switch between thinking about two different concepts, and to think about multiple concepts simultaneously, and can happen unconsciously (task switching) or consciously (task shifting) (Archambeau and Gevers, 2018). Cognitive flexibility was assessed in the Spanish preadolescents using the TMTA (detailed in the previous paragraph) and the part B of the Trail Making Test (TMTB) (Tombaugh, 2004). In the TMTB preadolescents were instructed to draw lines alternating between 13 encircled numbers and 12 letters (from A to L) in an ascending number-letter sequence (1–A–2–B– etc.) distributed on a computer screen as quickly and accurately as possible. Time to complete the task (in ms) was recorded and higher (i.e. slower) time to complete task B indicates a lower task switching capacity. A task shifting score was calculated as follows: *[TMTB(ms)-TMTA(ms)]/TMTA (ms)]* (Camelo et al., 2019; Tombaugh, 2004). A higher score indicates a lower task shifting capacity.

2.3.6. *Working memory*

Working memory is the retention of a small amount of information in a readily accessible form (Cowan, 2014). Working memory was assessed in the Spanish preadolescents and adolescents using the N-back test (Pelegrina et al., 2015). Participants were required to respond whenever a stimuli (number) was presented on the screen that matched the one presented 3 trials back. Primary outcomes of interest were HRT (the mean response time in ms for all correct answer), and d prima (d') which allows the distinction of signal and noise taking into account the number of correct rejections, the number of false alarms, the number of hits, and the number of misses (Deserno et al., 2012). d' is indicative of accuracy of the performance of the test and higher HRT and lower d' values indicate lower working memory.

2.3.7. *Semantic verbal fluency*

Semantic verbal fluency involves retrieval of words from conceptual memory (Patterson et al., 2011). Semantic fluency was assessed in the Spanish preadolescents and adolescents using the Semantic Verbal Fluency Test (Sauzéon et al., 2004). Participants had to name in 60 s as many words of animals as they could (Ardila, 2020). The outcome is the number of words that do not repeat. Animals were considered valid if their change of gender or age implied a change of word, or if they referred to fantastic or extinct animals, but animals from the same family scored fewer points. Less number of words indicates a lower semantic fluency.

2.4. Potential confounding variables

The potential confounding variables were a *priori* defined with a Directed Acyclic Graph (DAG) according to the existing literature (Hernan, 2006). Maternal educational level (primary or lower (low), secondary (medium), or university or higher (high)), maternal social class based on the international standard classification of occupations (managers and technicians (high), skilled manual/non-manual (medium), or semi-skilled and unskilled (low)), maternal country of birth (country of the cohort, or others), and maternal smoking during pregnancy (yes or no) were assessed at birth of the child. Maternal anxiety and depressive symptoms were assessed at 5 years of the child using the Depression Anxiety Stress Scale (DASS) (Lovibond and Lovibond, 1995) in the Dutch cohort and the Symptom Checklist-90-Revised (González de Rivera et al., 1989) in the Spanish sub-cohorts of Valencia, Sabadell, and Gipuzkoa. Sex of the child was collected at birth, and age, physical activity, weight, and height were collected or measured at the cognitive function assessment. In the Dutch cohort, physical activity was scored by calculating the Metabolic Equivalent (MET) score for the various reported activities using the compendium of physical activities (Ainsworth et al., 2000) and categorized as low/medium (<percentile 80th) or high (≥percentile 80th). In the Spanish cohort, physical activity was collected in minutes of overall physical activity and categorized as low/medium (≤90 min/day) or high (>90 min/day). Body mass index was calculated as weight/height^2.

2.5. Statistical analysis

After checking that all assumptions of the models were fulfilled, we used a linear mixed-effects model with cohort (i.e. ABCD, INMA-Valencia, INMA-Sabadell, and INMA-Gipuzkoa) as random intercept to assess the association between estimated overall and source-specific whole-brain RF-EMF doses and non-verbal intelligence score. We used linear regression models to assess the association between estimated overall and source-specific whole-brain RF-EMF doses and processing speed index, HRT and HRT (SE) of the Attentional Network Task, visual attention score, task switching score, task shifting score, and HRT and d' of the N-back test, and semantic fluency score. We used negative binomial regression models to assess the association between estimated whole-brain RF-EMF doses and omission errors, and commission errors of the Attentional Network Task. All models were adjusted for potential confounding variables specified in the previous section. Additionally, linear and negative regression models were adjusted for INMA subcohort. To assess the influence of the assumptions of the integrated RF-EMF exposure model on our results, we estimated overall whole-brain RF-EMF dose based on two new scenarios slightly modifying our original assumptions and assessed their association with cognitive outcomes in the Dutch and Spanish preadolescents and in the Spanish adolescents. In one scenario (i.e. scenario that lead to a higher RF-EMF exposure), we assumed a proportion of 45% 2G calls, 55% 3G calls, and no hands-free used, and that preadolescents and adolescents were 35% playing video games, 50% streaming video, and 15% browsing the internet or checking social media when using tablet or laptop while wirelessly connected to the internet. In the other scenario (i.e. scenario that lead to a lower RF-EMF exposure), we assumed a proportion of 25% 2G calls, 75% 3G calls, and no hands-free used, and that preadolescents and adolescents were 45% playing video games, 30% streaming video, and 25% browsing the internet or checking social media when using tablet or laptop while wirelessly connected to the internet.

Multiple imputation of missing confounding variables for each cohort/sub-cohort was performed using chained equations where 25 completed datasets were generated and analysed (Nguyen et al., 2017) (Supplementary Table S1). The distributions of the imputed datasets were similar to the non-imputed datasets (data not shown). Of the mother-child pairs recruited initially in the Dutch and Spanish cohorts, Dutch and Spanish preadolescents included in this analysis (n = 1664 and n = 1,288, respectively) were more likely to have had higher weight and gestational age at birth, to have mothers with high level of education and social class at child's birth, and mothers from the country of the cohort, and that had smoked less during pregnancy compared to preadolescents excluded from the Dutch cohort (n = 6227) and from the Spanish cohort (n = 982) (Supplementary Tables S2-S3). Spanish adolescents included in this analysis (n = 261) were more likely to have mothers from high social class and that had smoked less during pregnancy compared to adolescents from the Spanish cohort not included (n = 221) (Supplementary Table S4). Thus, we used inverse probability weighting to correct for loss to follow-up and account for potential selection bias when including only preadolescents or adolescents with available data compared to the full cohort recruited at pregnancy. Variables used to calculate the weights are in Supplementary Table S5.

All analyses were performed using Stata version 15 (StataCorp, College Station, TX).

3. Results

3.1. Descriptive analysis

Dutch and Spanish preadolescents of our population had mothers more likely with high level of education, from high social classes, and from the country of the cohort, while Spanish adolescents had mothers more likely with low level of education and from medium social classes (Table 2). Spanish adolescents had a higher estimated overall whole-brain RF-EMF dose (105.4 mJ/kg/day) than the Dutch and Spanish preadolescents (90.1 mJ/kg/day) (Table 3). For Dutch and Spanish preadolescents, and Spanish adolescents, the primary contributor to the

Table 2
Maternal and individual characteristics of the Dutch and Spanish preadolescents, and Spanish adolescents included in our study population.

	Dutch and Spanish preadolescents (n = 2952)	**Spanish adolescents (n = 261)**
Maternal characteristics		
Educational level at child's birth		
High	60.1	16.7
Medium	27.8	31.3
Low	12.1	52.0
Social class based on occupation at child's birth		
High	54.4	20.8
Medium	23.4	65.9
Low	22.2	13.3
Country of birth (country of the cohort vs. others)	88.6	97.7
Anxiety symptoms at 5 years		
(no symptoms vs. at risk or pathological)	47.3	na
Depressive symptomes at 5 years		
(no symptoms vs. at risk or pathological)	37.9	na
Smoking during pregnancy (yes vs. no)	16.3	32.0
Individual characteristics		
Sex (female vs. male)	50.1	52.2
Age at cognitive function assessment, in years	10.0 (1.2)	17.6 (0.2)
Physical activity at cognitive function assessment (low/medium vs. high)	78.9	68.9
BMI at cognitive function assessment, in kg/m2	17.0 (2.5)	22.5 (3.6)

BMI, body mass index; na, data not available. Values are percentages for categorical variables and mean (SD) for continuous variables.

Table 3
Estimated overall whole-brain RF-EMF doses (mJ/kg/day) and contribution of each source-specific dose to the overall whole-brain RF-EMF dose (mean/overall dose, in %) in the Dutch and Spanish preadolescents, and Spanish adolescents.

Whole-brain RF-EMF doses	Dutch and Spanish preadolescents (n = 2952)		Spanish adolescents (n = 261)	
	Median (IQR)		Median (IQR)	
Overall dose	90.1 (42.7; 164.0)		105.4 (51.0; 295.7)	
Source-specific doses		%		%
Phone calls[a]	24.9 (2.1; 80.6)	70.3	83.6 (33.5; 269.8)	96.0
Screen activities[b]	1.4 (0.6; 2.5)	1.3	1.3 (0.1; 2.4)	0.5
Far-field[c]	13.4 (10.1; 32.9)	28.4	11.2 (11.2; 11.2)	3.5

IQR, interquartile range; RF-EMF, Radiofrequency Electromagnetic Fields; mJ, millijoules; kg, kilograms.
[a] Phone calls refer to mobile and DECT phone calls.
[b] Screen activities refer to screen activities with mobile communication devices including mobile phone use for internet browsing, e-mailing, and text messaging, tablet use, and laptop while wirelessly connected to the internet.
[c] RF-EMF exposure from different environmental RF-EMF sources (mobile phone base stations, FM radio and TV broadcast antennas, mobile phones, DECT phones, and WiFi) from different microenvironments (home, school, commuting, and outdoors).

overall whole-brain RF-EMF dose was phone calls (70.3% in preadolescents and 96.0% in adolescents), followed by far-field sources (28.4% in preadolescents and 4.7% in adolescents), and screen activities (1.3% in preadolescents and 0.5% in adolescents). Overall whole-brain RF-EMF dose was highly correlated with specific whole-brain RF-EMF dose from phone calls ($r = 0.79$ in preadolescents and $r = 0.88$ in adolescents) and specific whole-brain doses had a low correlation between each other (between −0.05 and 0.15 in the Dutch and Spanish preadolescents and between −0.18 and −0.03 in the Spanish adolescents) (Supplementary Table S6). Cognitive outcomes were poorly to moderately correlated with each other in the Dutch and Spanish preadolescents (Supplementary Table S7) and semantic fluency was poorly correlated with working memory in the Spanish adolescents (Supplementary Table S8).

Dutch and Spanish preadolescents having higher overall whole-brain RF-EMF dose, higher dose from phone calls, and higher dose from screen activities were more likely to be older and have mothers from high social class, from foreign countries, and with less anxiety and depressive symptoms (Supplementary Table S9). Dutch and Spanish preadolescents having higher whole-brain RF-EMF dose from far-field sources were more likely to have mothers with a low level of education and from low social class. In the Spanish adolescents, those with higher overall whole-brain RF-EMF dose and higher whole-brain RF-EMF dose from phone calls were more likely to be females and have mothers that smoked during pregnancy (Supplementary Table S10).

3.2. Estimated whole-brain RF-EMF doses and cognitive function

In the Dutch and Spanish preadolescents, higher estimated overall whole-brain and specific RF-EMF dose from phone calls were associated with lower non-verbal intelligence score [-0.10 points (95%CI -0.19; −0.02) per 100 mJ/kg/day increase in each exposure] (Table 4). Specific whole-brain RF-EMF doses from screen activities or from far-field sources were not related to non-verbal intelligence score.

Overall and source-specific whole-brain RF-EMF doses were not associated with information processing speed, attentional function, visual attention, and cognitive flexibility in preadolescents, or with working memory and semantic fluency in the Spanish preadolescents and adolescents (Fig. 1, and Supplementary Tables S11-13). Effect estimates showed both positive and negative associations, although they were far from reaching statistical significance.

Table 4
Association between estimated overall and source-specific whole-brain RF-EMF doses and non-verbal intelligence in the Dutch and the Spanish preadolescents (n = 2952).

Whole-brain RF-EMF doses (Δ100 mJ/kg/day)	B (95% CI)
Overall dose	−0.10 (−0.19; −0.02)
Source-specific doses	
Phone calls[a]	−0.10 (−0.19; −0.02)
Screen activities[b]	−18.13 (−37.09; 0.82)
Far-field[c]	0.27 (−0.11; 0.65)

B, Beta Coefficient; CI, confidence interval; kg, kilograms; mJ, millijoules; RF-EMF, Radiofrequency Electromagnetic Fields.
Linear mixed-effects regression models with cohort (ABCD, INMA-Valencia, INMA-Sabadell, INMA-Gipuzkoa) as random intercept adjusted for maternal educational level at child's birth, maternal social class based on occupation at child's birth, maternal country of birth, maternal anxiety and depressive symptoms at 5 years of the child, maternal smoking during pregnancy, and child sex, age, body mass index, and physical activity at cognitive function assessment.
[a] Phone calls refer to mobile and DECT phone calls.
[b] Screen activities refer to screen activities with mobile communication devices includes mobile phone use for internet browsing, e-mailing, and text messaging, tablet use, and laptop while wirelessly connected to the internet.
[c] RF-EMF exposure from different environmental RF-EMF sources (mobile phone base stations, FM radio and TV broadcast antennas, mobile phones, DECT phones, and WiFi) from different microenvironments (home, school, commuting, and outdoors).

3.3. Sensitivity analysis

Estimated overall whole-brain RF-EMF dose based on the assumptions of the higher-exposure scenario was 98.8 mJ/kg/day (IQR 50.0; 170.6) in preadolescents and 121.9 mJ/kg/day (IQR 55.0; 362.9) in adolescents and of the lower-exposure scenario was 53.4 mJ/kg/day (IQR 27.2; 118.4) in preadolescents and 78.8 mJ/kg/day (IQR 37.2; 216.1) in adolescents (Supplementary Table S14). All association between the new estimated overall whole-brain RF-EMF doses and cognitive function in the Dutch and Spanish preadolescents and in the Spanish adolescents remained materially unchanged (data not shown).

4. Discussion

Our study investigated the relationship of estimated overall and source-specific whole-brain RF-EMF dose with cognitive function in preadolescents and adolescents. We found that higher overall whole-brain RF-EMF dose and specific whole-brain RF-EMF dose from mobile and DECT phone calls were associated with lower non-verbal intelligence in preadolescents. However, none of the whole-brain RF-EMF doses influenced information processing speed, attentional function, visual attention, and cognitive flexibility in preadolescents. Also working memory and semantic fluency were not affected in both preadolescents and adolescents.

The ability to properly estimate the RF-EMF brain dose from several RF-EMF exposure sources represents an important step forward for the evaluation of the potential effects of RF-EMF exposure in health. Previous studies investigated the relationship of RF-EMF exposure with cognitive function. Nevertheless, most of them did not take into account important factors such as the organ of interest (i.e. the brain), RF-EMF sources other than phone calls (e.g. use of tablets and laptops), position of the RF-EMF source in relation to the body, and personal characteristics (e.g. sex, age, weight, and height). All these factors determine that individuals exposed to same amount of RF-EMF receive different doses to specific organs. The whole-brain RF-EMF dose approach is a recently developed method. Indeed, only one previous cohort study has assessed its association with cognitive function in 12–17 years of age preadolescents and adolescents (Foerster et al., 2018; Roser et al., 2016; Schoeni et al., 2015a). In a longitudinal analysis, the authors found that

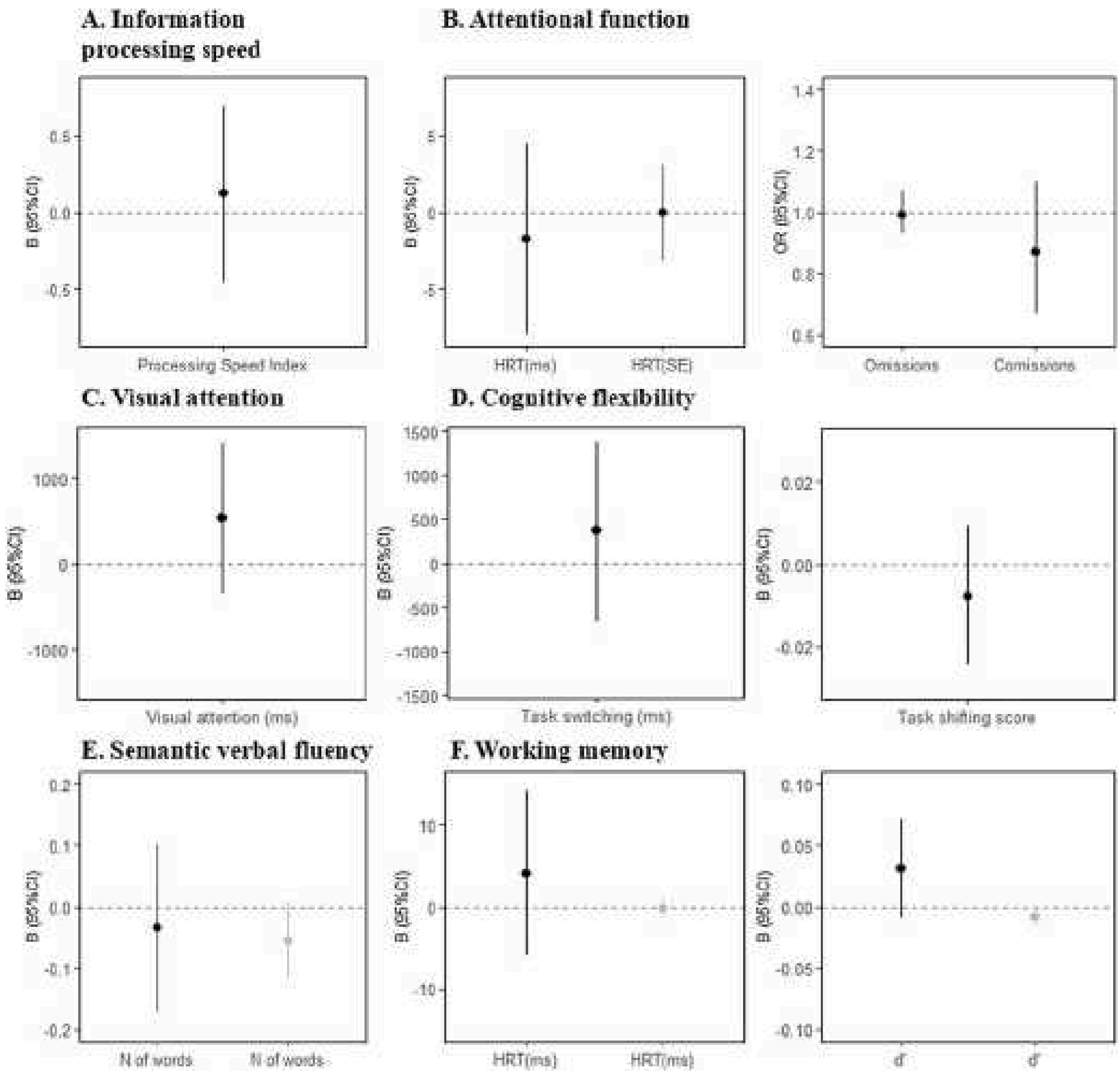

Fig. 1. Association between estimated overall whole-brain RF-EMF dose (per increase of 100 mJ/kg/day) and speed of information processing, attentional function, visual attention, cognitive flexibility, semantic verbal fluency, and working memory in the Spanish preadolescents (black lines, n = 1288) and Spanish adolescents (light grey lines, n = 261).
B, Beta Coefficient; Comissions, commission errors; CI, confidence interval; d', detectability; HRT, Hit Reaction Time (in milliseconds (ms)); HRT (SE), Hit Reaction Time (Standard Error); Omissions, omission errors; OR, odd ratio; TMTA, time to complete part A of the trail making test (in ms); TMTB, time to complete part B of the trail making test (in ms); N of words, number of words. Linear regression models adjusted for maternal educational level, maternal social class based on occupation, maternal country of birth, maternal smoking during pregnancy, child sex, age, body mass index, and physical activity. In preadolescents, linear regression models additionally adjusted for INMA sub-cohort (Valencia, Sabadell, Gipuzkoa) and maternal anxiety and depressive symptoms.

higher whole-brain RF-EMF dose was not associated with concentration capacity (Roser et al., 2016) but was associated with lower figural memory (Foerster et al., 2018; Schoeni et al., 2015a). In a previous study we did not find an association between whole-brain RF-EMF doses and volume alterations in subcortical brain regions involved in memory performance, such as the hippocampus and the amygdala (Cabré-Riera et al., 2020). However, higher RF-EMF exposure induced dendritic remodeling and decrease in viable cells in these subcortical structures in rats (Hussein et al., 2016; Li et al., 2012; Narayanan et al., 2018, 2015, 2010). Although we did not specifically assess figural memory in our study, non-verbal intelligence includes the ability to recognize and remember visual sequences. This ability allows understanding and interpreting the meaning of visual information. Figural memory implies remembering visual information and might be essential to optimally develop non-verbal intelligence, thus we would expect that memory impairments shape deficits in non-verbal intelligence. Also, if there is a true effect of RF-EMF exposure on the brain, as suggested in some experimental studies, cognitive abilities sharing common neural substrates would be similarly affected by RF-EMF exposure. Of note, in our study, we found very small effect estimates in the associations between whole-brain RF-EMF dose and non-verbal intelligence. Therefore, we cannot discard that our results might be due to chance.

No previous studies have assessed the relationship of brain RF-EMF exposure and non-verbal intelligence. Nevertheless, several studies have investigated the association between brain RF-EMF exposure using reported mobile and DECT phone calls, the primary contributors of RF-EMF exposure to the brain (Birks et al., 2018), and other cognitive tasks similar to those included in our study (Abramson et al., 2009; Bhatt et al., 2017; Guxens et al., 2016; Redmayne et al., 2016; Thomas et al., 2010; Zheng et al., 2014). In line with our results, two studies did not show any relationship between number of phone calls and information processing speed (Guxens et al., 2016) or minutes of phone calls with inattention (Zheng et al., 2014) in 5–13 years of age children and preadolescents. However, in contrast to our findings, other studies suggested that higher number of phone calls were related to poorer working memory (Abramson et al., 2009; Thomas et al., 2010), spatial and executive ability (Bhatt et al., 2017), and cognitive flexibility (Guxens et al., 2016) in 5–13 years of age children and preadolescents. Other studies investigated the association between number of phone calls and inhibitory control and visual recognition in 5–13 years of age children and preadolescents, showing mixed results (Abramson et al., 2009; Bhatt et al., 2017; Guxens et al., 2016; Redmayne et al., 2016). The assessment of brain exposure to RF-EMF using reported mobile and DECT phone calls might underestimate the actual brain exposure to RF-EMF since this approach do not take into account other RF-EMF sources that also contribute to the whole-brain RF-EMF dose such as screen activities with mobile communication devices (i.e. mobile phones, tablets, or laptops) wirelessly connected to the internet or far-field sources. This underestimation might be more pronounced in preadolescents than in adolescents since preadolescents make less phone calls but they do more screen activities with mobile communication devices (Birks et al., 2018; Eeftens et al., 2018). The different activity patterns and personal behavior related to the use of mobile communication devices explains dissimilarities in the whole-brain RF-EMF doses from phone calls and screen activities between ages (Eeftens et al., 2018).

The exposure to RF-EMF from far-field sources is mostly explained by distinct characteristics among regions (e.g. deployment of antennas and types of building) (Eeftens et al., 2018). In our study, adolescents were from Menorca, a Spanish Balearic island with lower levels of exposure from far-field sources compared to other regions of Spain (Birks et al., 2018). This fact explains the big differences in the contribution of far-field sources to the overall whole-brain RF-EMF dose between preadolescents and adolescents (28.4% in preadolescents and 4.7% in adolescents). We did not find any relationship between whole-brain RF-EMF dose from far-field sources and cognitive function. On the contrary, one study found that higher residential RF-EMF exposure from mobile phone base stations was associated with improved inhibitory control and cognitive flexibility, and reduced visuomotor coordination in 5-6-year-old children (Guxens et al., 2016).

Nevertheless, all the studies prior to ours did not estimate the RF-EMF dose received by the brain from the different RF-EMF sources. Therefore, it is not possible to assess whether their findings are due to brain exposure to RF-EMF or to social and individual factors related to the use of mobile and DECT phones or to far-field sources. In our study, we could not independently assess whole-brain RF-EMF dose from mobile and DECT phone calls and use of mobile and DECT phones because whole-brain dose from mobile and DECT phone calls and minutes of phone calls were highly correlated ($r > 0.80$). Also, there is growing evidence that mobile communication devices can be beneficial for some cognitive abilities, if prudently used (Wilmer et al., 2017). This beneficial effect could mask potential negative effects of RF-EMF on cognitive function. Consequently, it is key to investigate two main aspects. First, we need to estimate whether the whole-brain RF-EMF dose from phones calls or the use of the phone itself leading to mental arousal, displacement of other activities more beneficial for brain development, or phone dependency among others is behind the observed associations between phone calls and cognitive function (Foerster et al., 2018; Roser et al., 2016; Schoeni et al., 2017, 2015b). Second, we need to assess whether the potential association between phone calls and cognitive function differs between children, preadolescents, and adolescents.

Strengths of this study are the availability of data in almost 3000 preadolescents from two population based birth cohort studies, the assessment of multiple mobile communication devices and cognitive function following similar protocols, and the use of a battery of validated neurocognitive tests. The main limitation of this study is its cross-sectional design. Preadolescents with lower non-verbal intelligence might be more prone to use mobile communication devices, thus, they would be exposed to higher whole-brain RF-EMF dose. To our knowledge, there are no previous studies showing a longitudinal association between lower cognitive function and higher use of mobile communication devices. However, we cannot entirely discard reverse causality. Another limitation might be the fact that in the Dutch cohort we assessed the cognitive function just in terms of non-verbal intelligence and only in preadolescents. Moreover, in the Spanish cohort, we could not evaluate non-verbal intelligence in adolescents. Therefore, we could not investigate whether whole-brain RF-EMF dose was related to non-verbal intelligence in adolescence, age in which brains are more exposed to RF-EMF as adolescents tend to make more phone calls than preadolescents. Furthermore, although we used an innovative and comprehensive tool to estimate whole-brain RF-EMF doses, such method builds on assumptions that could lead to non-differential misclassification of the exposure. This fact could lead to a potential underestimation of the effect. Finally, the use of mobile communication devices was self-reported or reported by the mother. A recent study showed that reported mobile phone use was a valid measure to distinguish between low and high exposed to RF-EMF from mobile phone use (Mireku et al., 2018). Nevertheless, objective measures could be used in new studies to improve accuracy on the measurements of the use of these devices. Such objective measures could be achieved through the use of validated applications installed in participants' mobile communication devices and tracking their actual use.

5. Conclusion

Adolescence is a cognitive demanding stage of life, and one of the most rapid phases of human development. Therefore, it is important to identify factors that could compromise brain development at this stage and permanently impair cognitive abilities. Our results suggest that overall estimated whole-brain RF-EMF dose and specific dose from phone calls were related to lower non-verbal intelligence in preadolescents. However, our findings also indicate that whole-brain RF-EMF doses were not related to information processing speed, attentional function, visual attention, and cognitive flexibility in preadolescents or to working memory and semantic fluency in both preadolescents and adolescents. Given the cross-sectional nature of the study, the small effect sizes, and the unknown biological mechanisms, we cannot discard that our results might be due to chance finding or reverse causality. Our findings open the field to future longitudinal studies to further investigate the association between brain exposure to RF-EMF and cognitive function.

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Declaration of competing interest

All authors declare that they have no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2020.113659.

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Review

Electromagnetic radiation as an emerging driver factor for the decline of insects

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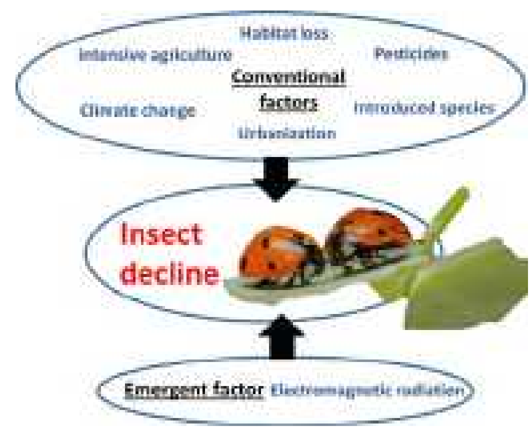
HIGHLIGHTS

- Biodiversity of insects is threatened worldwide.
- These reductions are mainly attributed to agricultural practice and pesticide use.
- There is sufficient evidence on the damage caused by electromagnetic radiation.
- Electromagnetic radiation may be a complementary driver in this decline.
- The precautionary principle should be applied before any new deployment (e.g. 5G).

GRAPHICAL ABSTRACT



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ABSTRACT

The biodiversity of insects is threatened worldwide. Numerous studies have reported the serious decline in insects that has occurred in recent decades. The same is happening with the important group of pollinators, with an essential utility for pollination of crops. Loss of insect diversity and abundance is expected to provoke cascading effects on food webs and ecosystem services. Many authors point out that reductions in insect abundance must be attributed mainly to agricultural practices and pesticide use. On the other hand, evidence for the effects of non-thermal microwave radiation on insects has been known for at least 50 years. The review carried out in this study shows that electromagnetic radiation should be considered seriously as a complementary driver for the dramatic decline in insects, acting in synergy with agricultural intensification, pesticides, invasive species and climate change. The extent that anthropogenic electromagnetic radiation represents a significant threat to insect pollinators is unresolved and plausible. For these reasons, and taking into account the benefits they provide to nature and humankind, the precautionary principle should be applied before any new deployment (such 5G) is considered.

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1. Insects and their importance in ecosystem services

There are numerous studies that show the fundamental importance of insects as key species in ecosystems (see for example: Noriega et al., 2018). Some of the most important ecosystem services they provide are climate regulation, crop pollination, pest control, decomposition and seed dispersal (Kremen and Chaplin-Kramer, 2007; Schowalter, 2013). Insects are at the structural and functional base of many of the world's ecosystems (Sánchez-Bayo and Wyckhuys, 2019), and numerous birds, lizards, frogs and bats feeds on insects (Nocera et al., 2012). The group of insect pollinators plays an important role in crop pollination, and insects provide an important contribution to crops as well as to wild plants (Powney et al., 2019).

2. The current decline of insects and causative drivers of this decline

Numerous studies have reported the serious decline in insects that has occurred in recent decades (Vogel, 2017). A study carried out in protected nature areas throughout Germany found a 76–82% decline in total flying insects between 1989 and 2016. The authors consider that agricultural intensification, with increased use of pesticide and fertilisers, may have aggravated the reduction in insect abundance over the last decades, whereas landscape modifications and climate change are unlikely explanatory factors (Hallmann et al., 2017).

A study of insects crashing into car windscreens in rural Denmark, based on data collected between 1997 and 2017, concluded that the number of insects had decreased by 80% in those 20 years, and the authors point out that reductions in insect abundance must mainly be attributed to agricultural practices and pesticide use (Møller, 2019). In a survey conducted in Kent (UK) in 2019, which examined the presence of crushed insects in the front grille above the licence plates of cars, a 50% reduction compared to 2004 was reported (Tinsley-Marshall et al., 2019).

Some authors also point out climate change as a cause of insect decline (Baranov et al., 2020). In a tropical rainforest in Puerto Rico, one study found a 30- to 60-fold decline (a 97–98% decline) in total insects captured in sticky traps between 1976 and 2012. This decline may be attributed to climate change, since between 1976 and 2012, mean maximum temperatures have risen by 2.0 °C, and tropical arthropods are particularly vulnerable to climate warming (Lister and Garcia, 2018). However, in colder climes and the mountains of temperate zones, this factor affects only a minority of species (Sánchez-Bayo and Wyckhuys, 2019).

After reviewing 73 historical reports of insect declines from across the globe, a recent study revealed that the biodiversity of insects is threatened worldwide (Sánchez-Bayo and Wyckhuys, 2019). The rates of decline may lead to the extinction of 40% of the world's insect species, both specialists and generalists. Based on the results of this review, the most affected groups in terrestrial ecosystems are *Lepidoptera*, *Hymenoptera* and *Coleoptera*, whereas in terms of aquatic taxa, *Odonata*, *Plecoptera*, *Trichoptera* and *Ephemeroptera* are most affected. The authors conclude that the main plausible drivers are, in order of importance: i) habitat loss and conversion to intensive agriculture and urbanisation; ii) pollution, mainly by synthetic pesticides and fertilisers; iii) pathogens and introduced species; iv) climate change (Sánchez-Bayo and Wyckhuys, 2019).

This same is happening with the important group of pollinators. A study has found evidence of declines across a large proportion of pollinator species in Britain between 1980 and 2013 (Powney et al., 2019). Another study strongly suggests a causal connection between local extinctions of functionally linked plant and pollinator species (Biesmeijer et al., 2006). Further, pollinator populations may collapse suddenly once drivers of pollinator decline reach a critical point (Lever et al., 2014). Key threats to pollinators include agricultural intensification (particularly habitat loss and pesticide use), climate change and the spread of alien species (Powney et al., 2019). The decline of pollinators may have important ecological and economic impacts that could significantly affect the maintenance of wild plant diversity, crop production and human welfare (Lázaro et al., 2016).

Loss of insect diversity and abundance is expected to provoke cascading effects on food webs and ecosystem services (Hallmann et al., 2017; Møller, 2019). For example, associated with the decline of insects, parallel decreases in insectivorous lizards, frogs and birds have been documented (Lister and Garcia, 2018). Pesticides have dramatically altered insect community structures and decimated populations, triggering nutritional consequences for aerially foraging insectivorous birds and bats (Nebel et al., 2010; Nocera et al., 2012). Agriculture is the largest contributor to insect and biodiversity loss, destroying biodiversity by converting natural habitats into intensely managed systems and by releasing pollutants, fertilisers and pesticides (Dudley and Alexander, 2017).

3. Scientific evidence for electromagnetic radiation as a factor contributing to insect decline

Insects are especially sensitive to electromagnetic radiation. An increasing number of reports indicate that flies and spiders, among other invertebrates, disappear from areas that receive the highest levels of radiation from mobile telephone antennas, and these observations are consistent with numerous laboratory studies showing the negative effects of electromagnetic radiation (EMR) on reproductive success, development and navigation (Balmori, 2009; Lázaro et al., 2016).

Evidence for the effects of non-thermal microwave radiation on insects has been known for at least 50 years, e.g., the abnormal development of irradiated coleopteran pupae (Carpenter and Livstone, 1971). Radio frequency (RF) signals produced by mobile phones increased the numbers of offspring, elevated hsp70 levels by non-thermal stress and caused other effects on reproduction and development of the fruit fly *Drosophila melanogaster* (Weisbrot et al., 2003). Another study showed that the reproductive capacity of fruit flies decreased by 50–60% after exposure to the RF signal of a mobile phone during the first 2–5 days of adult life (Panagopoulos et al., 2004). The same authors compared the biological activities of the two systems, GSM (900 MHz) and DCS (1800 MHz), and concluded that both types of radiation significantly decrease the reproductive capacity of fruit flies (Panagopoulos et al., 2007). This non-thermal effect diminished with distance (decreasing intensity) and is provoked by induction of cell death (Panagopoulos et al., 2010).

Other authors have also worked with this species and have observed a statistically significant decrease in mean fecundity (Atli and Ünlü, 2006). Further, the mean pupation time was delayed linearly with an increasing period of exposure to an electromagnetic field (EMF), and the mean offspring number was significantly lower than that of the control (Atli and Ünlü, 2007). Pupae from another dipteran, the house fly *Musca domestica*, were exposed to an EMF (50 Hz), and the results showed that the field significantly slowed down metamorphosis (Stanojević et al., 2005).

Insects may be equipped with the same magnetoreception system as birds, and there is evidence that the geomagnetic field reception in the American cockroach is sensitive to a weak RF field (Vácha et al., 2009). Several laboratory studies have been carried out with ants, demonstrating the important effects of artificial EMFs on their orientation by geomagnetic fields (Camlitepe et al., 2005). Other authors demonstrate how changes of low intensity in the normal local magnetic field values affect the behaviour of workers of three magnetosensitive ant species, inducing significant changes in their foraging activities (Pereira et al., 2019). Belgian researchers experimentally demonstrated the effect of 900-MHz electromagnetic waves on ant olfactory and visual learning, revealing an impact on their physiology (Cammaerts et al., 2012). The ants' speed of movement was immediately altered by the presence of electromagnetic waves (Cammaerts and Johansson, 2014). These authors state that electromagnetic radiation affects the behaviour and physiology of social insects, and such results provide convincing evidence of a negative impact of electromagnetic waves on insects, at least on those whose life depends on communication and memory (Cammaerts et al., 2012). Wireless technology has negative impacts on living organisms; ants react quickly to the existence of electromagnetic waves in their environment, and bees may behave abnormally when exposed to EMFs generated by GSM masts (Cammaerts et al., 2013).

To replace chemical insecticides for controlling pests of various species of plants and seeds, in several different studies, radiofrequency exposure was applied to *Callosobruchus chinensis* (Coleoptera), *Maruca vitrata* (Lepidoptera), *Nysius plebeius* and *Nysius hidakai* (Hemiptera). The EMF affected the developmental period, adult longevity, adult weight and the fecundity of subsequent generations in all these species of insects from different orders in the same way (Maharjan et al., 2019a, 2019b, 2020).

Studies have also been conducted on other invertebrates. A study performed in an RF electromagnetic field (RF-EMF) anechoic chamber, irradiating ticks (*Dermacentor reticulatus*) with a 900-MHz RF-EMF at levels below the proposed limit for public exposure to mobile phone base stations, found that exposure induces an immediate tick locomotor response manifested as a jerking movement, and ticks exhibited overall significantly greater movement in the presence of this electromagnetic radiation (Vargová et al., 2017).

In some studies conducted in natural habitats with real phone masts, electromagnetic radiation (EMR) emitted by telecommunication antennas affected the abundance and composition of several guilds of wild pollinator insects (Lázaro et al., 2016). Another study, also carried out in the field, examined the impact of exposure to the fields from mobile phone base stations (GSM 900 MHz) for a 48-h period on the reproductive capacity of four different invertebrate species. Although a significant impact on reproductive capacity was not found, probably because the exposure time was too short, the authors warned that more attention should be paid to the possible impacts of EMF radiation on biodiversity because the exposure to an RF-EMF is ubiquitous and is still increasing rapidly over large areas (Vijver et al., 2014).

As a result of most of the studies carried out, EMF radiation can be a problem for insects and for their orientation (Balmori, 2006, 2009, 2014 and 2015), and both laboratory and field studies on different invertebrate species have shown this.

4. Bee studies on electromagnetic radiation

Bees are highly sensitive to magnetic fields, especially for orientation and navigation, and for this reason, most of such studies have been carried out on bees. Adult honeybees possess a magnetoreception sense, and significant differences in their return rates have indicated that interactions exist between forager losses and exposure to magnetic fields, as well as during fluctuations in the Earth's magnetosphere (Ferrari, 2014).

The first study on the effects of EMFs on bees were carried out under power lines. Honeybee colonies exposed to a 765-kV, 60-Hz transmission line at 7 kV/m showed increased motor activity, abnormal propolisation, impaired hive weight gain, queen loss, abnormal production of queen cells, decreased sealed brood and poor winter survival. When the colonies were exposed to different electric fields with increasing distance from the line, different thresholds for biological effects were obtained (Greenberg et al., 1981). Another more recent study has shown that the extremely low-frequency EMF (50 Hz) emitted from powerlines affects honeybee olfactory learning, flight, foraging activity and feeding and may represent a prominent environmental stressor for honeybees, potentially reducing their ability to pollinate crops (Shepherd et al., 2018). In Italy, deleterious results of both pesticides and EMFs from a 132-kV (50-Hz) high-voltage power line have been found. In the electromagnetic-stress site, the effect of a behavioural over-activation of all analysed biomarkers was observed at the end of the season, and this finding poses potential problems for the winter survival of bees (Lupi et al., 2020).

Lopatina et al. (2019) studied the effect of non-ionising EMR from a Wi-Fi router on sensory olfactory excitability, food motivation and memory in honeybees and observed that a 24-hour exposure to Wi-Fi EMR had a significant inhibitory effect on food excitability and short-term memory. In natural conditions, worker piping announces either the swarming process of the bee colony or is a signal of disturbance, and active mobile phone handsets have a dramatic impact on the behaviour of the bees by inducing the worker piping signal (Favre, 2011). In another study, with GSM (900-MHz) cell phones, a significant decline in colony strength and egg-laying rate by the queen was observed. The behaviour of exposed foragers was negatively influenced by such exposure: there was neither honey nor pollen in the colony at the end of the experiment (Sharma and Kumar, 2010). In another study, queens exposed to telephone radiation in the test colonies produced fewer eggs/day compared to the control (Sainudeen Sahib, 2011). A more recent study provided solid evidence that mobile phone radiation significantly reduces hatching and may alter pupal development (Odemer and Odemer, 2019).

In a study carried out in Germany, with bees exposed to DECT radiation, only a few bees returned to the beehive, and they needed more time; also, honeycomb weight was lower in irradiated beehives (Stever et al., 2005; Harst et al., 2006). The concentrations of carbohydrates, proteins and lipids in the haemolymph increased under the influence of cell phone radiation (Kumar et al., 2013). Another study observed an increase in mortality in two conditions: after exposure to HF (13.56 MHz) and to UHF (868 MHz) (Darney et al., 2016).

Regarding the colony collapse disorder (CCD) observed in honeybee colonies around the world, several authors consider that EMR exposure provides a better explanation than other theories (Sainudeen Sahib, 2011; Cammaerts et al., 2012). Several authors warn that the massive amount of radiation produced by mobile phones and towers disturbs the navigational skills of honeybees, preventing them from returning to their hives (Warnke, 2009; Sainudeen Sahib, 2011). In fact, winter colony losses in the northeast USA correlated with the occurrence of annual geomagnetic storms, and abnormal fluctuations in magnetic fields related to the epidemiology of honeybee losses are consistent with their behaviour and development (Ferrari, 2014).

5. Action mechanisms

There are well-known mechanisms of action of low-frequency pulsed RF, such as interference with calcium channels in cells (Pall, 2013; Panagopoulos and Balmori, 2017) and deleterious effects on sperm and reproductive systems (Panagopoulos et al., 2004;

Panagopoulos, 2012; Adams et al., 2014). In vertebrates, studies have also found a pathologic leakage across the blood-brain barrier (Salford et al., 2003) and interference with brain waves (Mann and Roschkle, 1996; Beasond and Semm, 2002; Kramarenko and Tan, 2003). Microwave radiation has particular effects on nervous, immune and reproductive systems (Balmori, 2009).

In recent years, there has been an important advance in understanding the underlying mechanisms for orientation in birds, insects and other groups. It has also been verified that RF-EMFs alter the biological response characteristics of cryptochrome receptors. These results are consistent with the radical-pair mechanism of magnetosensing. Since cryptochromes are molecules highly sensitive to RF radiation and are found in many organisms, including humans, these results also may have more general implications for the capacity of living organisms to respond to man-made electromagnetic noise by analogy with broadband RF, which has previously been shown to disrupt the orientation of birds (Engels et al., 2014). These possible risks have already been indicated by Balmori (2015).

A recent study has warned that future, more short wavelengths of electromagnetic fields used for the wireless telecommunication systems (5G), will become comparable to the body size of insects, and therefore, the absorption of RF-EMF in this group is expected to increase (Thielens et al., 2018).

6. The precautionary principle and the importance of seriously considering EMR as a factor of insect decline

Despite the strong scientific evidence of the negative impacts of electromagnetic radiation on insects, a recent study funded by the European Union's Horizon 2020 Research and Innovation Programme (EKLIPSE) stated that our current knowledge concerning the impact of anthropogenic RF-EMR on pollinators (and other invertebrates) is inconclusive (Vanbergen et al., 2019). Thus, the extent to which anthropogenic EMR represents a significant threat to insect pollinators is unresolved. For these reasons, and taking into account the benefits they provide to nature and humankind, the precautionary principle of the European Union (Communication from the Commission on the Precautionary Principle, 2000) should be applied.

The potential effects of RF-EMFs on most taxonomic groups, including migratory birds, bats and insects, are largely unknown, and the potential effects on wildlife could become more relevant with the expected adoption of new mobile network technology (5G), raising the possibility of unintended biological consequences (Sutherland et al., 2018). Thus, before any new deployment (such 5G) is considered, its effects should be clearly assessed, at least while conclusions are drawn and these existing uncertainties are overcome, according to the official document 'Late Lessons of Early Warnings' (European Environment Agency, 2013).

A letter by the United States Department of the Interior sent to the National Telecommunications and Information Administration in the Department of Commerce warns about the scarcity of studies carried out on the impacts from non-ionising EMR emitted by communication towers (United States Department of the Interior, 2014). The precise potential effects of increases in EMR on wildlife, which are not yet well recognised by the global conservation community, have been identified as an important emerging issue for global conservation and biological diversity (Sutherland et al., 2018). Thus, as we have explained in this review, EMR should be seriously considered as a complementary driver for the dramatic decline in insects in recent studies, acting in synergy with agricultural intensification, pesticides, invasive species and climate change.

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Declaration of competing interest

The author declare that have no conflict of interest.

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Letter

Setting Guidelines for Electromagnetic Exposures and Research Needs

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Current limits for exposures to nonionizing electromagnetic fields (EMF) are set, based on relatively short-term exposures. Long-term exposures to weak EMF are not addressed in the current guidelines. Nevertheless, a large and growing amount of evidence indicates that long-term exposure to weak fields can affect biological systems and might have effects on human health. If they do, the public health issues could be important because of the very large fraction of the population worldwide that is exposed. We also discuss research that needs to be done to clarify questions about the effects of weak fields. In addition to the current short-term exposure guidelines, we propose an approach to how weak field exposure guidelines for long-term exposures might be set, in which the responsibility for limiting exposure is divided between the manufacturer, system operator, and individual being exposed. Bioelectromagnetics. © 2020 Bioelectromagnetics Society

Keywords: weak electromagnetic fields; long term exposures; exposure guidelines; human health

INTRODUCTION

The Institute of Electrical and Electronics Engineers (IEEE) and International Commission on Non-Ionizing Radiation Protection (ICNIRP) have both recently issued the revised guidelines for exposures to electromagnetic fields (EMF) from 0 (DC) to 300 GHz [IEEE, 2019; ICNIRP, 2020]. They somewhat modify the existing guidelines on exposures [IEEE, 2005; ICNIRP, 2009a for static magnetic fields; ICNIRP, 2010 for low-frequency fields; ICNIRP, 2009b for high-frequency fields] in forming the basis of standards in most countries around the world. Though recently revised to some extent, the recommended limits on exposure have not changed very much since 1998. Current exposure limits are based at low frequencies on externally applied electric fields being large enough to stimulate the firing of a nerve cell at approximately 5,000 V/m and at higher frequencies on specific absorption rates, SAR in W/kg, large enough to cause temperature rise of approximately 1 °C over a period of 6 min. In the 30–300 MHz range, this typically corresponds to incident powers of about 10 W/m^2. Both IEEE and ICNIRP base their analyses on rigorous reviews of the scientific literature and on established firm evidence of health effects in humans. The present guidelines are based on acute exposures; to date both IEEE and ICNIRP have not found sufficient evidence to include health effects of long-term exposures at lower levels.

However, over the last 20 years the evidence has become extremely strong that weaker EMF over the whole range for frequencies from static through millimeter waves can modify biological processes. There is now solid experimental evidence and supporting theory showing that weak fields, especially but not exclusively at low frequencies, can modify reactive free radical concentrations and that changes in radical concentration

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[Correction added on 22 Apr 2020, after first online publication: removed part of sentence referring to 4 W/m2].

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and that of other signaling molecules, such as hydrogen peroxide and calcium, can modify biological processes [Batchelor et al., 1993; Bingham, 1996; Timmel et al., 1998; Woodward et al., 2001; De Iuliis et al., 2009; Castello et al., 2014; Li and Heroux, 2014; Usselman et al., 2014; Barnes and Greenebaum, 2015]. Static and low-frequency magnetic fields have shown both acceleration and inhibition of cancer cell growth rates in the culture [Bingham, 1996; De Iuliis et al., 2009; Castello et al., 2014; Li and Heroux, 2014; Gurhan et al., 2020]. Both the acceleration and inhibition of growth rates of planarian [Van Huizen et al., 2019] have been demonstrated with static magnetic fields in the range from 0.5 to 600 μT. At radio frequencies, both increases and decreases in cancer cell growth rates have been measured in the range from 1.8 to 7 MHz for power densities of less than 0.1 W/m^2 and a magnetic flux density of 24 nT [Castello et al., 2014; Usselman et al., 2014; Vijayalaxmi et al., 2014; Usselman et al., 2016]. Other examples include changes in male fertility [Avendano et al., 2012]. See also book chapters by Feychting et al. [2017] Kheifets et al. [2017] and Wood and Loughran [2017] for reviews of studies that show positive, negative, and no changes for exposures to weak EMF. We argue below that experimental results showing positive, negative, and no changes in the same parameter are not invariably the evidence of poor experimental controls but also arise because of inherent feedback processes where the biological system adjusts to bring the system back to the desired operating conditions [Barnes and Kandala, 2018]. Additionally, it is very difficult to control and repeat the initial slightly different conditions in the organism; and small differences can lead to different results.

The evidence that weak radiofrequency (RF) and low-frequency fields can modify human health is still less strong, but the experiments supporting both conclusions are too numerous to be uniformly written off as a group due to poor technique, poor dosimetry, or lack of blinding in some cases, or other good laboratory practices. Based on recent studies by the National Toxicology Program (NTP) [Smith-Roe et al., 2020] and the Ramazini Foundation [Falcioni et al., 2018] as well as laboratory data, the International Agency for Research on Cancer (IARC) has declared RF fields as possible human carcinogens [IARC, 2013]. A recent paper extends the NTP studies by evaluating genotoxicity in animals exposed to fields at or over the guideline limits and found DNA damage in Comet assays [Smith-Roe et al., 2020]. Many other papers indicate similar results, but many negative results are also in the literature. The papers presenting the guidelines themselves and the literature reviews supporting them present some of these references, including WHO [1993, 2007a,b] and ICNIRP [2009a,b, 2010]. Others may be found in IARC [2013], Belyaev et al. [2016], Zhang et al. [2017], Sienkiewicz and Van Rongen [2019], Elwood and Wood [2019], and Stanley and Friedman [2019], as well as in many others. Lin [2018, 2019] has critically reviewed the strengths and weaknesses of the NTP studies. A recent advisory panel has recommended to IARC that RF radiation be a part of the list of agents whose carcinogenicity is reassessed in the next 5-year period [IARC, 2019].

The results of these papers have not been considered convincing or relevant by the reviewing organization's panels due to methodological issues, because they did not relate closely enough to human health, and because the experimental results are mixed, showing increases, decreases, or no change in similar situations. However, taken as a group they do provide strong evidence that weak EMF can be sensed by biological systems, as well as suggestive evidence that fields may affect human health.

At least part of the explanation for the mixed results is likely to be that biological feedback processes often cancel out perturbations that would otherwise take biological systems out of their normal operating range [Vijayalaxmi et al., 2014]. For example, if we exercise, the body temperature starts to rise, and we begin to sweat in order to limit the temperature rise to within the normal operating range. If we get cold, we start to shiver. With EMF we appear to be modifying oxidative stress [De Iuliis et al., 2009; Castello et al., 2014; Usselman et al., 2014, 2016], cancer cell growth rates [Castello et al., 2014; Usselman et al., 2014, 2016; Sherrard et al., 2018], membrane potentials [Ye and Kaszuba 2019], and concentrations of calcium, reactive oxygen species (ROS), superoxide ($O2^-$), nitric oxide (NO), hydrogen peroxide (H_2O_2), and intercellular pH [Cichon et al., 2017; Gurhan et al., 2020; Osera et al., 2015; Sonntag, 1998]. The body reacts to bring these levels back to within the normal operating range, but there is a time delay in these feedback processes. For periodic inputs, this can lead to either amplification or attenuation of the perturbation. There are many oscillating systems in the body, so the timing of the perturbation makes a difference, just as it does in how pushing a swing at the peak accelerates it, while pushing in the same direction at the bottom slows it down. Dröge [2002] reviews data on oxidative stress that show oxidative stress may be increased by a factor of ten or more for short times during exercise and returns to the normal range upon relaxation. He also shows that long-term elevations of the ROS lead to a shift in the baseline levels, and the elevated levels are associated with cancer, aging, and Alzheimer's. The effects of oxidative stress and other radicals are covered in detail by Halliwell and Gutteridge [2015].

As a result of limited data showing health effects from exposures that are acceptable within the current guidelines limiting exposure, controversies have arisen concerning whether the guidelines and the standards based on them are at an appropriate level, especially with regard to RF devices. Many existing or new uses of these technologies currently expose the user to more low levels of EMF than in the past. Due to improvements such as higher circuit sensitivity and the use of hands-free or speakers on telephones or instant messaging instead of phone calls, exposure from a single phone call is reduced, but in general the overall usage has increased. The need for higher data rates has led to the use of higher frequencies and more base stations, closer together and a reduction in transmitter power. The spreading use of RF technology and the application of it to new uses and higher frequencies have fed suspicion that the health of the public is at risk from extended, low-level exposure. Fear is heightened since some diseases, including autoimmune diseases, are on the rise. In addition, some individuals who have symptoms or diseases, ranging from pains of unknown origin to specific diseases, are convinced that EMF exposure is the cause, sometimes called idiopathic intolerance attributed to EMF (IDI-EMF). However, a number of controlled laboratory experiments that expose them blindly to fields or no-fields has not produced any correlations between the symptoms and the subjects' ability to identify if the fields were on or off [Hansson Mild et al., 2006; Verrender et al., 2018].

At the same time, the greater usefulness and convenience of the same RF technologies has embedded them more deeply into all levels of both highly developed and developing societies. The portable, hand-held cell phone device is not going away, nor will the other uses of RF technology. Indeed, the range of frequency exposures will expand further with the advent of 5G technology. At present, the current standards are saying that there is no evidence that fields are harmful, and the attention of the regulators, funding agencies, and others is directed elsewhere. But there is also a growing collection of scientific results from laboratories in the United States, Europe, Japan, China, and elsewhere that says that EMF do have effects, as well as a small but vocal group of people inside and outside of science who are positively convinced that we are harming ourselves with the growing use of RF technology.

NEXT STEPS IN FURTHER RESEARCH

At the present time, we do not know what exposure conditions lead to resetting the baselines for the concentrations of reactive oxygen and other molecules that lead to problems such as oxidative stress and how these conditions are associated with cognitive effects, aging, cancer, and other diseases. We hypothesize that this is a potential cause for health effects, while other causes may also exist. While data exist on the current levels of exposure from 4G and earlier versions of mobile phones, and theoretical estimates exist on the levels of exposure that will exist with the higher frequencies of 5G systems that are currently being installed or contemplated, we currently have only very limited good data on 5G. One important research need is to measure these exposure levels under various actual conditions. It is currently not clear that, with focused beams and higher data rates leading to shorter-on times, whether the personal exposures will increase or decrease with the increased number of lower-power base stations.

Considerable research work needs to be done to solidify the effects identified above, as well as many others. This work must be done carefully, using the best laboratory practices and sufficiently large samples to produce significant results [e.g., Valberg, 1995; Portelli 2019]. It may be useful, especially if funding comes from a pool contributed by industry, to establish and fund a small oversight group of distinguished bioelectromagnetics scientists, to choose projects and monitor them onsite, ensuring that they are likely to accomplish their goals. This group would be similar to the ones used by the Navy, Environmental Protection Agency (EPA), National Institute of Environmental Health Sciences (NIEHS), the New York State Power Authority, and others in the 1970s and 1980s [Dietrich, 1998].

The research on oxidative stress and feedback loops discussed above should identify when changes in the concentrations of these and other molecules lead to concentrations that are not corrected by the body's feedback and control systems or through other mechanisms, and have increased the probabilities for causing adverse health effects. For example, experiments could be done in the cell phone and wireless bands at different power levels for different numbers of hours per day and days per week to see when the concentration levels of H_2O_2, NO, and other molecules leading to oxidative stress change to levels outside the normal range. This could be a variation on the National Toxicology Program study [Smith-Roe et al., 2020] and Ramazzini study [Falcioni et al., 2018]. This study would need to be coupled with biochemical studies on when changes in these molecular concentrations lead to problems. Measurements need to be made on the changes in biological parameters, such as reactive free radical concentration, Ca, NO, H_2O_2, and other signaling molecules, as a function of the exposure parameters. This needs to be at levels ranging from molecules in solution through cell culture and whole animals to humans. These results need to be used to develop models that can be correlated with epidemiological studies to minimize exposure conditions that lead to undesired health effects or at least to the ability to predict the probability of a health effect under varying patterns of use. These are likely to be functions of the user's age, health, and other stresses.

An example of projects that might be initiated would look at the possible effects of 5G signals on the growth of melanoma. The first experiment might be to look at the skin under exposure to 5 G signals to see if there are changes in the levels of reactive oxygen and other signaling molecules, such as hydrogen peroxide and calcium, as a function of exposure parameters such as intensity and length of exposure. A second set of measurements might be to look at changes in the growth rates of melanoma cells in the culture as a function of intensity and length of exposure. These experiments might have two objectives. The first would be to find the minimum signal that modifies growth rates, and the second might be to see if there are exposure parameters that inhibit or accelerate its growth. A third set of experiments could be to look at animal models. The third set of experiments is likely to be expensive, requiring an effort on the order of the NTP studies, and could include additional measurements on the changes in chemistry as function of time and exposure parameters. A fourth set of experiments, if there turns out to be exposure parameters that inhibit the growth of melanoma, might be on humans. Many other examples of following up effects that have significant backing in the literature could be proposed.

Funding for research into the effects of EMF in the United States is close to nonexistent, though the National Institutes of Health (NIH) and the Defense Department have a few mission-related programs. Elsewhere, support is better, though a great deal of European funding is concentrated on aggregating prior results or on the question of idiopathic intolerance or hypersensitivity. We believe a carefully targeted program of federal research funds is called for, supplemented by communications system operators and corporations that manufacture equipment, under independent scientific management. Both governmental and private entities that emit RF signals would be well advised to fund research to elucidate and define threshold signal levels for the generation of long-term biological effects. Given the way the current product liability law works, an able lawyer might well convince a jury that exposures within the current limits have caused cancer, cognitive disabilities in children, etc., which could cost billions of dollars.

PROPOSED APPROACH TO SETTING EXPOSURE LIMITS

From these and other lines of solid research, the guidelines for exposure could be revised. Increased emphasis on long-term exposures may require refining the concept of dose to more flexibly combine exposure time and field intensity or energy absorbed. Eventual guidelines might suggest limiting cell phone calls to X hours per day with exposure levels above Y W/m^2, and for Z days per week exposure should be less than Y W/m^2 to allow the body to reset its baseline. The time between heavy exposures might be initially estimated by looking at recovery times from other stresses such as exercise. Major league starting pitchers usually are given several days between starts. In other cases, overnight may be good enough. Training also increases the speed of recovery. A possibility might be that cell phones and WiFi are turned off at night or over the weekend to allow for resetting of the oxidative baseline levels.

Even as further research is needed, an approach to setting exposure limits should be considered. We would like to propose that a starting point might be to consider the way standards are set for driving a car. Virtually everyone knows that driving a car can be dangerous, but most of us still drive them. With automobiles we have rules of the road, such as which side of the highway we drive on, and speed limits that vary with location and with further adjustments for conditions such as rain and snow, set by competent authorities. Most of us consider that the value of traveling by car is greater than the risk. For cell phones and other devices, suggested limits might be recommended on the field strengths, length of exposure, and times in between use. These recommended limits could well be a function of frequency, amplitude, and modulation systems and will clearly depend on the condition of the person being exposed. Some people will be more sensitive than others and the sensitivity of a given individual could well change with time. It is likely over time that we will find that some frequency and patterns are more biologically active than others are. However, we have yet to achieve consensus on these questions, in part because the research on linking exposure to weak EMF directly to human health is too weak to make a convincing argument for foregoing the convenience of cell phones and other electromagnetic devices.

Currently, our standards seem to be effective in preventing easily demonstrated biological damage for short-term exposure for most people. However, it is not clear whether the biological effects seen for lower levels of exposure and long-term exposure are not resulting in medical problems for a much larger number of people. Additionally, there seem to be a smaller number of "hypersensitive people" who have very real and serious problems that they believe are based on exposure to weak RF fields. What is missing in the current guidelines or regulations are guidelines for long-term exposure to weak EMF.

Guidelines should be set at three levels: the individual user, local company, and national or international level. An important issue is, what part of limits on exposures should be placed on the manufacturers and system operators, if any, and what part should be left to the user to control. For example, the problem of limiting the number of hours of use may well be up to the user to decide, given the information that is known at the time. The individual user is already, consciously or unconsciously, setting personal limits, though without external guidance. The user does or does not use RF equipment of various types, does or does not set limits on how long and how frequently to use it, does or does not decide to use hands-free mobile phone accessories or speaker phones, etc. External guidance, in terms of informed recommendations or at least analysis of various intensities and styles of usage from some agency such as the Federal Communications Commission (FCC) or NIH, would be useful.

Limits on the time for operations of base stations and exposures in adjacent living spaces are not controlled by the user and must be set by competent authorities, based on scientific evidence. It is likely to be difficult to specify times when exposures to RF signals are zero or below some limit. What will be needed is being able to say with some certainty that exposure below a given level has not been shown to cause changes in body chemistry above some level. A starting point might be current levels from TV and radio stations that are large enough to give signal-to-noise ratios around 20 dB (100-fold) with typical receiving systems. Currently, mean values for the population's exposure to these systems are estimated to be around 0.1 V/m and peak exposures range up to 2 V/m, which exceed current exposure limits for a small fraction of the population. Therefore, one starting point for exposure limits might be an average of 0.1 V/m, not based on research but on practicality, until further research results dictate either a lower or higher limit.

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Estimated whole-brain and lobe-specific radiofrequency electromagnetic fields doses and brain volumes in preadolescents

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ABSTRACT

Objective: To assess the association between estimated whole-brain and lobe-specific radiofrequency electromagnetic fields (RF-EMF) doses, using an improved integrated RF-EMF exposure model, and brain volumes in preadolescents at 9–12 years old.

Methods: Cross-sectional analysis in preadolescents aged 9–12 years from the Generation R Study, a population-based birth cohort set up in Rotterdam, The Netherlands (n = 2592). An integrated exposure model was used to estimate whole-brain and lobe-specific RF-EMF doses (mJ/kg/day) from different RF-EMF sources including mobile and Digital Enhanced Cordless Telecommunications (DECT) phone calls, other mobile phone uses than calling, tablet use, laptop use, and far-field sources. Whole-brain and lobe-specific RF-EMF doses were estimated for all RF-EMF sources together (i.e. overall) and for three groups of RF-EMF sources that lead to a different pattern of RF-EMF exposure. Information on brain volumes was extracted from magnetic resonance imaging scans.

Results: Estimated overall whole-brain RF-EMF dose was 84.3 mJ/kg/day. The highest overall lobe-specific dose was estimated in the temporal lobe (307.1 mJ/kg/day). Whole-brain and lobe-specific RF-EMF doses from all RF-EMF sources together, from mobile and DECT phone calls, and from far-field sources were not associated with global, cortical, or subcortical brain volumes. However, a higher whole-brain RF-EMF dose from mobile phone use for internet browsing, e-mailing, and text messaging, tablet use, and laptop use while wirelessly connected to the internet was associated with a smaller caudate volume.

Conclusions: Our results suggest that estimated whole-brain and lobe-specific RF-EMF doses were not related to brain volumes in preadolescents at 9–12 years old. Screen activities with mobile communication devices while

Abbreviations: RF-EMF, radiofrequency electromagnetic fields; MRI, magnetic resonance imaging; DECT, Digital Enhanced Cordless Telecommunications; mJ, millijoule; min, minutes; W, watt; IQR, interquartile range; IQ, intelligence quotient; BMI, body mass index; B, beta; CI, confidence interval

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wirelessly connected to the internet lead to low RF-EMF dose to the brain and our observed association may thus rather reflect effects of social or individual factors related to these specific uses of mobile communication devices. However, we cannot discard residual confounding, chance finding, or reverse causality. Further studies on mobile communication devices and their potential negative associations with brain development are warranted, regardless whether associations are due to RF-EMF exposure or to other factors related to their use.

1. Introduction

Children have dramatically increased their use of mobile communication devices such as mobile phones or tablets in the last decade (Birks et al., 2018; ICT, 2017). The use of these devices has raised concerns among paediatricians, parents, teachers, and public health practitioners due to their possible negative health consequences (Vijayalaxmi and Scarfi, 2014; SSM's council, 2016). One of the concerns is related to the exposure to radiofrequency electromagnetic fields (RF-EMF) emitted by these devices (Foerster et al., 2018; Roser et al., 2017; World Health Organization, 2014). Children are the most vulnerable part of the population to the potential RF-EMF effects as their brain is still rapidly developing (Kheifets et al., 2005). Moreover, children will experience long periods of exposure to RF-EMF because they start using mobile communication devices at an early age and are likely to continue using them through their life.

Brain development is a multistep process beginning early in gestation and continuing into the postnatal period (Rice and Barone, 2000). Brain magnetic resonance imaging (MRI) has been used to examine typical and atypical morphological brain development and some associations have been described between brain volume alterations and cognitive function and behavioural problems (Arhan et al., 2017; Blanken et al., 2015; Libero et al., 2014; Pangelinan et al., 2011). However, epidemiological studies examining the association between RF-EMF exposure and brain development in children have only used neuropsychological tests or questionnaires measuring cognitive function and behavioural problems (Guxens et al., 2016, 2018; Redmayne et al., 2016; Roser et al., 2016; Schoeni et al., 2015a, 2015b; Thomas et al., 2010; Zheng et al., 2014). The study of brain volumes using MRI might give insight to the potential structural brain alterations behind some of the observed associations between RF-EMF exposure and cognitive function and behavioural problems.

Another important issue in this type of research is the assessment of the exposure to RF-EMF. Most epidemiological studies have used parental or self-reported information on use of different mobile communication devices (e.g. mobile phone, Digital Enhanced Cordless Telecommunications (DECT) phone, tablet) (Abramson et al., 2009; Bhatt et al., 2017; Guxens et al., 2016; Redmayne et al., 2016; Schoeni et al., 2015; Thomas et al., 2010; Zheng et al., 2014), estimated residential exposure to RF-EMF from mobile phone base stations (Guxens et al., 2016), or measured personal exposure of different RF-EMF sources using portable devices for a short period of time (Heinrich et al., 2010). All these approaches only assessed a portion of the overall RF-EMF exposure. Thus an estimation that would integrate the exposure of all RF-EMF sources, and more specifically that would also estimate the dose of RF-EMF received in the brain, is needed to better investigate the potential associations between RF-EMF exposure and brain development. So far, only one study developed an RF-EMF exposure model which included several RF-EMF exposure sources and estimated the RF-EMF dose of all these sources received in the whole brain (Roser et al., 2015). They found that higher estimated whole-brain RF-EMF dose was not associated with behavioural problems and concentration capacity but was related to lower figural memory in children and adolescents at 12–17 years old (Foerster et al., 2018; Schoeni et al., 2015; Roser et al., 2016). In the present study, we use a recently developed integrated RF-EMF exposure model including a larger number of RF-EMF exposure sources and the assessment of lobe-specific RF-EMF doses, which allows for a more comprehensive study of the potential association between RF-EMF exposure and brain development. Moreover, we estimated whole-brain and lobe-specific RF-EMF doses from three groups of RF-EMF sources that lead to a different pattern of RF-EMF exposure: i) brain RF-EMF doses from mobile and DECT phone calls which are the primary contributors of RF-EMF exposure to the brain leading to peak exposures very close to the head but for short periods of time; ii) brain RF-EMF doses from mobile phone use for internet browsing, e-mailing, and text messaging, tablet use, and laptop use while wirelessly connected to the internet which lead to low doses and might mainly represent a variety of social or individual factors related to these type of uses; and iii) brain RF-EMF doses from far-field sources (e.g. mobile phone base stations, FM radio and TV broadcast antennas, WiFi) which lead to low doses but are received continuously along the day (Birks et al., 2018; Birks et al., 2020).

Therefore, the aim of the current study was to assess the association between estimated whole-brain and lobe-specific RF-EMF doses using an improved integrated RF-EMF exposure model and brain volumes in preadolescents at 9–12 years old.

2. Methods

2.1. Study design and population

This is a cross-sectional analysis embedded in the Generation R Study, a population-based birth cohort study from fetal life onwards in Rotterdam, the Netherlands. A total of 9901 pregnant women were enrolled and children were born between April 2002 and January 2006. Between 2013 and 2015, a total of 3992 preadolescents at 9–12 years old underwent a MRI assessment, and 3303 of them had information on mobile communication devices use. After excluding preadolescents with incidental findings or poor neuroimaging quality, we included 2592 preadolescents (26.2% of the original cohort) in our analyses (Supplementary Fig. S1). The Medical Ethics Committee of the Erasmus Medical Centre approved the study and written informed consent was obtained from parents.

2.2. Estimated whole-brain and lobe-specific RF-EMF dose

We applied an integrative RF-EMF exposure model to estimate whole-brain and lobe-specific (i.e. frontal, parietal, temporal, occipital) RF-EMF doses due to several RF-EMF exposure sources (Birks et al., 2020; Liorni et al., 2020; van Wel et al., 2020). This model is built using information on the use of mobile communication devices (i.e. near-field RF-EMF sources) and estimations of exposure to environmental RF-EMF sources (i.e. far-field RF-EMF sources).

2.2.1. Near-field RF-EMF sources

Information of the use of mobile communication devices close to the body was reported by one of the parents using questionnaires when participants were 9–12 years. Duration of use of (i) mobile phone for calling, (ii) DECT phone for calling, (iii) mobile phone for internet browsing, e-mailing, and text messaging while wirelessly connected to the internet (named other mobile phone uses), (iv) tablet while wirelessly connected to the internet, and (v) laptop while wirelessly connected to the internet were collected in minutes/day.

2.2.2. Far-field RF-EMF sources

We estimated RF-EMF exposure to different environmental RF-EMF sources (mobile phone base stations, FM radio and TV broadcast antennas, mobile phones, DECT phones, and WiFi) based on the microenvironments where preadolescents spend most of their time such as home, school, commuting, and outdoors.

To estimate RF-EMF exposure from mobile phone base stations at home, a validated 3D geospatial radio wave propagation model called NISMap was used (Beekhuizen et al., 2013, 2014; Bürgi et al., 2009; Huss et al., 2015). In brief, NISMap computes the field strengths induced by emissions from mobile phone base stations for any location in 3D-space using detailed characteristics of the antennas and the 3D geometry of the urban environment. The model has been validated with outside, inside, and personal measurements showing reliable rank-order predictions (Beekhuizen et al., 2013, 2014; Martens et al., 2015). We assessed the emission in three mobile phone communication bands that were in use at the time of the study (GSM900, GSM1800, and UMTS) using a country-wide mobile phone base stations data set from 2014. Using the geo-coded address of each child and the floor level of his/her bedroom at the time of the brain imaging, we computed the RF-EMF exposure from mobile phone base stations at each preadolescent's bedroom.

RF-EMF exposure from mobile phone base stations in the other microenvironments besides home and from the other far-field RF-EMF sources (FM radio and TV broadcast antennas, mobile phones, DECT phones, and WiFi) in all microenvironments was approximated using the average of personal RF-EMF measurements of up to 72 hours by 56 preadolescents of around 12 years of age in Amsterdam in a previous study (Birks et al., 2018), as data was not available for the participants of the Generation R Study.

2.2.3. Integrated RF-EMF exposure model

We applied the integrated RF-EMF exposure model to estimate whole-brain and lobe-specific (i.e. frontal, parietal, temporal, occipital) RF-EMF doses (Birks et al., 2020; Liorni et al., 2020; van Wel et al., 2020). Briefly, the model combines three types of information: i) the estimated ratio of the absorbed power to the mass in which it is absorbed of each specific RF-EMF source for each brain region which already takes into account the protection role of the head, known as specific absorption rate (SAR, in Watts (W)/kilogram (kg)), normalized to 1 W output power, ii) the output power of each RF-EMF source and activity (in W), and iii) the daily duration of use or exposure of each RF-EMF source and activity (in minutes (min)/day). First, for each brain region the model estimated a specific RF-EMF dose (millijoules (mJ)/kg/day) to each RF-EMF source (mobile phone calls, DECT phone calls, other mobile phone uses, tablet use, laptop use, and far-field) as follows:

$$\textbf{Specific RF-EMF dose}_{\text{brain region, source}} = \textbf{SAR}_{\text{brain region, source}} \times \textbf{Output power}_{\text{source}} \times \textbf{Duration}_{\text{source}} \tag{1}$$

Then, overall whole-brain RF-EMF doses and overall frontal, parietal, temporal, and occipital RF-EMF doses were calculated combining the specific RF-EMF doses of all RF-EMF sources by brain region:

$$\textbf{Overall RF-EMF dose}_{\text{brain region}} = \sum\nolimits_{\text{source}} (\textbf{SAR}_{\text{brain region, source}} \times \textbf{Output power}_{\text{source}} \times \textbf{Duration}_{\text{source}}) \tag{2}$$

Moreover, whole-brain and lobe-specific RF-EMF doses for three groups of RF-EMF exposure sources ((i) mobile and DECT phone calls (named phone calls), (ii) other mobile phone uses, tablet use, and laptop use while wirelessly connected to the internet (named screen activities), and (iii) far-field sources) were calculated following the same procedure.

To apply the integrated RF-EMF exposure model, we had to make some assumptions (van Wel et al., 2020). Based on the mobile phone use in preadolescents, adolescents, and young adults in Europe collected in the same period of time than in our study, we assumed a proportion of 35% 2G calls, 65% 3G calls, and no hands-free devices use (Langer et al., 2017). Other mobile phone uses, laptop use, and tablet use were assumed to occur using WiFi at 2.4 GHz and WiFi data transfer rates were estimated to be 54 Megabits per second. During the timeslots where preadolescents were using other mobile phone uses, we assumed that preadolescents were 40% of that time playing video games, 40% of that time streaming video, and 20% of that time browsing the internet or checking social media. For each device and activity, we averaged the SAR values from the different possible positions of use available to obtain one SAR value per activity that could be inserted in Equation (1) and (2).

2.3. Brain volumes

To familiarize the participating preadolescents with magnetic resonance environment, each preadolescent underwent a mock scanning session prior to the actual MRI session (White et al., 2018). The scans were performed on a 3 Tesla General Electric scanner (GE, MR750W, Milwaukee, USA) using an 8-channel receive-only head coil. The structural T1 images were obtained using the following sequence parameters: TR = 8.77 ms; TE = 3.4 ms; TI = 600 ms; Flip Angle = 10°; FOV = 220 mm × 220 mm; acquisition matrix = 220 × 220; slice thickness = 1 mm; number of slices = 230; voxel size = 1 mm × 1 mm × 1 mm; and ARC Acceleration = 2. The obtained T1 images were then processed through the FreeSurfer analysis suite, version 6.0 (Fischl, 2012). Global metrics of cortical and subcortical volumes were extracted. For our analysis we included the volumes of the total brain, cortical gray matter, cortical white matter, cerebellar gray matter, and cerebellar white matter as global brain volumes. The volumes of frontal, parietal, temporal, and occipital lobes were included as cortical lobar volumes. The volumes of the hippocampus, amygdala, thalamus, putamen, caudate, nucleus accumbens, and pallidum were considered as subcortical volumes (Supplementary Table S1). The pre-processing, correction, and assessment of the quality of the images are described in detail elsewhere (Muetzel et al., 2018).

2.4. Potential confounding variables

The potential confounding variables were *a priori* defined with a Directed Acyclic Graph (Hernán et al., 2002). Maternal and family characteristics included maternal ethnicity (Dutch, Asian, African, or European and others) collected during pregnancy, maternal educational level (primary or lower (low), secondary (medium), or university or higher (high)) collected when the child was 5 years old, as well as maternal smoking (yes vs. no), employment status (paid vs. non-paid), household income (< 2000€/month (low), 2000–3999€ (medium), or > 3999€ (high)) and anxiety and depressive symptoms assessed using the Brief Symptom Inventory (de Beurs and Zitman, 2006; L.R. Derogatis and N. Melisaratos, 1983) collected when the child was 9–12 years old. Preadolescent's characteristics included age at the brain imaging assessment, sex collected at birth, intelligence quotient assessed using the Snijders-Oomen Nonverbal Intelligence test (Tellegen et al., 1998) at 5 years old, and body mass index (kg/m^2) measured at 9–12 years old.

2.5. Other covariates

We also collected information on preadolescent's handedness due to the previously reported differences in brain volumes between right and left-handers (Jang et al., 2017).

2.6. Statistical analysis

After checking that all assumptions of the models were fulfilled, we used linear regression models to assess the association between overall and source-specific whole-brain RF-EMF doses and global and subcortical brain volumes, and between overall and source-specific RF-EMF doses to each specific lobe and cortical lobar volumes. We also adjusted our models for the potential confounding variables described above and preadolescent's handedness. All models were corrected for multiple testing using false discovery rate (Simes, 1986). We applied false discovery rating at once to a total of 64 tests and we obtained corrected critical p-values for each association. Additionally, we adjusted cortical lobar volumes, subcortical volumes, and cortical gray matter, cortical white matter, cerebellar cortex, and cerebellar white matter volumes for intracranial volume to ascertain relativity to the head size. Total brain volume was not adjusted for intracranial volume because they were highly correlated ($r = 0.93$).

Multiple imputation of missing confounding variables was performed using chained equations where 25 completed datasets were generated and analyzed (Nguyen et al., 2017). The percentage of missing values was < 18% and distributions in imputed datasets were very similar to those in the observed dataset (data not shown). Preadolescents included in the analysis ($n = 2592$) were more likely to have parents with a higher level of education, with a higher household income, and older compared with those non-included ($n = 7309$) (Supplementary Table S2). We used inverse probability weighting to correct for loss to follow-up and account for potential selection bias when including only preadolescents with available data ($n = 2592$) compared to the full cohort recruited at pregnancy ($n = 9901$).

All analyses were performed using Stata version 15 (StataCorp, College Station, TX).

3. Results

Most of the preadolescents had Dutch and highly educated mothers and were from middle or high income families (Table 1). Estimated overall whole-brain RF-EMF dose was 84.3 mJ/kg/day and the highest dose was estimated in the temporal lobe (307.1 mJ/kg/day). The major contributor to the overall whole-brain RF-EMF dose was the dose from mobile and DECT phone calls (61.5%) while the dose from screen activities with mobile communication devices while wirelessly connected to the internet and from far-field sources contributed 17.4% and 21.1%, respectively (Supplementary Table S3). These percentages varied between each lobe-specific RF-EMF dose. Overall whole-brain RF-EMF dose was highly correlated with overall lobe-specific RF-EMF doses ($r > 0.79$) and source-specific whole-brain RF-EMF doses were not correlated between each other (between -0.02 and -0.12) (data not shown). The associations between maternal, family, preadolescents' characteristics and overall and source-specific estimated whole-brain RF-EMF doses are shown in Table S4.

None of the estimated whole-brain RF-EMF doses was associated with global brain volumes (Table 2). Regarding cortical lobar volumes, only higher estimated frontal RF-EMF dose from screen activities with mobile communication devices while wirelessly connected to the internet was related to a smaller frontal lobe volume [B − 39.72 mm^3 (95% CI -78.23; -1.21)] (Table 3). However, this association did not remain after correcting for multiple testing. Overall estimated whole-brain RF-EMF dose and whole-brain RF-EMF dose from mobile and DECT phone calls and from far-field sources were not related to subcortical volumes (Table 4). However, higher estimated whole-brain RF-EMF dose from screen activities with mobile communication devices while wirelessly connected to the internet was associated with smaller caudate volume [B -5.02 mm^3 (95% CI -7.78; -2.25)] and this association remained after correcting for multiple testing. Associations did not materially change after adjusting for intracranial volume (data not shown).

4. Discussion

In the present study, we applied an improved integrated RF-EMF exposure model to estimate whole-brain and lobe-specific RF-EMF doses including several RF-EMF exposure sources and we investigated their association with brain volumes in preadolescents at 9–12 years of age. We did not find a relationship of estimated whole-brain or lobe-specific RF-EMF doses from overall RF-EMF sources, from mobile and DECT phone calls, or from far-field sources with global, cortical, or subcortical brain volumes. However, we found an association between higher estimated whole-brain RF-EMF dose from mobile phone use for internet browsing, e-mailing, and text messaging, tablet use, and laptop use while wirelessly connected to the internet, a group of RF-EMF sources that lead to low RF-EMF exposure to the brain, and smaller caudate volume.

We conducted the first epidemiological study exploring the relationship of RF-EMF brain doses with brain volumes in preadolescents. Most of the previous studies have assessed the association between the different RF-EMF sources separately and the development of the brain, but our integrative approach allows a more comprehensive assessment of the overall brain dose from several RF-EMF sources, as well as the brain dose from three groups of RF-EMF sources that lead to a different pattern of RF-EMF exposure. We did not find an association between estimated whole-brain or lobe-specific RF-EMF doses from overall RF-EMF sources or from mobile and DECT phone calls and brain volumes.

Table 1
Distribution of maternal, family, and preadolescent characteristics, and overall whole-brain and lobe-specific RF-EMF doses ($n = 2592$).

	Distribution
Maternal characteristics	
Ethnicity, %	
Dutch	60.9
Asian	19.6
African	10.1
European and others	9.4
Educational level, %	
High	54.9
Medium	39.2
Low	5.9
Smoking (yes vs. no), %	13.5
Depressive symptoms[a], median (IQR)	0.0 (0.0; 0.2)
Anxiety symptoms[a], median (IQR)	0.2 (0.0; 0.3)
Employment status (paid vs. non-paid), %	79.4
Family characteristics	
Household income, %	
High	42.3
Medium	39.2
Low	18.5
Preadolescent characteristics	
Sex (female vs. male), %	50.7
Age (in years), median (IQR)	9.9 (9.8; 10.3)
IQ score at 5 years old[b], median (IQR)	103.0 (93.0; 113.0)
BMI at 9–12 years old (kg/m^2), median (IQR)	16.9 (15.7; 18.6)
Overall RF-EMF doses	
Whole-brain (mJ/kg/day), median (IQR)	84.3 (43.4; 155.5)
Frontal lobe (mJ/kg/day), median (IQR)	111.8 (66.5; 202.0)
Parietal lobe (mJ/kg/day), median (IQR)	81.6 (57.6; 147.0)
Temporal lobe (mJ/kg/day), median (IQR)	307.1 (70.8;612.8)
Occipital lobe (mJ/kg/day), median (IQR)	100.6 (62.3; 179.9)

BMI, body mass index; IQ, intelligence quotient; IQR, interquartile range; mJ, milijoules; kg, kilograms; RF-EMF, Radiofrequency Electromagnetic Fields.
If there are two categories: the listed percentage indicates the fraction in the first category.
[a] Higher score indicates more symptoms.
[b] Higher score indicates higher IQ.

Table 2
Association between estimated overall and source-specific whole-brain RF-EMF doses and global brain volumes (mm^3) in preadolescents at 9–12 years of age.

Whole-brain RF-EMF doses (Δ1 mJ/kg/day)	**Total brain B (95% CI)**	**Cortical gray matter B (95% CI)**	**Cortical white matter B (95% CI)**	**Cerebellar cortex B (95% CI)**	**Cerebellar white matter B (95% CI)**
Overall dose	−1.29 (−9.91; 7.32)	−0.97 (−5.24; 3.31)	−0.79 (−4.74; 3.16)	0.26 (−0.66; 1.18)	0.20 (−0.05; 0.44)
Specific doses					
Phone calls	−0.69 (−9.41; 8.03)	−0.68 (−5.01; 3.64)	−0.54 (−4.53; 3.46)	0.30 (−0.63; 1.23)	0.22 (−0.03; 0.47)
Screen activities[a]	−173.66 (−443.86; 96.53)	−60.22 (−194.31; 73.86)	−91.49 (−215.31; 32.33)	−12.20 (−41.07; 16.67)	−2.13 (−9.82; 5.57)
Far-field sources[b]	−20.74 (−79.40; 37.92)	−11.05 (−40.18; 18.08)	−8.04 (−34.91; 18.83)	−0.78 (−7.04; 5.49)	−0.64 (−2.31; 1.02)

B, Beta coefficient; CI, confidence interval; DECT, Digital Enhanced Cordless Telecommunications; kg, kilograms; mJ, millijoules; RF-EMF, Radiofrequency Electromagnetic Fields.
Linear regression models adjusted for maternal educational level, maternal ethnicity, maternal employment status, maternal smoking, maternal depressive and anxiety symptoms, household income, and child intelligence quotient, sex, age, body mass index, and handedness.
[a] Screen activities includes mobile phone use for internet browsing, e-mailing, and text messaging, tablet use, and laptop use while wirelessly connected to the internet.
[b] RF-EMF exposure from different environmental RF-EMF sources (mobile phone base stations, FM radio and TV broadcast antennas, mobile phones, DECT phones, and WiFi) from different microenvironments (home, school, commuting, and outdoors).

However, higher estimated whole-brain RF-EMF dose from other mobile phone uses, tablet use, and laptop use while wirelessly connected to the internet was associated with a smaller caudate volume. If this observed association was driven by the RF-EMF dose that the brain absorbs from the use of the mobile communication devices, we would expect to also find an association with the brain dose received from mobile and DECT phone calls. These are the primary contributors of RF-EMF exposure to the brain leading to peak exposures very close to the head, while mobile phone use for internet browsing, e-mailing, and text messaging, tablet use, and laptop use while wirelessly connected to the internet lead to low RF-EMF exposure to the brain including the subcortical brain structures such as the caudate (Birks et al., 2020). Thus there is concern whether the possible health effects of these specific uses of mobile phone, tablet, and laptop are due to social or individual factors related to the time preadolescents spend with these devices or the specific activities that they undertake with these devices instead of their emitted RF-EMF exposure. In our study, almost all participants reported to use these mobile communication devices always wirelessly connected to the internet, thus the estimated RF-EMF brain dose from each device and the reported time spent with each device were highly correlated (between 0.75 and 0.99). Hence, we were unable to disentangle them. Moreover, we might miss relevant information related to the use of these mobile communication devices which is essential for properly studying its relationship with brain development (e.g. type of screen activity performed with these devices, family structure, psychological well-being, or relationship with friends). Therefore, we cannot entirely discard that our results are due to residual confounding or to chance finding. Moreover, reverse causality could also explain our results. Children and young adults with some psychiatric disorders such as Attention-Deficit/Hyperactivity Disorder have been shown to have a smaller caudate brain volume (Greven et al., 2015; Hoogman et al., 2017; Voelbel et al., 2006), and it could be hypothesized that individuals with these disorders have a higher use of mobile communication devices. Given that the potential relationship of RF-EMF exposure and brain volumes was not investigated to date, our analysis was exploratory and needs to be replicated in other population-based studies. Moreover, further studies are warranted due to the expected increase in the use of mobile communication devices and changes in RF-EMF exposure (e.g. introduction of new devices to the market, changes in the patterns of use such as more texting and less calling, or changes in network and devices characteristics such as the introduction of the 5G technology).

Experimental studies in animals have previously showed that exposure to RF-EMF is related to brain morphology alterations. In particular, higher RF-EMF exposure induced denditric remodelling and decreased viable cells in the hippocampus and the amygdala in rats

Table 3
Association between estimated overall and source-specific RF-EMF doses to each brain lobe and cortical lobar volumes (mm^3) in preadolescents at 9–12 years of age.

Lobe-specific RF-EMF doses (Δ1 mJ/kg/day)	**Frontal lobe B (95% CI)**	**Parietal lobe B (95% CI)**	**Temporal lobe B (95% CI)**	**Occipital lobe B (95% CI)**
Overall dose	−0.19 (−1.89; 1.51)	−1.43 (−3.84; 0.98)	0.01 (−0.18; 0.20)	−0.36 (−1.13; 0.42)
Specific doses				
Phone calls	−0.04 (−1.84; 1.77)	−2.16 (−6.18; 1.87)	0.01 (−0.18; 0.21)	0.01 (−0.91; 0.93)
Screen activities[a]	**−39.72 (−78.23; −1.21)**	−17.89 (−61.11; 25.32)	−29.37 (−94.41; 35.67)	−2.68 (−26.11; 20.75)
Far-field sources[b]	−0.80 (−5.96; 4.37)	−0.97 (−3.99; 2.05)	−0.83 (−4.36; 2.71)	−1.29 (−2.74; 0.16)

B, Beta coefficient; CI, confidence interval; DECT, Digital Enhanced Cordless Telecommunications; kg, kilograms; mJ, millijoules; RF-EMF, Radiofrequency Electromagnetic Fields.
Linear regression models adjusted for maternal educational level, maternal ethnicity, maternal employment status, maternal smoking, maternal depressive and anxiety symptoms, household income, and child intelligence quotient, sex, age, body mass index, and handedness. In bold, p-value < 0.05.
[a] Screen activities includes mobile phone use for internet browsing, e-mailing, and text messaging, tablet use, and laptop use while wirelessly connected to the internet.
[b] RF-EMF exposure from different environmental RF-EMF sources (mobile phone base stations, FM radio and TV broadcast antennas, mobile phones, DECT phones, and WiFi) from different microenvironments (home, school, commuting, and outdoors).

Table 4
Association between estimated overall and source-specific whole-brain RF-EMF doses and subcortical volumes (mm^3) in preadolescents at 9–12 years of age.

Whole-brain RF-EMF doses (Δ1 mJ/kg/day)	**Hippocampus B (95% CI)**	**Amygdala B (95% CI)**	**Thalamus B (95% CI)**	**Putamen B (95% CI)**	**Caudate B (95% CI)**	**Nucleus accumbens B (95% CI)**	**Pallidum B (95% CI)**
Overall dose	−0.02 (−0.08; 0.05)	0.00 (−0.04; 0.03)	0.01 (−0.10; 0.12)	0.03 (−0.06; 0.13)	−0.02 (−0.11; 0.07)	0.01 (−0.01; 0.03)	0.00 (−0.03; 0.04)
Specific doses							
Phone calls	−0.02 (−0.08; 0.05)	0.00 (−0.03; 0.03)	0.02 (−0.10; 0.13)	0.03 (−0.07; 0.13)	−0.01 (−0.10; 0.08)	0.01 (−0.01; 0.03)	0.00 (−0.03; 0.04)
Screen activities[a]Screen activities[a]	0.86 (−1.13; 2.85)	0.13 (−0.89; 1.15)	−1.34 (−4.91; 2.22)	−0.38 (−3.46; 2.70)	**−5.02 (−7.78; −2.25)***	−0.48 (−1.02; 0.06)	−0.93 (−2.07; 0.22)
Far-field sources[b]	−0.05 (−0.49; 0.38)	−0.12 (−0.34; 0.10)	−0.19 (−0.96; 0.58)	0.30 (−0.36; 0.97)	−0.29 (−0.89; 0.31)	0.05 (−0.07; 0.17)	0.05 (−0.20; 0.30)

B, Beta coefficient; CI, confidence interval; DECT, Digital Enhanced Cordless Telecommunications; kg, kilograms; mJ, millijoules; RF-EMF, Radiofrequency Electromagnetic Fields.
Linear regression models adjusted for maternal educational level, maternal ethnicity, maternal employment status, maternal smoking; maternal depressive and anxiety symptoms, household income, and child intelligence quotient, sex, age, body mass index, and handedness. In bold and *, associations that remained after correction for multiple testing (p-value < corrected critical p-value (0.0008)).

[a] Screen activities includes mobile phone use for internet browsing, e-mailing, and text messaging, tablet use, and laptop use while wirelessly connected to the internet.

[b] RF-EMF exposure from different environmental RF-EMF sources (mobile phone base stations, FM radio and TV broadcast antennas, mobile phones, DECT phones, and WiFi) from different microenvironments (home, school, commuting, and outdoors).

(Hussein et al., 2016; Li et al., 2012; Narayanan et al., 2010, 2015, 2018). In our study, we did not find an association between the brain RF-EMF doses and the volume of the hippocampus or the amygdala. Unfortunately, we could not estimate RF-EMF doses in these subcortical structures. Among other functions, the hippocampus plays an important role in the formation of new memories (Leszczynski, 2011) and the amygdala is involved in memory consolidation (McGaugh, 2004). Interestingly, a longitudinal epidemiological study found that a higher estimated whole-brain RF-EMF dose in preadolescents and adolescents with right-side preference for the phone calls was related to a decreased figural memory performance, which involves mainly the right hemisphere (Golby et al., 2001), and not to verbal memory performance, which involves mainly the left hemisphere, after one year of follow-up (Foerster et al., 2018). The authors suggested that the association between RF-EMF brain dose and memory might be driven by disturbed sleep (Foerster et al., 2018), as previous studies found alterations in the electroencephalogram (EEG) during sleep in participants exposed to RF-EMF (Loughran et al., 2012; Lustenberger et al., 2015; Regel et al., 2007; Schmid et al., 2012) and disturbed sleep have been related to poorer memory consolidation (Taveras et al., 2017) and disturbed subcortical structures such as hippocampus (Koyanagi et al., 2019; Sawangjit et al., 2018). The brain is dynamic and responds to many external inputs, including environmental exposures. This dynamism might not always translate to detectable structural brain alterations but to small brain activity changes that could explain the observed associations between RF-EMF exposure and impaired cognitive function in previous studies (Abramson et al., 2009; Bhatt et al., 2017; Calvente et al., 2016; Foerster et al., 2018; Guxens et al., 2016; Heinrich et al., 2010; Redmayne et al., 2016; Roser et al., 2016; Schoeni et al., 2015a, 2015b; Thomas, 2010; Zheng et al., 2014), as well as the observed brain effects in animal studies (Jang et al., 2017; Nguyen et al., 2017; Simes, 1986; Voelbel et al., 2006; Tellegen et al., 1998). Studies investigating the relationship between brain exposure to RF-EMF and functional magnetic resonance imaging measures would be of interest.

The strengths of this study are the collection of detailed information on the use of mobile communication devices in a large cohort of preadolescents, the estimation of whole-brain and lobe-specific RF-EMF doses including a large number of RF-EMF exposure sources, and the availability of brain structural imaging data for about 2500 participants. The main limitation of this study is its cross-sectional design. If an association between RF-EMF exposure to the brain and brain volumes exists, effects might appear after a longer cumulative exposure. Thus studies with longitudinal data on both the use of mobile communication devices and brain volumes are needed. Moreover, we used an innovative and comprehensive tool to estimate brain RF-EMF doses but it builds on several assumptions which could lead to non-differential misclassification of the exposure leading to a potential underestimation of the effect estimates (Liorni et al., 2020; van Wel et al., 2020). In addition, the use of mobile communication devices was reported by the parents and did not include its use at school which might underestimate the actual use. Objective measures such as applications installed in preadolescents' devices tracking their actual use, previously validated, could be used in new studies to improve accuracy of the measurement of the use of mobile communication devices. Finally, although we adjusted our models for several potential confounding variables we cannot discard residual confounding for unavailable variables such as paternal socioeconomic status.

5. Conclusion

Our results suggest that estimated whole-brain and lobe-specific RF-EMF doses were not related to brain volumes in preadolescents aged 9–12 years. Our findings might also indicate that social or individual factors related to certain uses of mobile communication devices such as mobile phone use for internet browsing, e-mailing, and text messaging, tablet use, and laptop use while wirelessly connected to the internet, instead of the RF-EMF exposure to the brain by these uses, could be related to a smaller caudate volume, although we cannot discard residual confounding, chance finding, or reverse causality. Further studies on mobile communication devices and their potential negative associations with brain development are warranted, regardless whether associations are due to RF-EMF exposure or to other factors related to their use.

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CRediT authorship contribution statement

Alba Cabré-Riera: Conceptualization, Formal analysis, Investigation, Writing - original draft, Visualization. **Hanan El Marroun:** Conceptualization, Supervision, Writing - review & editing. **Ryan Muetzel:** Methodology, Software, Writing - review & editing. **Luuk van Wel:** Methodology, Software, Writing - review & editing. **Ilaria Liorni:** Methodology, Software, Writing - review & editing. **Arno Thielens:** Methodology, Writing - review & editing. **Laura Ellen Birks:** Formal analysis, Writing - review & editing. **Livia Pierotti:** Formal analysis, Writing - review & editing. **Anke Huss:** Funding acquisition, Writing - review & editing. **Wout Joseph:** Methodology, Funding acquisition, Writing - review & editing. **Joe Wiart:** Methodology, Writing - review & editing. **Myles Capstick:** Methodology, Funding acquisition, Writing - review & editing. **Manon Hillegers:** Funding acquisition, Writing - review & editing. **Roel Vermeulen:** Methodology, Funding acquisition, Writing - review & editing. **Elisabeth Cardis:** Funding acquisition, Writing - review & editing. **Martine Vrijheid:** Funding acquisition, Writing - review & editing. **Tonya White:** Methodology, Funding acquisition, Writing - review & editing. **Martin Röösli:** Conceptualization, Funding acquisition, Writing - review & editing. **Henning Tiemeier:** Conceptualization, Funding acquisition, Writing - review & editing. **Mònica Guxens:** Conceptualization, Funding acquisition, Supervision, Writing - review & editing.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2020.105808.

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Original Article
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Anatomy Section

Effect of 1800-2100 MHz Electromagnetic Radiation on Learning-Memory and Hippocampal Morphology in Swiss Albino Mice

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ABSTRACT

Introduction: With advancing technology the mobile phone with multiple features is used as a multipurpose device and attract people of all age groups. Increased usage of mobile phone raises the question of possible adverse effects on health.

Aim: To assess the 1800-2100 MHz radiation effect on learning-memory and microscopic anatomy of hippocampal Cornu Ammonis (CA3) neurons in mice.

Materials and Methods: A total of 18 albino mice were divided into 3 groups (6 Mice per group). Group-I: Control Group, Group-II: Exposed to Radio frequency-Electromagnetic radiation (RF-EMR) for 30 minutes/day for 3 months, Group-III: Exposed to RF-EMR for 60 minutes/day for 3 months. Followed by the exposure, learning memory was assessed by using Hebb-Williams maze in all the groups. The mice were then sacrificed, brains were dissected out and sections were taken at the level of hippocampus and then stained with Haematoxylin and Eosin for microscopy. The results were expressed in Mean±SD and analysed by using one-way (analysis of variance) ANOVA followed by LSD (Least Square Difference) test for paired wise data. The p-value<0.05 was considered as statistically significant.

Results: The time taken by the animal to reach the target chamber was significantly increased in Group-III (exposed 60 minutes/day for 3 months), whereas group-II (exposed 30 minutes/day for 3 months) showed no significant changes when compared to Group-I (control group). Microscopic anatomy of hippocampal CA3 neurons in exposed group shows less number of pyramidal cells with darkened nuclei, cytoplasm was vacuolated and cells were scattered.

Conclusion: Exposure to 1800-2100 MHz radiation leads to damage and decrease of neurons in hippocampal region, which alters the learning and memory.

Keywords: Cornu ammonis, Hebb-Williams maze, Radio frequency

INTRODUCTION

The extensive use of Global System for Mobile communication (GSM) mobile phones throughout the world raises the possible adverse effects on human health especially on the Central Nervous System (CNS), the brain. In many countries more than half of the population relies/depend on mobiles for wireless communication and internet data [1]. In 2015, more than 7 billion people were using mobiles in the world, estimating to 62.9% of the world's population. Rapid increase of mobile users in general and specifically upto 80% of youngsters owning a mobile has made communication and technology easier [2].

In this concern, there is a growing interest in scientific community for the potential deleterious effects of Radio Frequency Electro Magnetic Radiation (RF EMR) on the public health, especially much focus on the effects of RF EMR on structural and functional integrity of the brain because the radiation exposure is directly to the head region [3]. In 2006 and 2010, World Health Organisation (WHO) issued a research agenda for high priority research on effects of RF exposure on ageing and neurodegenerative diseases in animals and effects of pre and post-natal RF exposure on development and behaviour in animals [4,5]. The mobile phone releases non-ionising radiation which has low frequency and considered to be safe, but recent studies evidenced that it has an impact on the living tissues especially on the brain which can cause headache, memory loss, heat over the ear, decreased concentration and other cognitive effects [6].

The hippocampus is a part of brain which belongs to the limbic system and is involved in cognitive functions like spatial learning and working memory. It plays a crucial role in the formation of new memories and it is considered as a sensitive region and is affected by mobile phone radiation. The hippocampus is a "S"-shaped folded structure located on the floor of the lateral ventricle on both the cerebral hemispheres. Hippocampal formation consists of hippocampus proper, dentate gyrus and subiculum. Hippocampus proper is also known as Cornu Ammonis (CA), which consists of CA1, CA2, CA3 and CA4 sub-regions [7].

Studies have found that damage to the hippocampal neurons may lead to impairment of memory and learning, behavioural disturbances and impact on Hypothalamo-Pituitary-Adrenal (HPA) axis [3,8,9]. The present study was undertaken to evaluate the long term exposure effect of mobile phone radiofrequency electromagnetic radiation-4G (1800-2100 MHz) on cognitive functions like spatial learning, working memory and hippocampal morphology in adult swiss albino mice.

MATERIALS AND METHODS

The Experimental study was carried out after the approval of Institutional Animal Ethical Committee (IAEC/PHARMA/SDUMC/2017-18/04). The study was conducted at central animal house Sri Devaraj Urs Medical College, Kolar from November 2017-January 2018, the duration of the study was 3 months.

Animals

Six weeks old healthy male Swiss-Albino Mice were used in this study, the animals were procured from Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA) registered brooders-Invivo Biosciences, Bengaluru.

The Swiss-Albino Mice were kept in polypropylene cages with a temperature of 23±2°C, humidity 55±5% and 10 hours light, 14 hours dark cycle and free access to standard pellet food and water ad libitum. The experimental animal care was taken as per the Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA) guidelines.

Inclusion and Exclusion Criterion

Male healthy active Swiss-Albino mice with average weight of 20 grams when procured were included in this study. Female swiss albino mice and lesser weight mice were excluded from this study.

Experiment Design

A total of 18 Male Swiss-Albino Mice were taken and they were divided into three groups.

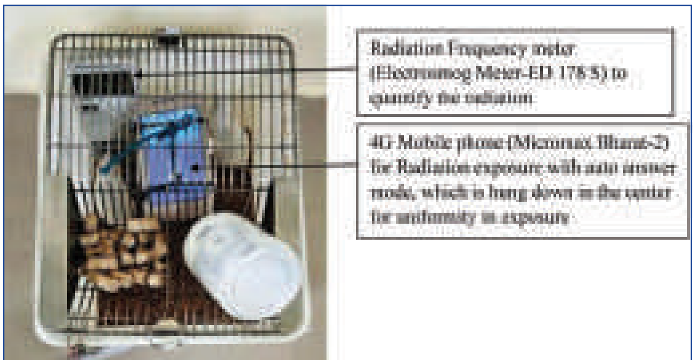
Group I: Control group-consists of 6 mice (non-exposed group).

Group II: 30 minutes exposure group-consists of 6 mice which were exposed to Mobile Phones (MP) RF-EMR for 30 minutes/day for 3 months.

Group III: 60 minutes exposure group-consists of 6 mice which were exposed to MP RF-EMR for 60 minutes/day for 3 months.

Mobile phone: 4G android mobile phones (Micromax Bharat-2 with a Specific Absorption Rate (SAR) of 1.6 Watt/Kg) with same specification and with same mobile network were used in this study, keeping a GSM (2100 MHz) mobile phone in silent with auto answer mode. The mobiles were hung down from the roof of the mice cage and the radiation which they emitted during the exposure was quantified by radiation frequency meter (Electrosmog Meter-ED 178 S) which was kept at the periphery, 1950 MHz of RF-EMR was emitting till the periphery of the mice cage during the exposure, so the similar amount of radiation may affect/enters the mice brain.

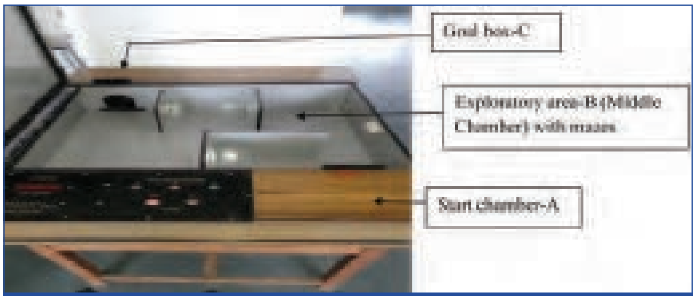
Exposure technique: Three Mice were kept in each cage during the exposure. Animals of group II and III were exposed to 30 minutes and 60 minutes/day for 3 months respectively. The mobile phones were hung down in the center of the cages during the exposure period for the uniformity of the radiation through out the cage [Table/Fig-1].



[Table/Fig-1]: Image shows the cage with mice and mobile phone during radiation exposure with Radiation Frequency Meter (Electrosmog Meter-ED 178 S) to quantify the mobile radiation.

Hebb-Williams Maze: Hebb-Williams Maze is used to test the spatial learning and working memory of the mice. The principle behind the Hebb-Williams Maze test is "The faster the mice navigates the maze, the better its spatial memory". The Hebb-Williams maze is a square shaped box which measures 60 cm (L)×60 cm (W)×10 cm (H) walls. It consists of start chamber-A (Animal Chamber) which is attached to the exploratory area-B (Middle Chamber) and a goal box-C, located at the opposite end of the start chamber and contains a small food reward. All three chambers were provided with removable doors to allow the animal to move from one chamber to the next.

After 12 hours of fasting, the mice was placed in the start chamber-A and allowed to enter into the exploratory area-B (middle chamber), once the animal enters into middle chamber the door was closed to prevent back entry. The time taken by the animal to reach The Reward Chamber (TRC) from the start chamber was recorded. The animals were trained for 3 days (3 trials/day) and the readings were taken at the 4th day. Low scores indicates better memory, while the high scores indicates poor memory in animals [Table/Fig-2] [10,11].



[Table/Fig-2]: Hebb-Williams Maze instrument to assess the spatial learning and working memory in Swiss-Albino mice.

Tissue Processing

After the behavioural analysis the mice were euthanized, perfused transcardially with normal saline and the brains were extracted out, fixed in 10% buffered formalin, dehydrated in ascending grades of ethyl based alcohol like 60%, 70%, 80%, 90% and absolute alcohol, cleared in xylene, impregnated in paraffin wax at 60°C, embedded with the help of L-moulds and then 6 μm paraffin sections were taken using rotary microtome at the level of the dorsal hippocampus to assess the hippocampal CA3 cellular architecture with the help of H and E staining. To prevent the bias, every 5th section was taken and the slides were decoded after the histological assessment. Viable neuronal quantification was assessed with the help of ocular micrometer fixed to light microscope (40X).

STATISTICAL ANALYSIS

The results were expressed in Mean±SD and analysed by using one-way ANOVA followed by Least Square Difference (LSD) test for paired wise data. The $p<0.05$ was considered as statistically significant.

RESULTS

Body Weights of the Mice

The mean body weight of the control group mice was 32.3 grams, 30 min/day radiation exposed mice for 3 months had 31.8 grams and 60 min/day radiation exposed mice for 3 months had 32.7 grams, the mean weight between the three groups didn't show any significant difference.

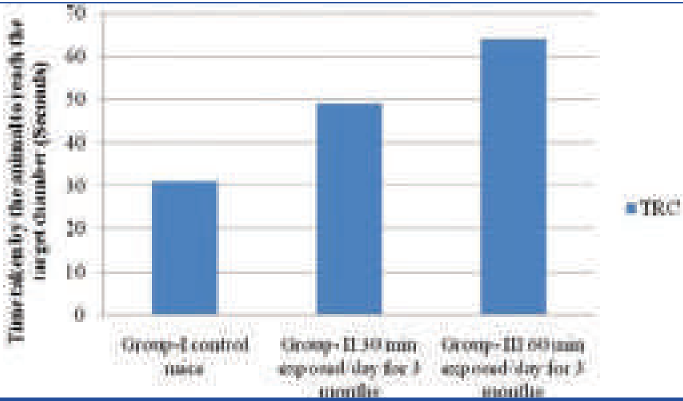
Effect of Radiation on Learning Memory in Hebb-Williams Maze

The time taken by the mice to reach the target chamber from the starting chamber was significantly increased in group II (30 min exposed/day) and group III (60 min exposed/day) compared to group I (non-exposed group).

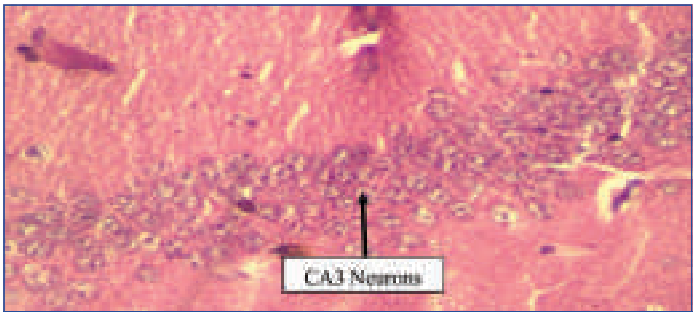
The time taken by the animal to reach The Reward Chamber (TRC) scores in Group I vs Group II (31±15.48 vs 49±17.62 seconds), was not significant ($p>0.05$); Group I vs Group III (31±15.48 vs 64±22.99 seconds), was statistically significant ($p<0.05$) [Table/Fig-3].

Microscopic Anatomy of Hippocampal Cornu Ammonis (CA3) Neurons

Histological sections of haematoxylin and eosin stained hippocampal CA3 pyramidal neurons showed marked difference between control group and RF-EMR exposed groups (group II and III). Sections of control group showed 5-6 layers of compactly arranged pyramidal cells which were healthy with clear nucleus [Table/Fig-4]. Group II (30 min exposure for 3 months) showed less number of pyramidal neurons with darkened nuclei (non-viable neurons) which was

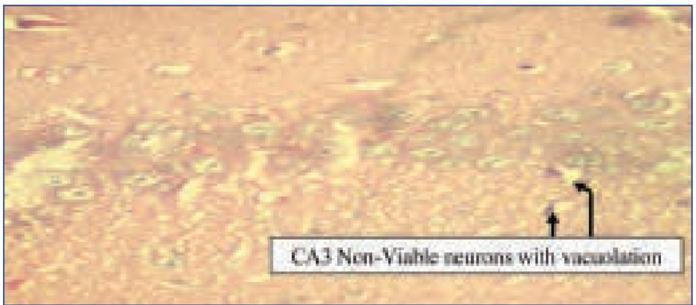


[Table/Fig-3]: Effect of Mobile phone radiofrequency-electro-magnetic radiation (MP RF-EMR) on learning and memory by using Hebb-Williams maze- group I, II and III.

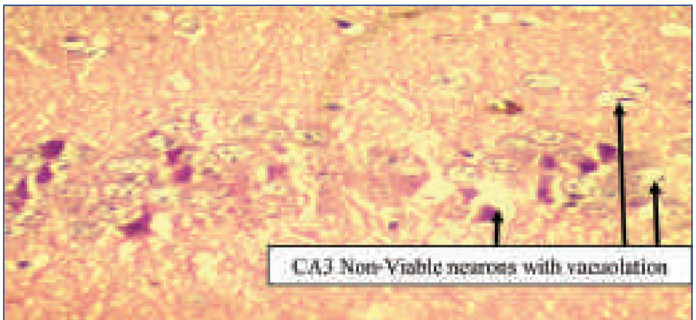


[Table/Fig-4]: Group I (non-exposed)-Control group H and E stained Hippocampal pyramidal normal neurons (Arrow) in high power (40X)

scattered when compared to control group [Table/Fig-5]. Group III (60 min exposure for 3 months) showed very less number of pyramidal neurons with more number of darkened nuclei (more non-viable neurons) with vacuolation in cytoplasm and scattered arrangement of pyramidal neurons when compared to group I and group II [Table/Fig-6].



[Table/Fig-5]: Group-II (30 min exposed for 3 months) H and E stained Hippocampal pyramidal neurons (Arrow) in high power (40X) showed less in number, Non-Viable and scattered with vacuolation in cytoplasm.



[Table/Fig-6]: Group- III (60 min exposed for 3 months) H and E stained Hippocampal pyramidal neurons (Arrow) in high power (40X) showed very less in number, Non-Viable and scattered with vacuolation in cytoplasm

DISCUSSION

With advancement of technology like 2G to 3G, 3G to 4G in the telecommunication field, the mobile phones are being used for communication, internet data and as multipurpose device. However over-usage of mobiles with advance multiple features has adverse effects on the brain especially on the hippocampus, which is a sensitive region on the temporal lobe of the brain responsible for spatial learning and working memory, an important cognitive function [7].

In this study, Hebb-Williams maze analysis was used to assess the learning and memory in albino mice exposed to mobile phone radiation frequency and control group [10,11]. In the present study, MP RF-EMR exposed mice took significantly increased time to reach the target chamber in Hebb-Williams maze when compared to the control group, which shows memory retention and memory retrieval is being affected and leads to memory impairment in the mice. Studies have shown that RF EMR exposure will impair the learning and memory, which may be due to neurodegenerative changes and alterations in the morphology of the hippocampus [7,8].

On histological examination, radiation exposed hippocampal CA3 neurons showed less number of pyramidal cells with darkened nuclei (Non-viable), vacuolated cytoplasm and cells were scattered in arrangement. The altered structural integrity in the hippocampus might be the cause for impairment of learning memory. Decrease in pyramidal cell count may be due to inhibition of neurogenesis and this was supported by Odaci E et al., [12]. Bolla SR reported that exposure to 800 MHz mobile radiation for 30 days leads to increased neuronal damage and decreased viable neurons in hippocampal CA3 region [9].

Nittby H et al., reported that exposure to 900 GSM radiation will reduce memory functions in rat, which is similar to our study [1]. MP RF exposure to 900-1800 MHz radiation leads to decrease in nuclear diameter and reduce neuronal density in the hippocampus [13]. Findings on exposure to 50-217 Hz low frequency radiation with television and mobile phone have impact on learning and memory [14]. Fragopoulou AF et al., reported that consolidation and retrieval memory deficits were observed in mice exposed to 9 hr 30 mins for 4 days with 900 MHz non-ionising radiation [15]. Heat shock proteins-HSP 27 and HSP 70 related stress levels are elevated in rat hippocampus exposed to 2450 MHz radiation [16]. A 2.14 GHz Radiation frequency exposure at 4 Watt/kg specific absorption rate increases the body temperature to 1.5°C compared to baseline and upregulates some stress markers like HSP and Heat Shock Transcription Factor (HSF) gene expressions in cerebellum and cerebral cortex [17].

LIMITATION

The outcome of the present rodent study may not extrapolate with human population due to many reasons like Thickness of the skull bone, Weight/Volume of the brain, Specific Absorption Rate (SAR), Duration of exposure, Frequency of radiation and Lifespan of the human population.

CONCLUSION

In this present study, we evaluated the chronic exposure effect of MP RF-EMR- 4G (1800-2100 MHz) on cognitive functions like spatial learning, working memory and hippocampal morphology in adult swiss albino mice. We observed that MP RF-EMR exposed mice took significantly increased time to reach the target chamber in Hebb-Williams maze when compared to the control group. Radiation exposed hippocampal CA3 neurons showed less number of pyramidal cells with darkened nuclei (Non-viable), vacuolation in cytoplasm and cells were scattered in arrangement. The altered structural integrity in the hippocampus may alter the spatial learning and memory.

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Original article

Effect of 2400 MHz mobile phone radiation exposure on the behavior and hippocampus morphology in Swiss mouse model

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ABSTRACT

Electromagnetic field exposure to the nervous system can cause neurological changes. The effects of extremely low-frequency electromagnetic fields, such as second-generation and third-generation radiation, have been studied in most studies. The current study aimed to explore fourth-generation cellular phone radiation on hippocampal morphology and behavior in mice. Swiss albino male mice (n = 30) were randomly categorized into 3 groups; control, 40 min, and 60 min exposure to 2400 MHz radiofrequency electromagnetic radiation (RF-EMR) daily for 60 days. The control mice were housed in the same environments but were not exposed to anything. Anxiety-like behaviors were tested using the elevated plus-maze. For histological and stereological examination, the brain was dissected from the cranial cavity. On Cresyl violet stained brain slices, the number of pyramidal neurons in the cornu ammonis of the hippocampus were counted. In exposed mice compared to control mice, a significant increase in anxiety-like behavior has been observed. Histological observations have shown many black and dark blue cytoplasmic cells with shrunken morphology degenerative alterations in the neuronal hippocampus in the radiation exposed mice. In the RF-EMR mouse hippocampus, stereological analyses revealed a significant decrease in pyramidal and granule neurons compared to controls. Our findings suggest that 2400-MHz RF-EMR cell phone radiation affects the structural integrity of the hippocampus, which would lead to behavioral changes such as anxiety. However, it alerts us to the possible long-term detrimental effects of exposure to RF-EMR.

1. Introduction

Mobile phones emit radiofrequency electromagnetic radiation (RF-EMR) surrounding them, which has negative health consequences. RF-EMR exposure can contribute to neurological and physiological alterations and behavioral abnormalities in adolescents and young adults. The radiation emitted from the mobile phone not only damages the brain and creates cognitive and behavioral deterioration (Cassel et al., 2004). Numerous experimental investigations on the impact of electromagnetic fields (EMF) on the brain and nervous system have been conducted (Bas et al., 2009a; Chen et al., 2014; Odaci et al., 2008). During the conversation with mobile phones, people usually bring one's cellphone near to their heads. As a result, the brain is more exposed to radiation than any other body part (Irmak et al., 2002). The frequency range of RF-EMR of mobile phones using the Global System for Mobile communication (GSM) system is 300 MHz (MHz) to 300 GHz (GHz) (Dubreuil et al., 2002). Smartphones operate on the 900–2600 MHz frequency all around the world. Male mice were exposed to 2400 MHz frequency RF-EMR for a long time in our study.

Previous findings have shown that oxidative stress responds to exposure to RF-EMR (Consales et al., 2012; Yüksel et al., 2016; Yurekli et al., 2006). Oxidants could interrupt cellular membrane enzyme activity, impair cellular activities, and perhaps lead to cell death (Achudume, A.C., Onibere, B., Nwoha, P., Alatise, O., Aina, 2012; Hasan et al., 2021b; Karim et al., 2020; Kobir et al., 2020). Most noticeable behavioral and cognitive disorders of the

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central nervous system identified in both people and animals regarding long-term smartphone radiation exposure (Babadi-Akashe et al., 2014; Söderqvist et al., 2015; Zhao et al., 2012). Exposure to EMF has indeed been documented to have a variety of neurological consequences, such as decreased number of Cornu Ammonis (CA) pyramidal and Purkinje cells (Aslan et al., 2017; Baş et al., 2013;Odaci et al., 2008; Şahin et al., 2015), increased dark cell cytoplasm (Salford et al., 2003), behavioral changes (Ikinci et al., 2013) and concentration disturbances (Dunusoy et al., 2017). Many research focused on behavioral problems caused by RF-EMR exposure, including learning and memory loss in rats (Lai et al., 1994; Wang and Lai, 2000). They reported that low-frequency RF-EMR affects spatial memory and places learning tasks in rodents through water mazes or radial arm mazes. Such findings suggest that people have no conscious awareness of EMF consequences due to the extensive overuse of mobile phones. EMF exposure has many reversible or permanent effects on nerve tissue. No long-term studies on the consequences of 2400 MHz fourth-generation (4G) cell phone radiation exposure on the nervous system have been done.

Therefore, this study has been conducted to explored and evaluate the impact of a 2400 MHz 4G RF-EMR from a cell phone on the brain of mice models, with particular attention to hippocampus morphology.

2. Materials and methods

2.1. Procedures involving animals and ethics

The study took place in the Anatomy and Histology Department, Faculty of Veterinary Science, Bangladesh. This study was approved by the Bangladesh Agricultural University Animal Ethics Committee (AWEEC/BAU/2019–46). The International Center for Diarrheal Disease Research (ICDDRB), Mohakhali, Dhaka, supplied healthy Swiss male albino mice (6 weeks old). At the time of collection, the average physical weight of the mice was 29 ± 5 g. The mice were housed in plastic cages 52 cm × 36 cm × 25 cm in a regulated temperature (24 ± 2 °C) setting with 12-hour light and 12 h dark cycle, 40 percent humidity, and regular feed and ad libitum drinking water.

2.2. Groups of experiment

Thirty male mice were used in this study. The mice were categorized into three groups (Groups I, II, and III) after 1-week acclimatization; each group contained ten mice (n = 10). The body weights were documented before radiation exposure begins. Group I was considered to control fed mice standard diet and fresh drinking water ad libitum without radiation exposure. Group II: Mice were exposed to 2400 MHz 4G modulated RF-EMR for 40 min/day for two months. Group III: Mice were exposed to 2400 MHz 4G modulated RF-EMR for 60 min/day for two months, simultaneously. Each group was kept in a rectangular plastic cage enclosed in a compartmentalized wire mesh.

2.3. Radiofrequency electromagnetic radiation (RF-EMR) exposure system

In this experiment, two 4G interconnected 2400 MHz mobile phones (Huawei GR5 2017) were used for radiation exposure with a Specific Absorption Rate (SAR) of 2.7 W/kg. During the exposure period, test animals were placed in plastic cages in the EMF exposure room. There are no other electric devices such as a PC, laptop, camera, or any EMF emitting sources in the EMF exposure room. The control room is separate from the EMF exposure room. The elevated plus-maze was situated in another room next to the EMF exposure room for the behavioral study. So, we ensured that there were no other sources of EMF. For uniform radiation exposure during the exposure time, the automatic answer mode mobile phone was positioned in the center of the mouse cage's roof (Kumar et al., 2009; Narayanan et al., 2009a). During the RF-EMR application, the temperature and humidity of the exposure room and the mouse cage were monitored daily with a digital thermometer. When radiation exposure was provided to mice, the intensity of electromagnetic radiation released by cell phones was measured in an interactive active call by the ED-78S Electrosmog frequency meter (CORNET Microsystem Inc., Santa Clara, CA 95,050 USA) with frequencies ranging from 100 kHz to 2.5 GHz and ensured that radiation exposure was evenly distributed on mice. The average power density in this study just before the radiation exposure was 530 $\mu W/cm^2$ and during the radiation exposure was 738 $\mu W/cm^2$. Every day, before RF-EMR exposure began, the intensity of RF-EMR of the mobile phone was determined. A call was given from another 4G connected 2400 MHz mobile phone to expose the mice. The mobile phone batteries were charged continuously. The experimental groups were continuously exposed to RF-EMR from mobile phones from 10.00 AM to 10.40 AM and 10.00 AM to 11.00 AM, daily for 60 days. Under standard lab conditions, the mice of the control group were maintained without exposure to electromagnetic radiation. The electric field or power density of radiofrequency electromagnetic radiation where the control group was also measured by the ED-78S Electrosmog frequency meter (CORNET Microsystem Inc., Santa Clara, CA 95,050 USA) and the frequencies ranging from 100 kHz to 2.5 GHz. This exposure system is similar to that used in earlier studies for the applications of 900 to 2400-MHz RF-EMR (Hasan et al., 2021a; Hasan and Islam, 2020; Narayanan et al., 2009b; Saikhedkar et al., 2014; Sokolovic et al., 2008).

2.4. Behavioural study

The elevated plus maze (EPM) is a method of assessing fear and anxiety-like responses in mice based on their natural preference for open, elevated areas (Pellow et al., 1985). In our study, the EPM framework was made from wood consisting of four arms (50 cm in length × 5 cm in wide) attached to the central pillar (5 cm × 5 cm): 40 cm high fences in closed arms but open arms have no wall. The maze is standing with four legs 70 cm above the floor. Mice are allowed to access all arms and walk freely around them. The closed arms, therefore, gave the animals a safe zone. Above the maze, a video camera was installed, and behind a white curtain, a monitor was placed. The testing room consisted of a large laboratory without sound attenuation facilities. After two months of exposure, all mice were tested. At the time of behavior testing, individual mice were weighed daily. Mice were familiar with the examination room half an hour before the behavior examination. Behavioral assessment was performed in a luminous red room. The EPM examination was conducted even though explained previously (Kauppila et al., 1991; Liu et al., 2002). On the central square, the Mice were placed with an open arm and allowed to explore the maze for five minutes; following that, the mouse was brought from the maze to its cage.

Before a new mouse was tested, the EPM apparatus was cleaned up with 20 percent alcohol to eliminate any putrid odor index. The movement and other behavioral activities of each mouse in the EPM were recorded used a video camera which was then analyzed using the automated tracking program Ethovision XT 10.1 version (Fig. 1A). The number of open and closed arms entrances and the length of time spent in the open arms were considered indications of fear and anxiety-like behavior. When the mouse had entirely reached the arm (4 legs in the arm), it counted one entry in a par-

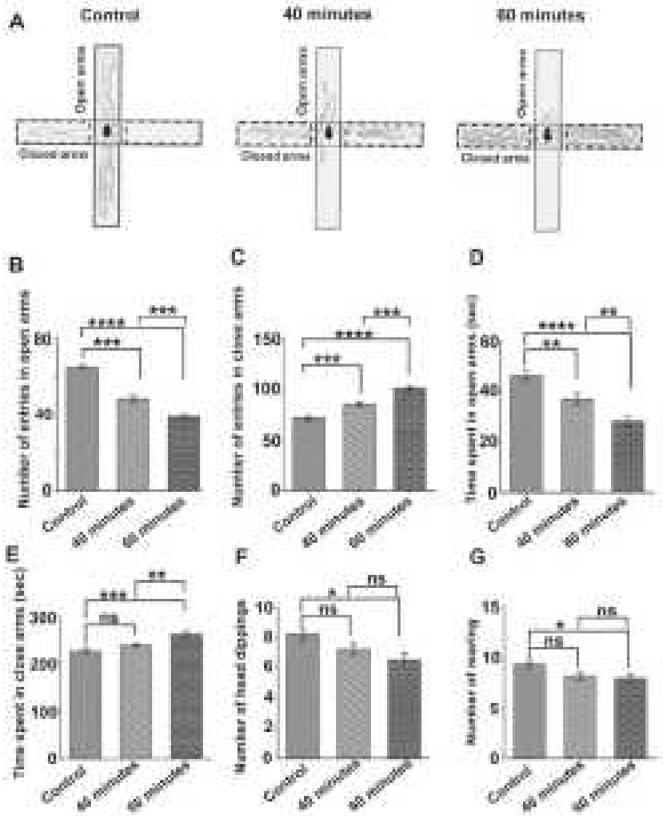

Fig. 1. (A). The movement track report of the elevated plus maze (EPM). (B-G) Histograms showing the behavioral parameters of the EPM test in the different experimental groups. The 40 and 60 min of exposed mice had significantly decreased in entry (B) and time spent (D) in the open arms relative to the control mice, while entry (C) and time spent (E) in closed arms were significantly increased. Compared to the 40-minute exposed mice, the 60-minute exposed mice had lower entrances (B) and time spent in the open arms (D). In 40 min, there were no significant changes in the number of head dippings (F) or rearing (G). However, a significant difference was observed in 60 min compared with the control mice. Results presented as Mean ± SEM (n = 10 mice in each group). "ns" indicates not significant ($p > 0.05$). (*) shows a statistically significant difference at the $p < 0.05$ level; (**) indicates a statistically significant difference at the $p < 0.01$ level; (***) indicates a statistically significant difference at the $p < 0.001$ level; (****) shows a statistically significant difference at the $p < 0.0001$ level.

ticular arm. The frequency of open and closed arms entrances, as well as the length of time spent on open and closed arms as well as the number of head dipping (mouse lowered its head toward the floor over the sides of the open arm), and rearing (mouse standing on hind legs with front paws against walls of the maze) behaviors were calculated and recorded from the plus-maze. The increase in the number of mice entering and the duration of stay in the open arms was considered an indicator of reduced anxiety (Pellow et al., 1985). The mice were sacrificed after the behavioral test, and the brain tissue was collected and separated from the hippocampus for histopathological study after proper perfusion fixation.

2.5. Tissue processing for histopathological studies

Each mouse was weighed and placed on an autopsy board after being thoroughly anesthetized.

Then the mice were preserved by perfusion method. Then the brain was removed from the cranial cavity, and it was kept in 10% formalin solution for post-fixation of 48 h. The gross analysis took into consideration factors such as color and weight. For the histological study, the brain's left hemisphere was trimmed into 5 mm^2 sizes. Then, the tissues were washed in PBS four times and each for 30 min; dehydration was done using an ascending grade of ethyl alcohol (70%, 80%, 95%, 100%, 100%, and 100%) solutions. The tissues were immersed in 70% ethyl alcohol overnight. The incubation time for 80% and 95% ethyl alcohol was 8 h; 100% ethyl alcohol was 2 h each time. The tissues were cleared in a series of xylene and embedded in paraffin. Then, a Leica rotary microtome was used, 5-μm thick serial slices were cut. Each mouse had twenty-five sections fixed sequentially on slides. Hematoxylin & Eosin (H & E) staining was performed for histopathological observation. Tissue processing and staining procedures have been carried out following (Drury, 1983).

Cresyl violet (CV) stain was also used for stereological analysis and quantification of neurons in the hippocampal subregions. The serial sections of the brain were deparaffinized in three changes of xylene for 5 min each. Then the sections were rehydrated in descending grade of ethyl alcohol of 5 concentrations for 5 min in each step. Then the sections were hydrated in deionized water for 5 min and finally stained with 0.1% aqueous solution of Cresyl violet stain for 20 min. Then the sections were differentiated with 70% alcohol for optimum staining and finally dehydrated with two changes of 90% absolute ethanol for 5 min each step. The sections were then air-dried for 10 min and cleared in two changes of xylene for 5 min each, and lastly, coverslipped with DPX.

2.6. Quantification of neurons in the hippocampus

In CV-stained brain sections, the numbers of normal viable neuron cells in different hippocampus areas were quantified. Fig. 3 displays areas that have been confined to the quantitative analysis of neurons in the hippocampus. The number of normal viable neurons in CA1, CA2, CA3 & DG regions of the hippocampus was anticipated for each animal. For Quantitative analysis, the brain sections were obtained from five different hippocampal areas of each group. The high-quality pictures were taken using a Nikon digital camera mounted to an Olympus microscope with 100X lenses (Olympus BX 51 photographic light microscope).

The normal viable neurons were quantified using the imaging program NIS Elements Br version 4.30 software (Joy et al., 2018; Madhyastha et al., 2002; Massand et al., 2020). CA1, CA2, CA3 cornu ammonis sub-regions have a length of 350 μm, and a 50-μm × 100-μm rectangle for the dentate gyrus (DG) granular layer of the hippocampus was chosen for quantification of viable neurons in each hippocampal image. The cell counts in the CA1, CA, and CA3 regions were represented as the number of cells per unit length of the cell field (cells/350 μm length) and the granule cells in the dentate gyrus were presented as the number of cells per unit area (cells/150 μ^2) (Govindaiah et al., 1997; Madhyastha et al., 2002; Wood et al., 1993). Degenerating neurons were characterized as deformed, shrunken, pyknotic, and hyperchromatic neurons, which had an indistinct border between the cytoplasm and nucleus. Neurons with a distinctive structure as well as a spherical nucleus were the normal assessment criteria. To avoid manual bias while counting the cells, slides from different groups of mice were coded. This same method of stereological analysis was also used by (Joy et al., 2018; Madhyastha et al., 2002).

2.7. Analysis of statistics

Graph pad prism software version 7.0 was used to conduct statistical analysis. To identify the differences between experimental control and exposed groups, one-way analysis of variance (ANOVA) followed by Tukeýs multiple comparison test was used. Statistical significance was considered as a P-value ≤ of 0.05.

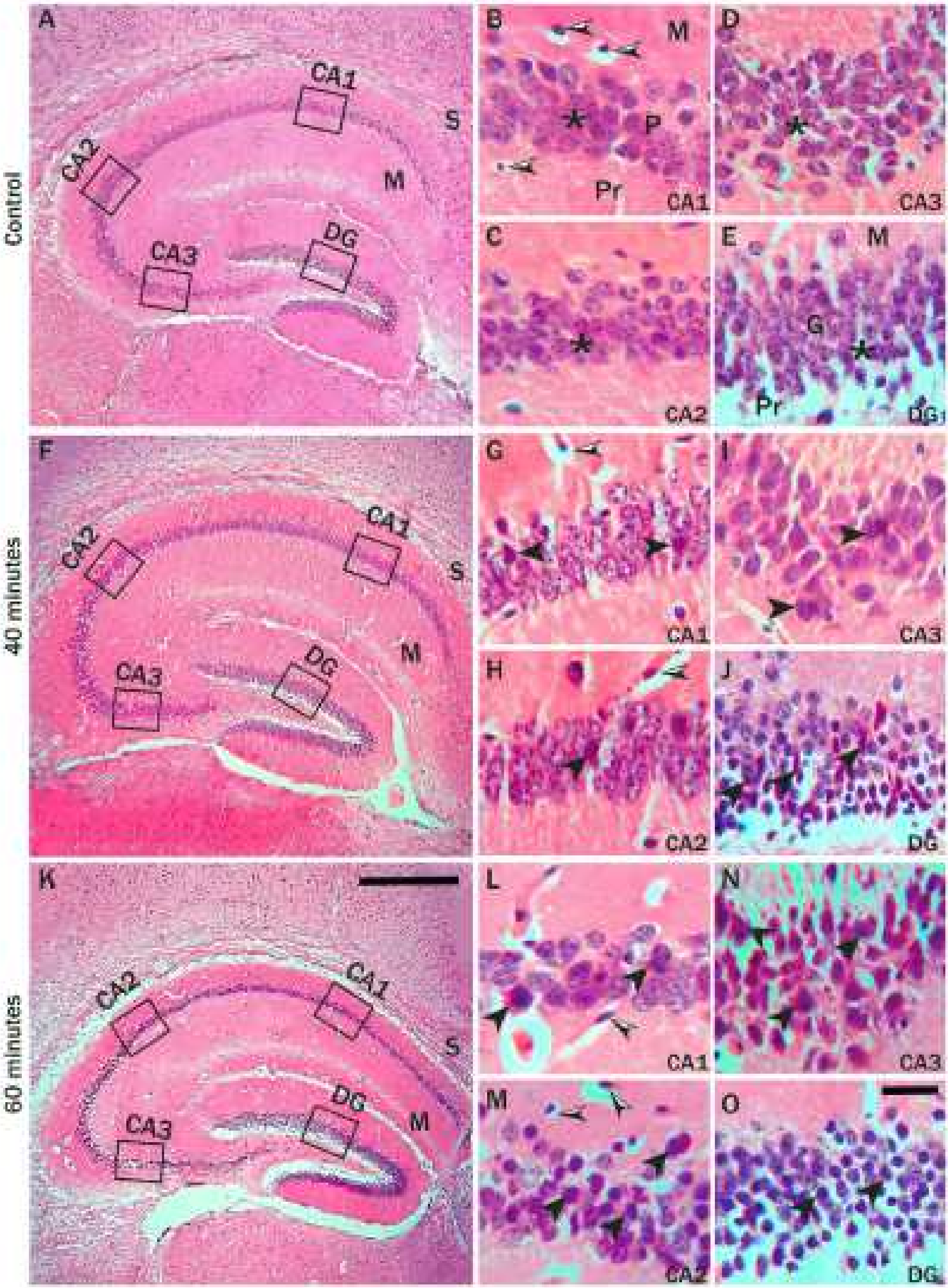

Fig. 2. Hematoxylin and Eosin-stained sections hippocampus of control (A-E), 40 min (F-J), and 60 min (K-O) exposed mice formed by Cornu Ammonis (CA) as CA1, CA2 & CA3 areas. It continued as a subiculum (S). Around the upper and lower limbs of CA3, the dentate gyrus (DG) is located. The Cornu Ammonis (CA) as CA1, CA2 & CA3 areas formed by three layers: the molecular layer (M), the pyramidal layer (P), and the polymorphic layer (Pr). The pyramidal layer contains pyramidal cells (stars), and both molecular & polymorphic layers contain astrocytes (black-white arrowheads). The dentate gyrus consists of the molecular layer (M), granular layer (G), and polymorphic layer (Pr). The granule cells in the granule layer were arranged in dense columns with large vesicular nuclei in control (E). In control mice (B-D), large vesicular healthy nuclei of pyramidal neuron cells. (G-I) representative microphotographs of CA1, CA2, CA3 region pyramidal layers of 40 min exposed mice showed degenerating neurons with darkly stained nuclei (arrowhead) with normal small dark nuclei astrocytes (black-white arrowheads) were observed. In the CA1, CA2, CA3 region 60 min radiation-exposed mice (L-N), there were more dark stained pyramidal neuron cells (arrowheads) compared to 40 min and control mice with normal small dark nuclei astrocytes (black-white arrowheads). In the DG of 40- and 60-minutes exposed mice (J & O), there was degeneration of granule cells with many dark-stained nuclei (arrowheads). However, the degenerated granule cells were more in 60 min compared to 40 min and control mice. Scale bar = 100 µm in A, F, K, and 20 µm in B-E, G-J, and L-O. (n = 10 mice in each group).

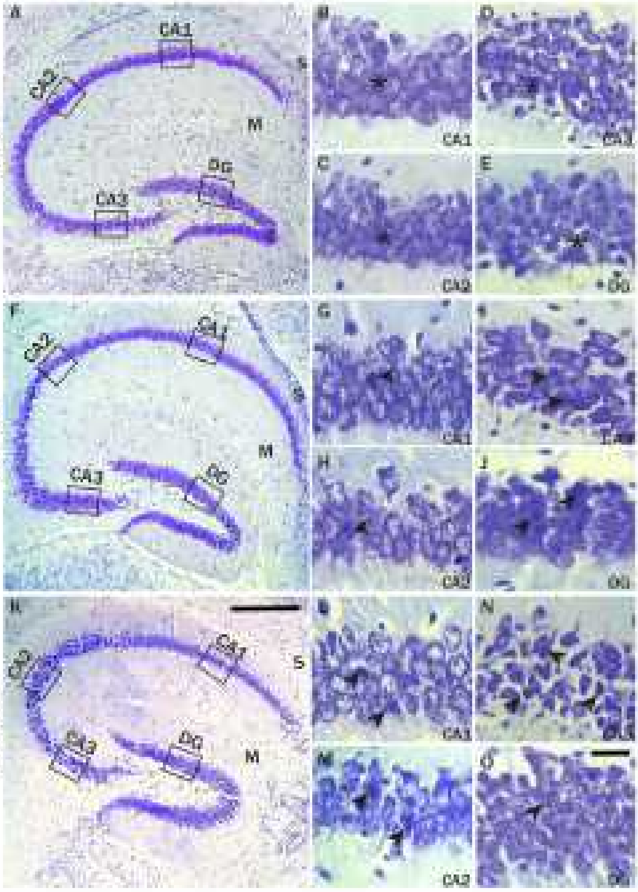

Fig. 3. Cresyl violet stained sections hippocampus of control (A–E), 40 min (F–J), and 60 min (K–O) exposed mice formed by Cornu Ammonis (CA) at CA1, CA2 & CA3 areas. It continued as a subiculum (S). Around the upper and lower limbs of CA3, the dentate gyrus (DG) is located. In control mice, the star indicates healthy neurons. The nuclei of cells and Nissl granular constituents of the cytoplasm appeared dark violet in all four regions in control mice (B-E). The rest of the cytoplasm appeared lightly stained. In radiation-exposed mice, the arrowheads represent degenerated neurons with dark cytoplasm and shrinkage in the cell body. In 40 min, exposed mouse pyramidal cells in CA1, CA2, CA3 regions (G, H, I) and granule cells (J) in the DG of the showed degenerated with darkly stained nuclei (arrowhead). In CA1, CA2, CA3 regions (L, M, N) and granular layer of the DG (O) of 60 min exposed mice showed the increased number of disorganized degenerated with darkly stained shrunken morphology pyramidal neuron cells (arrowhead) compared to the control and 40 min mice. Scale bar = 100 µm in A, F, K, and 20 µm in B-E, G-J, and L-O. (n = 10 mice in each group).

3. Results

3.1. Effects of RF-EMR exposure on anxiety-like behaviors

In this study, an EPM test was performed to assess the mouse's anxiogenic-like behavior exposed to 2400 MHz RF-EMR for two months. The frequency of entrances and duration spent in EPM's close arms and open arms is a measure of anxiety in mice. All mice in the control group were healthy and active without any unusual behavioral alterations during the entire experimental period. During the experiment, the mice' health conditions and their water and food consumption were checked daily. The Track Report (Fig. 1A) clearly shows that the control mice spent a significant amount of time in the open arms, but the exposed mice spent a greater amount of time in the closed arms. This means that the exposed mice have shown a reduced exploratory behavior and are more anxious than the control. This study indicated a significant reduction in open arm entrances in exposed mice, reflecting anxiety symptoms. In 40 min ($P \leq 0.001$), ($P \leq 0.01$), and 60 min ($P \leq 0.0001$), ($P \leq 0.0001$) of exposed mice compared with control mice, the entries (Fig. 1B) and time spent (Fig. 1D) in the open arm was reduced significantly.

In contrast, entry (Fig. 1C) and time spent (Fig. 1E) in closed arms were significantly enhanced in 40 min ($P \leq 0.001$), ($P \leq 0.0001$), and 60 min ($P \leq 0.0001$), ($P \leq 0.001$) exposed mice, respectively. The frequency of head dippings (Fig. 1F) and the number of rearing (Fig. 1G) was not significantly different in 40 min. However, a significant difference was found in 60 min ($P \leq 0.05$) than in the control mice. Statistical analysis indicated that 60 min of exposed mice showed a marked decline in open arm entry (Fig. 1B) and an increase in closed arm entry (Fig. 1C) compared with the 40 min group. It indicates that the mice exposed for 60 min ($P \leq 0.0001$) showed higher fear and anxiety-like behavior.

3.2. Histopathological study

3.2.1. Staining with hematoxylin and eosin

Microscopic observation of Hematoxylin and Eosin (H & E) stained hippocampus of control, 40- and 60-minutes exposed mice groups showing different regions of the hippocampus (Fig. 2). The Cornu Ammonis (CA) of the hippocampus is divided into CA1, CA2, and CA3 areas, with the dentate gyrus (DG) surrounding the upper and lower limbs of CA3. There was a regular form of pyramidal neuron cells in CA1, CA2, & CA3 regions (Fig. 2B, 2C, 2D) and granule cells in the DG (Fig. 2E), as well as there, were no dark cells in control mice. There have been some pathological changes in the hippocampus of mice that have been exposed to radiation compared to control mice. Pyramidal neurons exhibited degenerate neurons with black nuclei in CA1, CA2, CA3 area of 40 min exposed mouse (Fig. 2G, 2H, 2I). There was marked cellular degeneration with many dark granule cells in the granular layer of DG of 40-minute exposed mice (Fig. 2J). The pyramidal cells in the CA1, CA2, & CA3 areas of the hippocampus of 60 min exposed mice showed many dark stained irregular shape pyramidal neuronal cells with small dark nuclei compared to 40 min and control mice. In the DG of 60 min exposed mice, the granule cells showed excess degenerated dark cells (Fig. 2O).

3.2.2. Neuronal assay by cresyl violet staining

Cresyl Violet (CV) staining was performed to quantify the total number of normal pyramidal neurons of CA1, CA2, CA3 hippocampal regions, and granule cells in the granular layer of DG in different groups (Fig. 3). The nucleus and cytoplasm of neuron cells are shown in CV staining (Fig. 3A, 3F, 3 K). The nuclei are dark and appeared dark violet in all four regions in control mice (Fig. 3B, 3C, 3D, 3E). There were many abnormal sizes, and shaped cells among the normal pyramidal neurons in the RF-EMR exposed mice compared to the control. It is clearly shown that radiation exposure causes an irregular arrangement of the neurons, increasing darkly stained degenerated neurons and pyknosis. In CA1, CA2, CA3, and DG regions of 40 min, exposed mice showing darkly stained degenerated nuclei are interspersed between normal nerve cells (Fig. 3G, 3H, 3I, 3 J). Wherein 60 min exposed mice, indicating an increased number of disorganized and degenerated darkly stained shrunken morphology neuron cells compared to the control and 40 min mice (Fig. 3L, 3 M, 3 N, 3O).

The number of normal neurons in the hippocampus of exposed mice was significantly lower than the control ($P \leq 0.001$) (Fig. 4). CA1, CA2 and CA3 regions showed many pyknosis and degenerated neurons in exposed mice on CV staining (Fig. 3). In the CA1, CA2, & CA3 areas of the hippocampus of control mice, the total number of normal viable pyramidal neurons was 36.70 ± 1.13, 43.50 ± 0.98, 43.60 ± 1.14, and granule cell was 64.90 ± 1.57 in the DG region. In 40–60-minutes exposed mice, the total numbers of normal

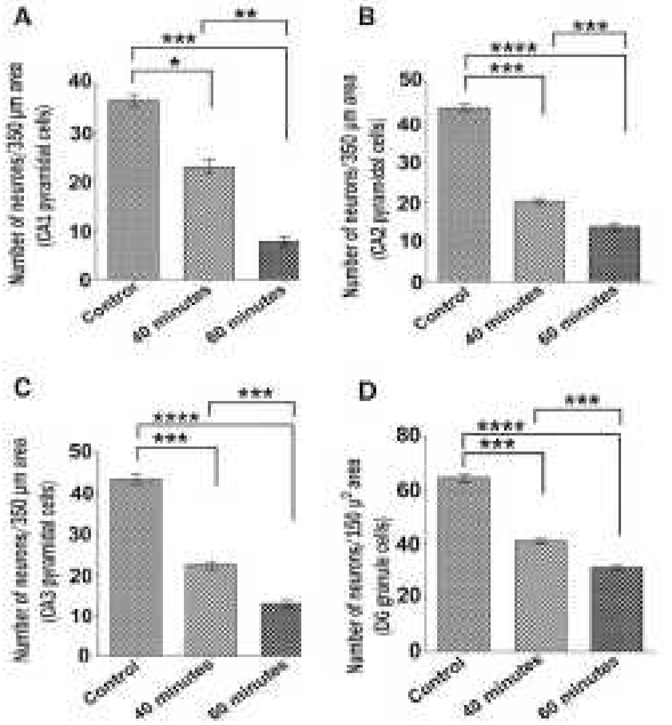

Fig. 4. The histogram shows the numbers of normal pyramidal neuron cells in different areas of the hippocampus of control, 40- and 60-minutes exposed mice (A-D). For measurement of viable neurons in each hippocampal imaging, a length of 350 μm of CA1, CA2, CA3 and 150 μ^2 area of DG layer was selected. Healthy viable neurons were decreased significantly in 60 min compared to 40 min and control mice. Results were presented as Mean ± SEM, (n = 10 mice in each group). (*) indicates a statistically significant difference at the $p < 0.05$ level; (**) indicates a statistically significant difference at the $p < 0.01$ level; (***) indicates a statistically significant difference at the $p < 0.001$ level; (****) indicates a statistically significant difference at the $p < 0.0001$ level. CA, Cornu Ammonis; DG, Dentate Gyrus.

viable neurons were CA1 [23.10 ± 1.52, 7.80 ± 0.95], CA2 [20.20 ± 0.65, 13.70 ± 0.86], CA3 [22.30 ± 1.05, 12.90 ± 0.80] and DG [41.20 ± 0.99, 31.20 ± 1.19] respectively, which were significantly lower than control (Fig. 4). The loss of viable neurons in CA1 ($P \leq 0.01$) and CA3 ($P \leq 0.01$) areas was higher (Fig. 4A & 4C). The number of dark cells increased while typical pyramidal neuronal cells reduced in the exposure group relative to the control. This study's findings showed that prolonged exposure to radiation causes more damage to the CA1, CA2, and CA3 pyramidal neurons and granule cells of the DG region of the brain hippocampus.

4. Discussion

The increasing use of cell phones has increased the risk of radiation exposure at ever earlier ages. The deleterious effects on the brain caused by RF-EMR released by smartphones are of great concern. The EMF effect depends on different factors such as frequency, duration of the exposure. The permissible limit for mobile phones is 2 W/kg SAR (This, 2010), but many of them have a 1.4 W/kg SAR value (Agarwal et al., 2011). RF-EMR has many effects on the biological system, especially the brain, liver, kidney, and heart (Hasan et al., 2021a; Odaci et al., 2015; Topal et al., 2015).

The mice in our experiment have been exposed to 2400-MHz RF-EMR because the mobile phones run in Bangladesh at this frequency. In contrast to previous studies, we allowed the mice to move around in their cages freely. The main reason for the mouse's free movement in the cages was to alleviate the anxiety caused by the immobilization inside the cage. From that viewpoint, our study is different from related literature studies. To mimic real-life conditions, we irradiated mice using a commonly used cell phone. We then performed behavioral and histological studies on brain tissue. We performed an Elevated Plus Maze (EPM) test after exposure to 2400 MHz RF-EMR and assessed anxiogenic-like behavior. This study has shown that exposure to mobile phone radiation increases anxiety levels related to neurobiological and cellular alterations. The frequency of entries in the EPM's open and closed arms indicates anxiety (Ehlers and Todd, 2017). The exposed mice showed less exploration and significantly higher avoidance of open arms than the control. The exposed mice also exhibited decreased rearing and head dipping behavior, which indicates reduced exploratory behavior.

In many experiments, the anxiolytic level was confirmed by a reduced entry in the close arm. In our study RF-EMR exposed mice revealed a decreased number of open arm entries because anxiolytic animals avoided open arm entrance and stayed in a nearby or safe area (Cui et al., 2007; Liu et al., 2008; Rodgers and Dalvi, 1997; Wąsik et al., 2019). Exploratory behaviors include open arm activity and more head dipping, showing a greater exploration level (Brown et al., 1999). In this experiment, a significant decline in exploratory behavior was assessed by a decreased time spent in the open arm in all exposed groups relative to the control. This is confirmed by earlier research of several authors who have reported lower exploratory behaviors and decreased anxiety in animals exposed to RF-EMR, vibration, and noise (Abbate et al., 2004; Khirazova et al., 2012). The statistically significant difference that has often been seen between the control groups confirmed the combined effects of RF-EMR and other stressors (Kumar et al., 2009). The open-arm avoidance index is an indicator of anxiety (Trullas and Skolnick, 1993).

Excessive amounts of reactive oxygen species (ROS) produced during electromagnetic radiation exposure were closely connected with apoptosis of neural cells (Kesari et al., 2011). Histopathological considerations have further confirmed the oxidative and behavior effects. The hippocampus of the exposed mouse brains, particularly CA1, CA2, CA3, and DG hippocampal areas, displayed severe neurodegeneration. This change was seen in degenerated neurons with darkly stained nuclei; some neurons are apoptotic than normal cells, stained by CV and H & E. The brains of control mice revealed normal pyramidal neuron cells with spherical shape visible nucleus no degenerated cells. The finding suggested that serious neurodegeneration is influenced by electromagnetic radiation. Our study results revealed that neurodegeneration in the CA and DG regions of the hippocampus due to exposure to 2400 MHz RF-EMR. Many studies have already highlighted the effect of 900 to 2100 MHz RF-EMR on the central nervous system. They found pyknotic neurons in the hippocampus's CA region (Baş et al., 2013), darkly stained granule cells in the DG areas (Odaci et al., 2008), and dark cytoplasm pyramidal neurons in the hippocampus of the experimental model after exposure of 9oo MHz RF-EMR (Şahin et al., 2015). Previous research also shows evidence of such an impact (Salford et al., 2003). They reported that neuronal alteration was represented as dispersed, darkly stained neurons distributed in all regions of the brain. O. Bas et al., 2009 reported many abnormal black and shrunken neurons with pyramidal cell loss in the EMR exposed rats. However, there are some variations between the present study and two previous research (Bas et al., 2009b; Odaci et al., 2008) in terms of the experimental method. In those two studies, the pregnant rats were exposed to 900 MHz RF-EMR. Then the number of neuron cells in the newborn rat's hippocampus was studied, wherein our study we used 2400 MHz RF-EMR exposure to mice. The damaged neurons were characterized by irregular cellular shapes with an increased nucleus and cytoplasm chromatin content and intense and homogenous stained nuclei (Sugimoto et al., 1990). The exposed mouse neurons had all these features, while none of the control mice exhibited these characteristics. The hippocampal cell damage gives us an indication of behavioral changes in exposed mice. In this study, anxiety-like behavior was significantly affected by long-term exposure to 2400 MHz RF-EMR. The histological observations of our study confirm elevated plus-maze parameters. Future studies should include detailed TUNEL Assay and immunohistochemistry to confirm the hippocampal cell damage.

Postnatal exposure to EMF resulted in a significant reduction in CA pyramidal cells in the EMF group, according to (Bas et al., 2009a). Mortazavi et al., 2017 reported that the total number of pyramidal cells were lost in 4-week-old males when exposed to 900 MHz EMF. The number of hippocampus pyramidal neurons (Baş et al., 2013) and granule cells of DG (Odaci et al., 2008) has been decreased following exposure to RF-EMR. This should be mentioned that the electromagnetic exposure process was structured differently in earlier research (Bas et al., 2009b) from that in the current research. However, the RF-EMR exposure process used in this study has been modified. The exposure system used in this study consisted of a 4G connected cell phone that continuously emitted 2400 MHz frequency RF-EMR. The mobile phone was placed just above the mice, allowing the mice to move in the cage freely.

Cell phones with frequencies ranging from 900 to 1800 MHz have been more popular during the last two decades. Such frequencies may have a lot of adverse effects on biological systems. Previous findings have shown that mobile radiation can cause ROS in different tissues (Misa-Agustiño et al., 2015; Ozguner et al., 2005). The excess production of ROS may induce oxidative stress and inflammation, resulting in changes in antioxidant defense mechanisms, as well as oxidative stress. Many studies have shown that electromagnetic radiation can cause oxidative damage to tissues. Increased antioxidant enzyme concentrations such as malondialdehyde, catalase, and superoxide dismutase may help evaluate the correlation between apoptosis and radiation (Dasdag et al., 2008; Kesari et al., 2010). The hippocampus regulates certain cognitive and behavioral functions that include retaining information during the learning process (Altun et al., 2017). There was an abnormal arrangement of neurons and a reduction in normal viable granule and pyramidal neurons in the hippocampus due to radiation exposure. Previous researchers have reported similar results with strong support for these findings (Kakkar and Kaur, 2011; Wang et al., 2017). Our stereological and histopathological findings showed a significant change in the hippocampus of the electromagnetic radiation-exposed mice consistent with the behavioral study findings. The result suggested that anxiety-like behavior was influenced by electromagnetic radiation. The generalization of the effects of mice experiments for human beings is still under question. This study, carried out using the frequency 2400-MHz, commonly used today in many countries for cellular communication, would significantly contribute to the literature about the consequences of long-term cell phone use on living tissue. However, based on our data, we cannot validate the hypothesis that 2400-MHz RF-EMR has the same effect on humans.

5. Conclusion

Our current study suggests that long-term exposure to 4G cell phone radiation has detrimental effects on anxiety-like behavior and changes in the morphological architecture of the hippocampus. The type of neuronal damage discussed here does not have immediate demonstrable results. However, it may lead to decreased brain reserve capacity in the long run, which could be discovered in other late neuronal diseases. However, further detailed experiments using different approaches (such as electron microscopic, autoradiographic, TUNNEL Assay, and immunohistochemistry) are required to determine whether such pathological alterations are reversed or persistent in getting a satisfactory conclusion in this regard. However, our current results might serve as primary data for further comprehensive studies on the effects of 4G cell phone radiation on the brain.

Author Contributions

The planning and research facilities were established by MRI and supervised the entire research. IH carried out the entire laboratory work and actively participated in the histological study and statistical analysis. MRJ and MNI provided and contributed to the cresyl violet staining. IH, MNI and MRI prepared the draft copy of the manuscript. IH, MRJ, MNI and MRI reviewed and edited the whole manuscript and finally approved the final version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data statement

All data generated or analyzed during this study are included in this article.

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Approval Statement

All experiments were approved by the Bangladesh Agricultural University Animal Ethics Committee (AWEEC/BAU/2019-46)

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BRIEFING

Effects of 5G wireless communication on human health

SUMMARY

The fifth generation of telecommunications technologies, 5G, is fundamental to achieving a European gigabit society by 2025.

The aim to cover all urban areas, railways and major roads with uninterrupted fifth generation wireless communication can only be achieved by creating a very dense network of antennas and transmitters. In other words, the number of higher frequency base stations and other devices will increase significantly.

This raises the question as to whether there is a negative impact on human health and environment from higher frequencies and billions of additional connections, which, according to research, will mean constant exposure for the whole population, including children. Whereas researchers generally consider such radio waves not to constitute a threat to the population, research to date has not addressed the constant exposure that 5G would introduce. Accordingly, a section of the scientific community considers that more research on the potential negative biological effects of electromagnetic fields (EMF) and 5G is needed, notably on the incidence of some serious human diseases. A further consideration is the need to bring together researchers from different disciplines, in particular medicine and physics or engineering, to conduct further research into the effects of 5G.

The EU's current provisions on exposure to wireless signals, the Council Recommendation on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), is now 20 years old, and thus does not take the specific technical characteristics of 5G into account.

In this Briefing

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Background

Under the EU digital single market strategy, the European Commission presented new policy measures in its 2016 communication on Connectivity for a Competitive Digital Single Market – Towards a European Gigabit Society. The Commission's aim is to advance the digitalisation of the EU and to increase its competitiveness by launching networks with much higher capacities, with 5G as a building block to achieve a 'gigabit society' by 2025. Its main characteristics would enable the internet of things, which means that billions of connections between devices share information.[1] The Commission has established the following connectivity targets for 2025:

- schools, universities, research centres, hospitals, main providers of public services and digitally intensive enterprises should have access to internet download/upload speeds of one gigabit of data per second;
- urban and rural households should have access to connectivity of download speed of at least 100 megabits per second;
- urban areas, major roads and railways should have uninterrupted 5G coverage.

The '5G for Europe: An action plan' presents measures for timely and coordinated deployment of 5G networks in Europe through a partnership between the Commission, Member States, and industry. This initiative concerns all private and public stakeholders, in all EU Member States.

The connectivity objective has been regulated by the adoption of the European Electronic Communication Code (EECC) at the end of 2018, under which EU Member States have to authorise the use of the new 5G frequency bands at 700 MHz, 3.5 GHz and 26 GHz[2] and reorganise them by the end of 2020,[3] in line with the EECC. This decision enables the take-up of 5G services in the Union.

According to the European 5G observatory, supported by the European Commission, at the end of September 2019, 165 trials had been carried out in the European Union and 11 Member States had already published their national 5G action plans.

Challenges and opportunities of 5G

Advantages

Allowing much larger volumes of data to be transported more quickly, and reducing response time, 5G will enable instantaneous connectivity to billions of devices, the internet of things and a truly connected EU population. Furthermore, millions of jobs and billions of euros could be expected to be gained from the digital economy.

The possibilities that the fifth generation of wireless communication offers, such as downloading or uploading one gigabit of data per second, may provide advantages, for instance, for the military and medical research, which could benefit from having access to such extremely high gigabit connectivity. However, the military, hospitals, the police and banks continue to use wired connections, at least for their most essential communications, mainly for security reasons. Wired networks generally offer a faster internet speed and are considered to be more secure. This is due to the fact that a wired network is only accessible through a physical cable connection, whereas with wireless networks, the signal may be broadcast outside the physical premises. Wired connection offers more control than radio or wifi, because such organisations already provide protection for servers and internal IT facilities within their physical locations, taking advantage of almost 100 % of the bandwidth, which also reduces response times. That also contributes to increased security.

Disadvantages

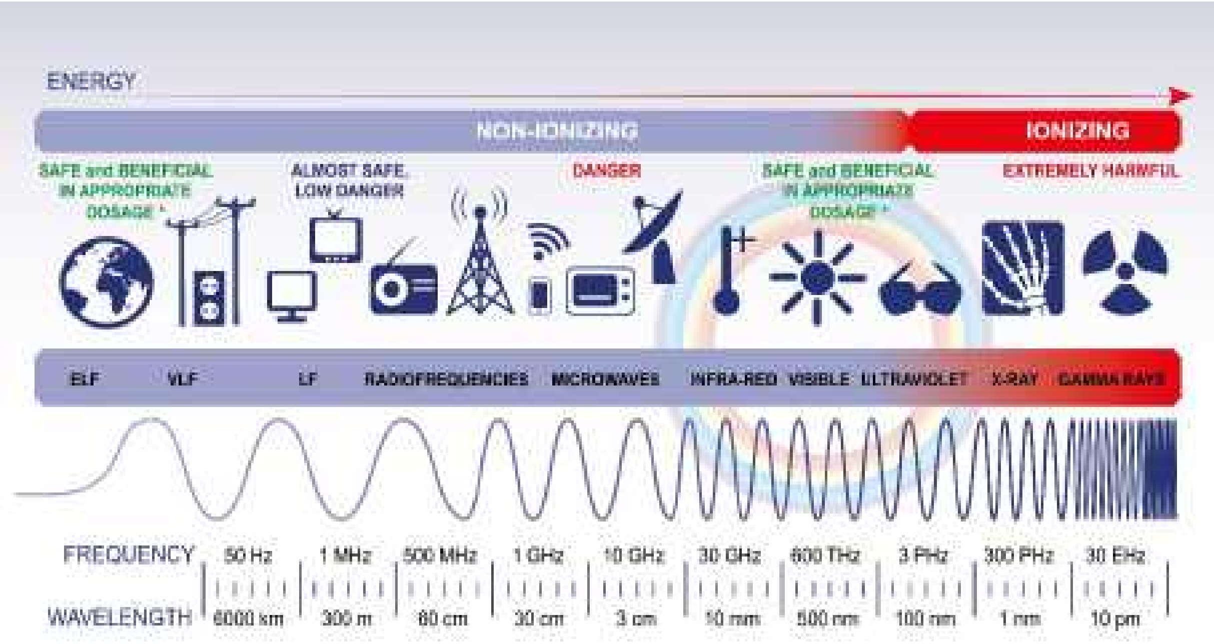
Because it is more complex and requires a denser coverage of base stations[4] to provide the expected capacity, 5G will cost much more to deploy than previous mobile technologies. According to European Commission estimates, to reach the target, including 5G coverage in all urban areas, this cost is estimated at around €500 billion by 2025.

Questions remain unanswered as to what 5G actually is, what it is for, whether it has impacts on human health and environment, whether it is secure, whether it offers good value for money or whether anyone will be prepared to pay for it.[5] As an alternative, according to some experts,[6] fibre optics would be more secure, safe and offer higher speed than 5G. However, fibre optics are not wireless.

Difference between 5G and current technology

Employing millimetre waves and higher frequencies than previous technologies, 5G needs a much more extensive network of antennas and other transmitting devices. Electromagnetic fields (EMF) are invisible areas of energy,[7] measured in hertz (Hz). Longer wavelengths with lower frequency are less powerful in terms of energy, while shorter wavelengths at higher frequencies are more powerful. Depending on the frequency, there are two categories of EMF: ionising and non-ionising radiation (see Figure 1).

Figure 1 – Electromagnetic spectrum



Source: Polina Kudelkina / Shutterstock.com.

Ionising radiation (mid to high-frequency) includes ultraviolet rays, x-rays and gamma rays. The energy from ionising radiation can damage human cells and cause cancer. Non-ionising radiation has lower frequencies and bigger wavelengths. Many experts are of the opinion that non-ionising radiation produces only thermal effects, or tissue heating, and that at high exposure levels, temperature-sensitive biological structures, including humans, and processes can become damaged.

Microwave and millimetre wavelength radiation is non-ionising. Millimetre wave ranges from around 10 to 1 millimetre. This is a very effective spectrum with large bandwidth, but it is also very sensitive to external variables and can be subject to interference from walls, trees or even rain.

For the first time, 5G will use millimetre waves in addition to the microwaves that have been used to date in 2G, 3G and 4G technology. Due to the limited coverage, to implement 5G, cell antennas will have to be installed very close to one another, which will result in constant exposure of the population to millimetre wave radiation. Use of 5G will also require new technologies to be employed, such as active antennas capable of beam-forming, massive inputs and outputs.[8] With higher frequencies and shortened ranges, base stations will be more closely packed into an area, to provide complete coverage and avoid 'not-spots'. This could mean possible ranges of 20-150 metres with smaller coverage areas per 'small cell.[9] A cell radius of 20 metres would imply about 800 base stations per square kilometre (or 'small area wireless access points' (SAWAPs), the term used in the EECC). This contrasts with 3G and 4G technologies, which use large or 'macro' cells, offering ranges of 2-15 kilometres or more, and therefore covering a larger area but allowing fewer simultaneous users since they have fewer individual channels.[10]

Furthermore, 5G will employ higher frequencies[11] than previous 'G' networks and greater bandwidth which will enable users to transfer wireless data faster.

Regulation of electromagnetic fields and 5G exposure

European Union

Primary responsibility for protecting the population from the potential harmful effects of EMF falls to the governments of EU Member States under Article 168 of the Treaty on the Functioning of the European Union. In 1996, the World Health Organization (WHO) established the International EMF Project to evaluate the scientific evidence of possible health effects of EMF in the frequency range from 0 to 300 GHz. It has elaborated 'model legislation' to offer a legal framework for implementing protection programmes against non-ionising radiation.

The International Commission on Non-Ionising Radiation Protection (ICNIRP), a non-governmental organisation formally recognised by WHO, issues guidelines for limiting exposure to electric, magnetic and electromagnetic fields (EMF), which are revised periodically. In the EU, **Council Recommendation** 1999/519/EC, of 12 July 1999, on the limitation of exposure of the general public to EMF (0 Hz to 300 GHz), follows these guidelines.

As the Council Recommendation is the common protective framework guiding EU Member States and setting basic restrictions and reference levels, depending on frequency, the following physical quantities specify basic restrictions on electromagnetic fields:

- between 0 and 1 Hz, basic restrictions are provided for magnetic flux density for static magnetic fields (0 Hz) and current density for time-varying fields[12] up to 1 Hz, to prevent effects on the cardiovascular and central nervous system;
- between 1 Hz and 10 MHz, basic restrictions are provided for current density[13] to prevent effects on nervous system functions;
- between 100 kHz and 10 GHz, basic restrictions on the specific absorption rate (SAR) are provided to prevent whole-body heat stress and excessive localised tissue heating. In the 100 kHz to 10 MHz range, restrictions on both current density and SAR are provided;
- between 10 GHz and 300 GHz, basic restrictions on power density are provided to prevent tissue heating on or near the surface of the human body.

While these exposure limits are non-binding on EU Member States, some Member States have nevertheless adopted stricter limits than those recommended above.

The recommendation encourages Member States to establish a common protective framework and inform the public of the health impact of electromagnetic fields, as well as to harmonise national approaches for measurement. The Council suggests that the European Commission keep possible health effects under review.

The **European Environment Agency** (EEA) has long advocated precaution concerning EMF exposure, pointing out that there were cases of failure to use the precautionary principle in the past, which have resulted in often irreversible damage to human health and environments. Appropriate, precautionary and proportionate actions taken now to avoid plausible and potentially serious threats to health from EMF are likely to be seen as prudent and wise from future perspectives. The EEA requests that EU Member States do more to inform citizens about the risks of EMF exposure, especially to children.

In its 2 April 2009 resolution, the European Parliament urged the Commission to review the scientific basis and adequacy of the EMF limits in Recommendation 1999/519/EC and to report back. Parliament also requested that the Scientific Committee on Emerging and Newly Identified Health Risks carry out a review of the EMF limits. Parliament requested consideration of the biological effects, acknowledging the results of studies that reveal harmful effects at lowest levels of electromagnetic radiation, as well as calling for active further research and consequently development of solutions to negate or reduce pulsations used for transmission. It suggested that the Commission elaborate a guide to available technology options for reducing exposure to EMF in coordination with experts from Member States and the industries concerned.

The European Commission **Scientific Committee on Emerging and Newly Identified Health Risks** (SCENIHR) has a mandate to evaluate the risks of electromagnetic fields and periodically reviews the scientific evidence available to assess whether it still supports the exposure limits proposed in Council Recommendation 1999/519/EC. In its latest opinion of January 2015, SCENIHR suggested that there is a lack of evidence that EMF radiation affects cognitive functions in humans or contributes to an increase of the cases of cancer in adults and children. However, the International EMF Alliance (IEMFA) suggested that many members of SCENIHR could have a conflict of interests, as they had professional relationships with or received funding from various telecom companies.

Consequently, the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER), replacing the former Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), indicated a preliminary estimate of the importance of 5G as high, in a statement in December 2018. Furthermore, it evaluates the scale, urgency and interactions (with ecosystems and species) of possible hazard as high. It suggested that there could be biological consequences from a 5G environment, due to the fact that there is a lack of 'evidence to inform the development of exposure guidelines to 5G technology'.

Council of Europe

Council of Europe Resolution 1815 (2011) points to the potential health effects of the very low frequency of electromagnetic fields surrounding power lines and electrical devices, which are the subject of ongoing research and public debate. It also states that some non-ionising frequencies appear to have more or less potentially harmful, non-thermal, biological effects on humans, other animals and plants, even when exposed to levels that are below the official threshold values. The resolution identifies young people and children as particularly vulnerable groups and suggests that there could be extremely high human and economic costs if early warnings are neglected. The issue of possible environmental and health effects of electromagnetic fields is considered to have clear parallels with other current issues: the licensing of medication, chemicals, pesticides, heavy metals or genetically modified organisms. The resolution highlights that the independence and credibility of the scientific expertise employed is crucial for a transparent and balanced assessment of possible negative effects on human health and environment. The resolution recommends:

- taking all reasonable measures to reduce exposure to EMF (especially from mobile phones) and particularly to protect children and young people who seem to be most at risk of developing head tumours;
- reconsidering the scientific basis for the present standards on exposure to electromagnetic fields set by the International Commission on Non-Ionising Radiation Protection, which have serious limitations;
- distributing information and awareness-raising campaigns on the risks of potentially harmful long-term biological effects on the environment and on human health, especially targeting children, teenagers and young people of reproductive age;
- giving preference to wired internet connections (for children in general and particularly in schools), and strictly regulating the use of mobile phones by schoolchildren on school premises;
- increasing public funding of independent research to evaluate health risks.

European Parliament

A resolution of 2 April 2009 on health concerns associated with electromagnetic fields urged the European Commission to review the scientific basis and adequacy of the EMF limits in Recommendation 1999/519/EC and to report back. It also requested that the Scientific Committee on Emerging and Newly Identified Health Risks carries out a review of the EMF limits.

Research on EMF and 5G effects on human health

The academic literature on EMF exposure effects and 5G in particular is growing rapidly. Some research papers support possible health risks, while others do not.

The WHO[14]/International Agency for Research on Cancer (IARC) classified radiofrequency EMF as possibly carcinogenic to humans in 2011. The IARC has recently prioritised EMF radiation for review in the next five years (2020-2024).

A section of the scientific community – mainly doctors and researchers in medical sciences – argues that there are negative impacts from EMF exposure and that these will increase with the implementation of 5G. A **5G appeal** was presented to the United Nations in 2015, and to the European Union from 2017, with an increasing number of scientists' signing (268 scientists and medical doctors as of 18 December 2019). The signatories state that with the increasingly extensive use of wireless technology, especially when 5G is deployed, nobody could avoid exposure to constant EMF radiation because of the huge number of 5G transmitters with an estimated 10 to 20 billion connections (to self-driving cars, buses, surveillance cameras, domestic appliances, etc.). In addition, the appeal states that a large number of scientific publications illustrate EMF exposure effects such as an elevated risk of cancer, genetic damage, learning and memory deficits, neurological disorders, etc. The appeal points out not only harm to humans, but also to the environment.

The appeal recommends a moratorium on the deployment of 5G for telecommunications until potential hazards for human health and the environment have been fully investigated by scientists independent of industry. They urge the EU to follow Resolution 1815 of the Council of Europe, and demand that a new assessment is carried out by an independent task force.

Ethics in research

The European Code of Conduct for Research Integrity (last revised in 2017) sets out principles of research integrity, criteria for good research practice, and describes how to prevent violations of research integrity.

The principles it states are the following:

- **Reliability** in ensuring the quality of research, reflected in the design, the methodology, the analysis and the use of resources.
- **Honesty** in developing, undertaking, reviewing, reporting and communicating research in a transparent, fair, full and unbiased way.
- **Respect** for colleagues, research participants, society, ecosystems, cultural heritage and the environment.
- **Accountability** for the research from idea to publication, for its management and organisation, for training, supervision and mentoring, and for its wider impacts.

In this regard, some scientists consider it necessary to establish new exposure limits that take account of the new characteristics of exposure. Such limits should be based on the biological effects of EMF radiation, rather than on the energy-based specific absorption rate.

Non-ionising radiation, which includes radiation from mobile phones and 5G, is perceived as harmless in general, due to its lack of potency. However, some of the above-mentioned scientists point out that, in the particular case of 5G, the issue is not the potency, but the pulse,[15] the frequency to which the whole population will be exposed due to the dense network of antennas and the estimated billions of simultaneous connections. As 5G employs a very high level of pulsations, the idea behind 5G is to use higher frequencies, which allows such high levels of pulsation, in order to carry very large amounts of information per second. Studies show that pulsed EMF are in most cases more biologically active and therefore more dangerous than non-pulsed EMF. Every single wireless communication device communicates at least partially via pulsations, and the smarter the device, the more pulsations. Consequently, even though 5G can be weak in terms of power, its constant abnormal pulse radiation can have an effect. Along with the mode and duration of exposures, characteristics of the 5G signal such as pulsing seem to increase the biologic and health impacts of exposure, including DNA damage, which is considered to be a cause of cancer. DNA damage is also linked to reproductive decline and neurodegenerative diseases.

A 2018 review of more recently published peer-reviewed articles on the biological and health effects of radio frequency EMF, including 5G, also verifies the available evidence on the effects of millimetre waves. The review concludes that evidence of the biological properties of radiofrequency EMF are accumulating progressively and even though they are, in some cases, still preliminary or controversial, point to the existence of multi-level interactions between high-frequency EMF and biological systems, and to the possibility of oncological and non-oncological (mainly reproductive, metabolic, neurological, microbiological) effects. Moreover, it points out that the wide and increasing density of wireless devices and antennas raises particular concerns. Taking this into account, '... although the biological effects of 5G communication systems are very scarcely investigated, an international action plan for the development of 5G networks has started, with a forthcoming increase in devices and density of small cells, and with the future use of millimetre waves'. However, there are indications that millimetre waves can increase skin temperature, promote cellular proliferation, and inflammatory and metabolic processes. According to the review, further studies are necessary to improve independent exploration of the health effects of radio frequency EMF in general and of millimetre waves in particular.[16]

Far less research exists to determine the effects of 5G technologies on humans and the environment, according to another review of studies published in 2018. Considering the already existing complex mix of lower frequencies, it argues that in addition to those, the expected higher frequency 5G radiation would cause negative impacts on physical and mental public health. Concretely in the case of millimetre waves, it analyses the results of studies which find effects on the skin, eyes, and immune system, and bacterial antibiotic resistance. The review suggests that the effects of radiofrequency EMF will be problematic to sort out epidemiologically, as no unexposed control group will remain. The study consequently calls for precaution in the deployment of this new technology. The author argues that while physicists and engineers give assurances that the only measure to harm health is heat, medical scientists indicate that there are other mechanisms whereby cellular functioning can be disrupted by non-thermal exposures to radiofrequency.

A 2016 review of scientific articles, covering experimental data on the oxidative effects of low-intensity radiofrequency radiation in living cells, finds that, among 100 currently available peer-reviewed studies (18 *in vitro* studies, 73 studies in animals, 3 studies in plants and 6 studies in humans), '... dealing with oxidative effects of low-intensity radiofrequency radiation, in general, 93 confirmed that radiofrequency radiation induces oxidative effects in biological systems'. More precisely, in 58 studies of laboratory rats, 54 show positive results, and 4 of 6 studies in humans were positive. In addition, 17 of the 18 of the *in vitro* studies were positive, including two on human spermatozoa and two on human blood cells. According to the authors, 'The analysis of modern data on biological effects of low-intensity radiofrequency radiation (RFR) leads to a firm conclusion that this physical agent is a powerful oxidative stressor for living cells'.

A 2018 study carried out on animals, showed that electromagnetic radiation emitted by wifi networks can lead to hyperglycaemia, increased oxidative stress and impaired insulin secretion in rat pancreatic islets. A method of creating diabetes (which can lead to kidney deficiency in the long term) in laboratory rats is to expose them, even briefly, to 2.4 GHz.

A 2019 report of the Swedish Radiation Safety Authority's Scientific Council on Electromagnetic Fields considers two large animal studies: the US National Toxicology Program (NTP) study and the

Italian Falcioni et al. study, which analyse the relationship between radio wave exposure and schwannoma of the heart in male rats.[17] The report concludes that there is some inconsistency in the results between the two studies and that no new causal relationship between EMF exposure and health risks was established. It recommends that further research is important, particularly regarding long-term effects and especially since the entire population will be exposed. It points out that a possible relationship between radio wave exposure and oxidative stress should be a subject of further research, as well as the association between weak low-frequency magnetic fields and childhood leukaemia, as observed in epidemiological studies.

The scientific community reaction in response to this report, is illustrated in the recent 'Commentary on the utility of the National Toxicology Program study on cell phone radiofrequency radiation data for assessing human health risks despite unfounded criticisms aimed at minimizing the findings of adverse health effects.' The author states that the NTP study was designed to test the hypothesis that, at non-thermal exposure intensities, mobile phone radiation could not lead to adverse health effects, and to provide data for assessment of health risks caused by any detected toxic or carcinogenic effects, as little was known about long-term exposure to mobile phone radiation health effects. Regarding the NTP study results, among others, the author defends the use of animal studies that can eliminate the need to wait until enough human cancer data are available before implementing strategies to protect public health. According to the author, the intensity of exposure in the brains of rats in the NTP study were similar to potential human mobile phone exposures.

In turn, a 2019 review of 94 articles, funded by Deutsche Telekom, states that the '... available studies do not provide adequate and sufficient information for a meaningful safety assessment, or for the question about non-thermal effects. There is a need for research regarding local heat developments on small surfaces, e.g., skin or the eye, and on any environmental impact. There was no consistent relationship between power density, exposure duration, or frequency, and exposure effects'.

There is no noticeable increase in everyday EMF exposure since 2012, despite the increasing use of wireless communication devices, according to another review of studies from 2019. Nevertheless, it remains unclear how well these studies of everyday exposure represent the population's absorbed radiofrequency EMF dose. This study maintains the urgent need for better quantification of the population's absorbed radiofrequency EMF dose from their own communication devices.

Stakeholders' views

Considering the huge estimated investment, the mobile telecommunications industry needs to convince governments of 5G's economic and social benefits and perform widespread marketing campaigns. 'It suits the industry if policy-makers believe that there is a race between nations to be the first to launch 5G services'.[18]

The EU telecommunications industry continues to state that the weight of evidence regarding harm from EMF exposures is inconclusive. The 5G Infrastructure Public Private Partnership (5G PPP), a joint initiative between the European Commission and European information and telecommunications (ICT) industry (ICT manufacturers, telecommunications operators, service providers, SMEs and research institutions), supports research and innovation to develop 5G networks that comply with international standards and regulations and develops systems designed to operate below the safe health limits of electromagnetic emissions.[19] However, it does not refer to the biological impacts of 5G radiation.

Nevertheless, according to the IEMFA, a need to measure real potential exposure to 5G and update the safety limits of such exposure does exist. The alliance calls for more research and scientific consent along these lines. It maintains that scientists with experience of long research into EMF health effects should be included in the SCENIHR, following the demands of the 2015 IEMFA complaint.[20]

The road ahead for 5G

There is an urgent need for economic recovery and leadership in implementing digital technologies; and for long-lasting economic growth in Europe. However, it is necessary to consider any possible collateral negative impacts. Taking the economic aspects of 5G into account, there are many challenges ahead on the path to achieving a 'gigabit society', such as for instance industry concerns whether the plans for commercial launch of 5G in 2020 will be fulfilled, considering the technical complexity and the necessary investment.

Other concerns relate to the creation of sufficient demand for 5G, security and health, safety and environmental issues.[21] These need wider public awareness and consent, however this is doubly salient regarding the possible negative health impacts due to the inescapability of constant exposure of citizens in a 5G environment. The recent academic literature illustrates that continuous wireless radiation seems to have biological effects especially considering the particular characteristics of 5G: the combination of millimetre waves, a higher frequency, the quantity of transmitters and the quantity of connections. Various studies suggest that 5G would affect the health of humans, plants, animals, insects, and microbes – and as 5G is an untested technology, a cautious approach would be prudent. The UN Universal Declaration of Human Rights, the Helsinki Accords and other international treaties recognise that informed consent prior to interventions that might affect human health is an essential, fundamental human right, which becomes even more controversial when considering children's and young people's exposure.

A certain divergence exists among scientists on the potential negative effects of EMF exposure and 5G. Experts rarely possess complementary backgrounds in both physics or engineering and medicine, therefore more complete scientific expertise could be achieved by combining research teams experienced in all relevant disciplines. Optical fibre technology has been suggested by some experts as a secure alternative to 5G, because the signal is confined within the fibre. Its potential is much higher than that of 5G and there is no comparison between optical fibre and wireless. Investment in optical fibre can be upgraded to superior speeds in the future, whereas it is necessary to change the whole system for wireless technologies.

According to the 2019 study '5G deployment: State of Play in Europe, USA and Asia' prepared for the European Parliament, long-term technology research is essential. 'One key problem is the unusual propagation phenomena, especially controlling and measuring radio frequency EMF exposure with Multiple Input Multiple Output (MIMO) at millimetre wave frequencies for the handset and the base station. The technology presents challenges to the current level of expertise (based on previous generations of mobile cellular radio engineering) both for suppliers and standards organisations who must incorporate the specifications in future 5G standards'. The study states that the main problem seems to be that it is not currently possible to accurately simulate or measure 5G emissions in the real world.

To understand potential mechanisms underlying possible health effects of EMF better and to characterise population levels of exposure, the Generalised EMF Research using Novel Methods (GERoNiMO) project was launched in 2014, funded under the EU's Seventh Framework Programme for Research and Technological Development to address pertinent questions on EMF and health. It proposes an integrated approach using epidemiological studies, exposure assessment techniques, mechanistic and animal models, and expert networks applying novel methods when possible. The project ended in 2018.

The European Commission has not yet conducted studies on the potential health risks of the 5G technology.[22]

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ENDNOTES

1 Industry estimates that 5G capacity will be 40 times that offered by current 4G technology. See M. Negreiro, Towards a European gigabit society Connectivity targets and 5G, EPRS, June 2017.

2 A Megahertz (MHz) is a million cycles per second and a Gigahertz (GHz) pulses at a billion cycles per second. In order to carry data at faster speeds, each new generation of telecommunications uses higher frequency radio waves.

3 See 5G deployment agenda.

4 In addition to spectrum licensing costs, a large share of the cost will be due to the much denser network needed, rolling out the small cells necessary to transmit signals in much higher frequency bands.

5 See '5G Deployment: State of Play in Europe, USA and Asia', European Parliament, June 2019.

6 'Fiber is safer, faster, more reliable, and far more cyber secure and energy efficient than wireless.' R. M. Powell. See also similar opinions from experts such as T. Schoechle and P. Héroux.

7 Also known as waves or radiation.

8 Which would make measuring radiation exposures even more difficult.

9 Usually, the longer the wavelength the further it travels. The higher frequency millimetre wavelengths of 5G travel only a few hundred metres.

10 See '5G Deployment: State of Play in Europe, USA and Asia', European Parliament, June 2019.

11 Radio frequency includes a continuum of the electromagnetic spectrum wavelengths from around 3 kHz to 300 GHz. The wavelengths in the radio frequency vary from hundreds of metres to fractions of a centimetre. The frequencies used in current digital communications have shorter wavelengths and faster data transfer. This enables the transfer of more data simultaneously.

12 Time-varying means that as time (t) increases, the magnetic field changes.

13 The amount of charge per unit of time that flows through a unit area of a chosen cross section.

14 According to the WHO, EMFs of all frequencies represent one of the most common and fastest growing environmental influences. Exposure of the whole population to EMFs will continue to increase along with technological advance.

15 An electromagnetic pulse is a short blowout of electromagnetic energy. Its origin can be manmade and can occur as a radiated, electric, or magnetic field or a conducted electric current.

16 Millimetre waves, which will be employed by 5G, are mostly absorbed within a few millimetres of human skin and in the surface layers of the cornea. Short-term exposure can have adverse physiological effects in the peripheral nervous system, the immune system and the cardiovascular system.

17 For more information on the two studies, see also the EPRS briefing on Mobile phones and health, March 2019.

18 See '5G Deployment: State of Play in Europe, USA and Asia', European Parliament, June 2019

19 According to the limits established by Council Recommendation 1999/519/EC.

20 In an open letter from 2011 to the Health and Consumer Policy Commissioner, public interest stakeholders expressed their concerns over the lack of transparency and pluralism in the evaluation of evidence by SCENIHR, and other EU risk assessment committees, of the health risks of non-ionising EMF radiation (see EPRS Briefing, March 2019).

21 See EPRS briefing 'Towards a European gigabit society: Connectivity targets and 5G', June 2017.

22 See answer given by the European Commission to parliamentary question E-005128/2018(ASW). See also 'MEP: Commission 'irresponsible' on 5G health risks', Euractiv, 12 December 2019.

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Effects of different mobile phone UMTS signals on DNA, apoptosis and oxidative stress in human lymphocytes

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ABSTRACT

Different scientific reports suggested link between exposure to radiofrequency radiation (RF) from mobile communications and induction of reactive oxygen species (ROS) and DNA damage while other studies have not found such a link. However, the available studies are not directly comparable because they were performed at different parameters of exposure, including carrier frequency of RF signal, which was shown to be a critical for appearance of the RF effects. For the first time, we comparatively analyzed genotoxic effects of UMTS signals at different frequency channels used by 3G mobile phones (1923, 1947.47, and 1977 MHz). Genotoxicity was examined in human lymphocytes exposed to RF for 1 h and 3 h using complimentary endpoints such as induction of ROS by imaging flow cytometry, DNA damage by alkaline comet assay, mutations in TP53 gene by RSM assay, preleukemic fusion genes (PFG) by RT-qPCR, and apoptosis by flow cytometry. No effects of RF exposure on ROS, apoptosis, PFG, and mutations in TP53 gene were revealed regardless the UMTS frequency while inhibition of a bulk RNA expression was found. On the other hand, we found relatively small but statistically significant induction of DNA damage in dependence on UMTS frequency channel with maximal effect at 1977.0 MHz. Our data support a notion that each specific signal used in mobile communication should be tested in specially designed experiments to rule out that prolonged exposure to RF from mobile communication would induce genotoxic effects and affect the health of human population.

1. Introduction

For last few decades, the environment has been increasingly suffered from a new type of pollution created by electromagnetic radiations from wireless mobile communication (Blackman et al., 1979; Adey, 1993). This generated serious concerns regarding health of humans and safety of biota (Balmori, 2010). Different studies showed serious potential impact of electromagnetic radiation on our environment (Balmori, 2009; Lopatina et al., 2019). This electromagnetic pollution from mobile communication may affect not only human beings but also animals and birds (Balmori and Hallberg, 2007). In 2011, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization, classified radiofrequency radiation (RF) including that from mobile phones as a possible carcinogen, group 2B (Baan et al., 2011). Long term mobile phone usage in different case control studies showed statistically significant association with increased risk of brain tumors (Wang and Guo, 2016; Bortkiewicz et al., 2017; Prasad et al., 2017; Yang et al., 2017).

As far as genotoxic effects are the most direct cause for carcinogenicity, available relevant studies were thoroughly reviewed in the IARC RF monograph (IARC, 2013). Diverse conclusions stemmed from these studies: in general, about half of studies found some RF genotoxicity (positive reports) while the other half have not (negative reports). This approximately similar numbers of positive and negative reports is in line with studies measuring some others biological endpoints of RF exposure (Huss et al., 2008; Apollonio et al., 2013; Cucurachi et al., 2013). While many studies on RF genotoxicity have been performed since the assessment of IARC in 2011, the balance between negative and positive studies did not change much (https://www.emf-portal.org/en/search/results?query=RF+genotoxicity&languageIds%5B%5D=en). However, results of all these studies are not directly comparable due to

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0269-7491/

dependence of the RF effects on a number of critical physical parameters of exposure, which vary significantly between studies (Belyaev, 2010; IARC, 2013). While specific absorption rate (SAR) and power flux density (PD) are the main determinants for the thermal RF effects, several other physical parameters of exposure including frequency, modulation, polarization, duration of exposure and also different biological variables have long been known to be critical for non-thermal RF biological effects such as induced by exposure to various sources of mobile communication (Blackman, 1992, 2009; Adey et al., 1999; Belyaev et al., 2000).

Free radicals are a group of highly reactive molecules having unpaired electrons in the outer orbit. Most known free radicals are reactive oxygen species (ROS) derived from oxygen metabolism. Upon overproduction, these reactive species can damage various molecules including DNA leading to increased mutations, changed cell death and cell growth, and thus contributing to the multistage carcinogenesis process. About 90% of available studies have reported that RF exposure causes oxidative stress as revealed by increase in ROS, oxidized proteins, peroxidized lipids and fragmented DNA, see for review (Georgiou, 2010; Yakymenko et al., 2015). However, the relevance of RF-induced ROS to DNA damage was less investigated and some studies reported that RF-induced ROS was not followed by DNA damage (Durdik et al., 2019).

It has been suggested that oxidative stress could be a key factor for RF-related incidence of brain tumors and childhood leukemias (De Iuliis, Newey et al., 2009). However, no studies are available to test whether mutations related to brain tumors and childhood leukemias are induced by exposure to RF signals used by mobile phones. In particular, different frequency channels of UMTS signals used in 3G technology have not been tested so far.

Tumor suppressor gene TP53 encoding p53 protein is the most commonly mutated gene in human cancers including brain tumors (Kandoth et al., 2013; Bouaoun et al., 2016). Somatic TP53 mutations have been detected in up to 20% of acute myeloid leukemia (AML), often associated with a complex karyotype, resulting into inferior survival rates (Grossmann et al., 2012; Rucker et al., 2012). Recent data suggested that somatic TP53 mutations may represent early leukemogenic events, possibly by initiating mutations acting as mediators of resistance in this type of leukemia (Lal et al., 2017).

Other early primary genetic abnormalities in the origination of acute childhood leukemia are chromosomal translocations in hematopoietic cells resulting in so-called preleukemic fusion genes (PFG). Two chromosomal translocations with corresponding PFG are frequent in pediatric acute lymphoid leukemia (ALL): t(12;21)(p13;q22) TEL-AML1 (24-26%) and t(4;11)(q21;q23) MLL-AF4 (~5%). MLL-AF9 belongs to the most frequent PFG for acute myeloid leukemia (AML). In this study, for the first time, we applied several complementary techniques to validate whether exposure of human lymphocytes to RF at different UMTS frequency channels induce ROS, DNA damage, apoptosis, TP53 mutations and most frequent PFG.

2. Materials and methods

2.1. Chemicals

Reagent grade chemicals were obtained from Sigma (St. Louis, MI, USA) and Merck (Darmstadt, Germany).

2.2. Ethical considerations

The Ethics Committee of Children's Hospital in Bratislava has approved this study. All UCB samples were provided with an informed consent from a parent for study participation.

2.3. Cells

In vitro cultures of human lymphocytes were used to investigate the effect of RF exposure. Cells were isolated from UCB and cell aliquots were cryopreserved in liquid nitrogen by Dr. M. Kubes (Eurocord, Slovakia) as described before (Vasilyev et al., 2013). Each sample was thawed in a water bath and diluted in Roswell Park Memorial Institute (RPMI) media supplemented with 10% Fetal Bovine Serum (FBS), and 1% antibiotics (100 IU/ml penicillin, 100 μg/ml streptomycin). After removal of adherent cells (mostly monocytes) by 1 h incubation in culture flasks, the remaining lymphocytes were subjected to RF exposure.

2.4. RF exposure

We used the RF exposure unit based on UMTS test mobile phone (model 6650, Nokia, Helsinki, Finland), output being 0.25 W, and transverse electromagnetic transmission line cells (TEM-cells) as previously described (Belyaev et al., 2009; Durdik et al., 2019). Phoenix software (Nokia, Helsinki, Finland) was used to control parameters of exposure.

As far as available data indicate dependence of the non-thermal RF effects on carrier frequency (Belyaev, 2010; Belyaev, 2015), different UMTS frequency channels were tested. Each channel represented a 5 MHz wide frequency band with the middle frequency of 1923, 1947.47, or 1977 MHz. RF exposure and sham exposure was performed simultaneously for 1 and 3 h in a humidified CO_2 incubator at 5% CO_2 and 37 °C (Heracell 150i, Thermo Fischer Scientific, Waltham, Massachusetts, USA) in two identical TEM-cells. Cells were exposed in 14 ml round-bottom tubes (Sarstedt, Numbrecht, Germany), 5 ml of cell suspension at concentration of 2×10^6 cells/ml in each tube. Standard UMTS modulation Quadrature Phase Shift Keying (QPSK) was used. The specific absorption rate (SAR) was determined by measurements and numerical calculations using the finite different time domain (FDTD)-method as comprehensively described elsewhere (Sarimov et al., 2004) (Belyaev et al., 2009). The obtained SAR of 40 mW/kg was much lower than the currently accepted value for mobile phones (2 W/kg). Our UMTS signals, including frequencies and modulations, were those ordinary used by 3G mobile phones and SAR values were in the range of those exposing people during ordinary mobile phone calls. Taking into account all possible uncertainties, the SAR values at all locations within the RF exposed samples were always well below any measurable thermal effect. We measured temperature of samples before and after exposures with a precision of 0.1^0C and didn't find any changes. Static magnetic field (SMF) at the locations of real and sham UMTS exposures was 37 μT and background extremely low frequency (ELF) magnetic field was not more than 0.1 μT rms. As a positive control, we used 1 h treatment with tert-Butyl Hydroperoxide (TBHP) at 20 μM or 200 μM.

2.5. Alkaline comet assay

Alkaline comet assay also known as single cell gel electrophoresis (SCGE) was performed according to Singh et al., (1988) and Tice et al., (2002) with minor modifications. Slides were prepared in duplicates. Briefly, 1×10^5 lymphocytes (20 μl) were mixed with 80 μl of warm 0.5% low melting agarose prepared in phosphate buffer saline (PBS) (0.02% KCl; 0.8% NaCl; 0.29% $Na_2H_3PO_4$ x $12H_2O$; 0.02% KH_3PO_4 in deionized water) and this mixture was layered as a second layer on slides precoated with 1% normal melting agarose and stored at 4 °C for 15 min. The slides were treated for 1 h in freshly prepared, chilled lysis buffer solution (25 mM NaCl, 100 mM sodium EDTA, 10 mM Tris, 1% Triton X −100, 10% DMSO, pH adjusted to 10) at 4 °C. Then slides were incubated in alkaline electrophoresis buffer (10 N NaCl, 200 mM EDTA, pH adjusted to 13) for 40 min followed by electrophoresis (0.67 V/cm) for 30 min in the same buffer. The slides were then neutralized with Tris buffer (0.4 M Tris, pH adjusted to 7.5), rinsed with distilled water, and stained by ethidium bromide (5 μg ml^{-1}) before analysis. A total of 100 cells from each of the duplicate slides were examined randomly by the Zeiss Axioscope 2 epifluorescence microscope (Carl Zeiss Microscopy, Jena, Germany). Comet assay results were analyzed as tail moment (TM), the product of the tail length and the tail intensity, using the Metafer software (Metasystems, Altlussheim, Germany).

2.6. Reactive oxygen species

ROS were analyzed using Cell ROX Green kit (Life technologies, New York, USA) as previously described (Durdik et al., 2017). Briefly, 2 μl of 2.5 mM Cell ROX solution was added directly to 500 μl of cell suspension in concentration 1×10^6/ml immediately after exposure or sham exposure. Then antibody against white blood cells (including lymphocyte) surface marker was added, specifically, 2 μl CD45-V450 conjugate (BD biosciences, San Jose, California, USA) along with 3 μl of 7-AAD (BD biosciences) for staining nonviable cells. After incubation for 45 min in the CO_2 incubator, the samples were analyzed by imaging flow cytometer (ImageStreamX-100, Amnis-Luminex) and IDEAS software (Amnis Corporation, Seattle, WA, USA). Compensation matrix was created by the compensation wizard in the FACS Diva software (BD Biosciences, San Jose, CA, USA) after acquisition of single color stained samples and unstained control.

2.7. Apoptosis

Cells were harvested immediately and 24 h after exposure and apoptosis was analyzed as previously described (Durdik et al., 2017) simultaneously with ROS measurements. Briefly, 5×10^5 cells were spun down (100 g/10 min), washed with PBS and resuspended in 100 μl of the Annexin kit buffer (Roche, Basel, Switzerland). Cells were then stained with Annexin-V (Roche, Basel, Switzerland), 7AAD (BD biosciences) and anti-human CD45-V450 (BD biosciences) for white blood cell staining. The percentage of live (Annexin-V negative, PI negative), early apoptotic (Annexin-V positive, PI negative) and late apoptotic/necrotic (LAN) (Annexin-V positive, PI positive) cells was assessed using BD FACS Canto II flow cytometer (BD biosciences). Where LAN cells were more abundant, compensation were performed on samples. Single color stained tubes were acquired and compensation were generated automatically by BD FACS Diva software.

2.8. RNA/DNA isolation and cDNA synthesis

RNA for analysis PFG was isolated from 2.5×10^6 cells immediately after the end of 1-h and 3-h RF exposure from 1977 MHz frequency with innuPREP DNA/RNA mini Kit (Analytik Jena, Germany). cDNA was synthesized by reverse transcription in the standard reaction containing 1 μg of total RNA as we previously described (Skorvaga et al., 2014). At the same time, DNA for analysis of TP53 gene mutation was isolated from 1.5×10^6 cells using DNAzol genomic DNA isolation reagent following manufacturer protocol (Molecular Research Center, Ohio, USA).

2.8.1. RSM assay

Restriction site mutation (RSM) assay detects point mutations at restriction enzyme sites in TP53 gene as loss of p53 function (Bates and Vousden, 1999). The RSM assay was performed according to (Morgan et al., 2003) with some modifications. Digestion of genomic DNA was performed in 15-μl reaction volume with 1 μl of highly efficient Anza restriction endonuclease (Thermo Fisher Scientific, Waltham, MA, USA) overnight at optimal temperature, followed by additional digestion with 1 μl for 2 h. PCR contained 0.1 mM each dNTP's (Thermo Fisher Scientific), 300 nM each forward and reverse primers (Sigma Genosys, St. Louis, MI, USA), 1 μg of double-digested DNA and 2.5 U Dream*Taq* DNA polymerase (Thermo Fisher Scientific) in 1x TK buffer (20 mM Tris.Cl, pH 8.5; 50 mM KCl) with 3 mM $MgCl_2$ final concentration. The PCR products were purified by ethanol precipitation and re-digested with 1 μl Anza restriction enzyme (Thermo Fisher Scientific) in 20-μl volume for 3 h. One half of re-digested PCR product was analyzed by 2% agarose gel electrophoresis with RedGel stain (Biotium, Fremont, CA, USA) present in the gel using 0.5x TBE running buffer (Serva, Heidelberg, Germany). The gels were photographed with Gel documentation system MiniBis Pro (DNR-Imaging Systems Ltd., Neve Yamin, Israel). Second half of re-digested PCR product was saved for cloning/sequencing in case when the mutation containing fragment was detected.

2.8.2. Analysis of PFG by real-time quantitative PCR

RT-qPCR was performed as was previously described (Skorvaga et al., 2014; Kosik et al., 2017) using AriaMX real-time PCR system (Agilent Technologies, USA). The protocol, primers and probes were designed according to Gabert et al., (2003). Frequently occurring ALL/AML-associated PFG were tested, namely: TEL-AML1, MLL2-AF4, and MLL-AF9. The samples were run in triplicate and regarded as positive if at least one reaction was tested positive.

2.9. Statistical analysis

Mean and standard deviation (SD) were computed for the scores and the statistical significance of effects were determined using analysis of variance (ANOVA) adjusted for multiple comparisons using post-hoc tests such as Fisher LSD or Scheffe test with Statistica software (Dell software, Round Rock, Texas, USA). Differences were considered statistically significant at the value of $p < 0.05$.

3. Results

3.1. DNA damage

UCB cells from three different probands were exposed to UMTS RF at different frequencies (1923, 1947.47, or 1977 MHz) for 1 h and 3 h. Upon RF exposure, DNA damage was analyzed by alkaline comet assay. The representative photomicrographs of cells with damaged DNA are shown in Fig. 1A & B. Blood lymphocytes are known to be very sensitive to apoptosis, for instance induced by regular freeze and thaw process. Apoptotic cells were differentiated from viable cells according to the appropriate guidelines (Fig. 1C) and were not analyzed for DNA damage by the comet assay. TBHP treated cells have shown statistically significant increase in the TM compared to the untreated cells (ANOVA, $p < 0.001$). The TMs measured in cells after RF exposure are shown in Table 1. Analysis of data by multifactorial ANOVA has shown statistically significant dependence of the tail moment on RF exposure ($p = 0.04$). However, no dependence on exposure duration was revealed providing possibility for pooling the data for 1 and 3 h. The RF effect was also observed as a higher tail moment in the samples exposed at the 1977 MHz frequency if the data from 1-h and 3-h exposures were pooled ($p = 0.04$). Further analysis of the 1977 MHz effects split according to the duration of exposure did not show higher TM in the exposed samples. Analysis of pooled or split data at other frequencies, 1923 or 1947.47 GHz, did not show statistically significant effect of RF exposure on DNA damage. Summarizing the results, we

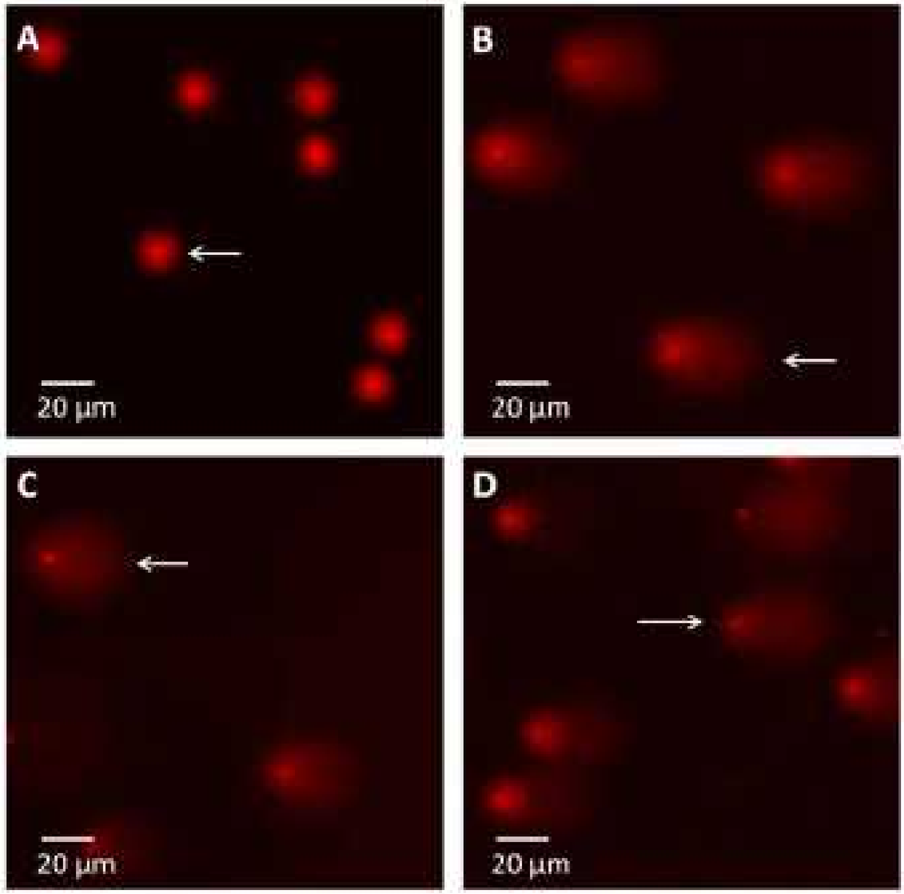

Fig. 1. Representative images of apoptotic cells and viable cells with and without DNA damage. A) Undamaged round-shape viable cells without DNA tails; B) DNA-damaged cells that contain a DNA tail and a head like a comet; C) late apoptotic cell with severely fragmented DNA around a small head; D) Severely DNA-damaged comet cells after treatment with TBHP.

Table 1
The data on alkaline comet assay for different frequencies of RF exposure.

Frequency (MHz)	Exposure duration (h)	Exposure	Tail moment (µM) (Mean ± SD)	P-value
1923.0	1	Exposed	3.79 ± 0.79	0.32
		Sham	2.86 ± 1.02	
	3	Exposed	3.94 ± 2.07	0.20
		Sham	2.71 ± 1.18	
1947.47	1	Exposed	6.07 ± 2.47	0.16
		Sham	4.72 ± 0.64	
	3	Exposed	4.34 ± 0.81	0.85
		Sham	4.52 ± 1.31	
1977.0	1	Exposed	2.12 ± 0.47	0.49
		Sham	1.84 ± 0.13	
	3	Exposed	2.71 ± 0.52	0.42
		Sham	2.03 ± 0.52	
Positive control	1	TBHB	25.53 ± 5.63	<0.001

Data from experiments with cells from three probands are shown. Differences between exposed and sham-exposed samples were defined by the univariate ANOVA followed by the post hoc Fisher LSD test.

observed relatively low but statistically significant effect of RF exposure on DNA damage in lymphocytes indicating dependence of this effect on the frequency of the UMTS signal.

3.2. Reactive oxygen species

As far as our comet assay results indicated that the effect of RF exposure could be frequency dependent, we exposed cells from 3 probands to UMTS for 1 and 3 h at the frequencies of 1923 and 1977 MHz and analyzed ROS and percentage of live $CD45^+$ lymphocytes immediately and also 24 h after 3-h exposure by the imaging flow cytometry (ImageStream X-100). Representative images of cells are shown in Fig. 6 (Supplementary Data) and obtained data in Figs. 2 and 3. Multifactorial ANOVA showed effect of neither RF exposure ($p = 0.36$), nor time of exposure/sham exposure ($p = 0.25$). By further analysis, we didn't find any difference in ROS between RF exposed and sham groups for all analyzed time points (ANOVA with Scheffe post-hoc, see Table 3, Supplementary data). As a positive control we used treatment with 200 μM TBHP that significantly induced ROS compared to the RF exposed/sham exposed samples (*t*-test, $p < 0.001$) (Table 3, Supplementary data).

Analysis of cell survival by staining with 7-AAD showed neither effect of UMTS exposure ($p = 0.94$) nor influence of frequency ($p = 0.12$) on cell viability. As expected, cell survival decreased with the time of incubation ($p < 0.001$), but the observed decrease in cell viability was caused by the endogenous apoptosis, not by the UMTS exposure.

3.3. Apoptosis

Using flow cytometry, we further analyzed apoptosis in cells from 3 probands immediately after 1-h and 3-h RF exposure at the frequency of 1977 MHz and also after 24-h incubation of the RF exposed samples (Table 4, Supplementary data). Representative figure of gating strategy to discriminate live cells, early apoptotic cells and LAN cells is shown in Fig. 7 (Supplementary data). Multifactorial ANOVA of pooled data showed significant dependence of cell viability on incubation time ($p < 0.001$). Similar decrease in cell viability was observed at 24 h compared to 3 h in both sham ($p = 0.02$) and RF exposed group ($p = 0.03$) suggesting endogenous nature of apoptosis in these cells. Indeed, RF exposure of cells did not result in any effect ($p = 0.95$) (Fig. 4). These data were in line with the results obtained by measuring 7-AAD LAN cells with imaging flow cytometry. We can conclude that UMTS exposure under chosen conditions did not induce apoptosis in lymphocytes. We didn't find any effect on apoptosis also in our previous study with 1947.47 MHz frequency (Durdik et al., 2019).

3.4. Mutational analysis of TP53 gene

We performed three experiments with cells of different probands to analyze whether UMTS exposure at 1977 MHz induces mutations in selected mutation hotspots of *TP53* gene, namely codon 175 (exon 5) and codon 213 (exon 6). Exposed and sham lymphocytes were collected immediately after 1-h and 3-h RF exposure and then 24-h post-exposure. In Fig. 5, the photo of a representative gel is shown. The size of mutated, i.e. digestion-resistant DNA fragment was expected to be 188 bp, in contrast to

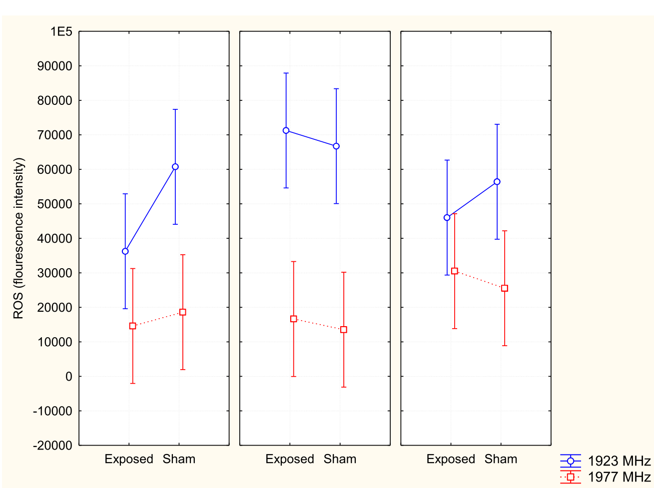

Fig. 2. ROS for different carrier frequencies and durations of UMTS RF exposure, imaging flow cytometry. The data from three experiments with cells from different probands are shown in each data point. Error bars show 95% confidence interval.

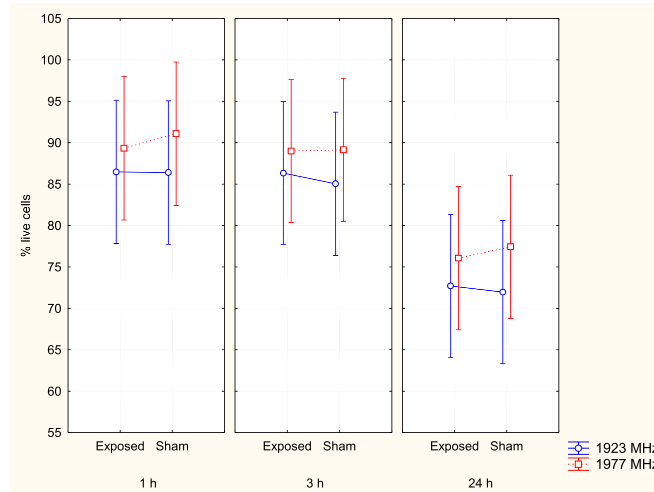

Fig. 3. Cell viability after UMTS RF exposure at different carrier frequencies and exposure durations as measured by imaging flow cytometry. The data from experiments with cells from three probands are shown. Error bars show 95% confidence interval.

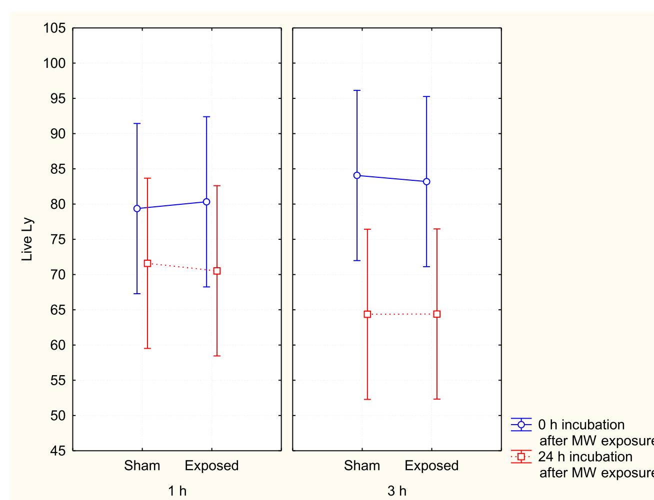

Fig. 4. Cell viability measured by FACS after different durations of RF exposure. The data from experiments with cells from three probands are shown. Error bars show 95% confidence interval.

fully digested PCR product yielding two fragments, 114 bp and 74 bp, respectively. The gel is highly overexposed in order to increase chance to visualize the mutated band. No mutations were detected at all tested conditionals of UMTS exposure using the RSM assay with sensitivity of $10^{-4} - 10^{-5}$.

3.5. Preleukemic fusion genes

We used UCB cells from three different probands to test possible induction of PFG by RF exposure at the 1977 MHz frequency. TEL-AML1, MLL2-AF4 and MLL1-AF9 preleukemic fusion genes, which are associated with ALL and AML, respectively, were analyzed by the RT-qPCR. We found TEL-AML1 positivity in three out from seven sham exposed samples but only in one out from seven UMTS exposed samples (Table 2). MLL2-AF4 fusion gene was found in two out from seven exposed/sham exposed. We did not observe MLL-AF9 PFG in any of the tested samples. All positive observations were characterized by very low number of PFG copies about 2.6

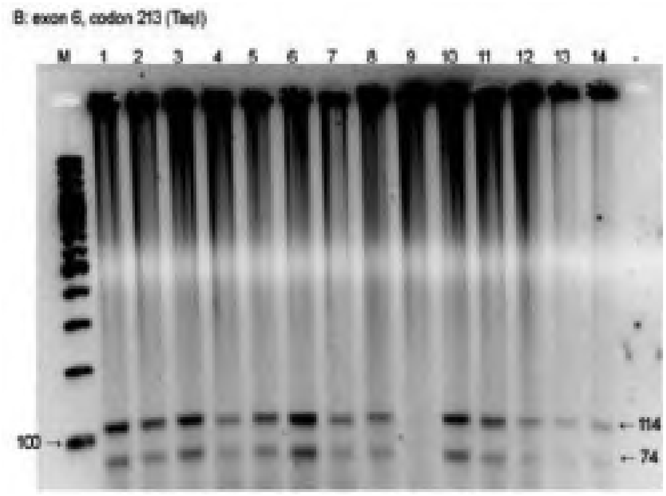

Fig. 5. Representative gel from the RSM experiment involving the TaqI restriction site of codon 213. M – 100 bp DNA ladder, 1–12: P377, P367, and P320 - sham 1 h, UMTS 1 h, sham 3 h, UMTS 3 h, respectively, 13 and 14: P367 sham 24 h and UMTS 24 h, respectively, - negative control (no DNA template in PCR). Two bands, corresponding to 114 bp and 74 bp, result from a complete digestion of exon 6, codon 213, in TaqI T↓CGA restriction site indicating that the mutation in this hot spot site of p53 gene was not introduced. In case of introducing a mutation in this site, a 188 bp band would appear.

copies per 10^5 cells showing that this positivity was at the level of sensitivity of the applied RT-qPCR method. Taking into account this fact and sporadic nature of the observed PFG positivity, we concluded that UMTS RF exposure at the 1977 MHz frequency did not induce the tested PFG. Additionally we compared the RNA expression as the yield of RNA per cell after the UMTS and sham exposure. Analysis by multifactorial ANOVA has shown significant effect of UMTS exposure on RNA expression ($p = 0.03$). By further analysis by one-way ANOVA followed by Fisher LSD we found significant reduction of RNA in cells upon 1-h UMTS exposure ($p = 0.03$).

4. Discussion

In the present investigation, we analyzed non-thermal effects of RF from 3G mobile phone at different UMTS frequency channels on human lymphocytes. We used complimentary biomarkers to assess DNA damage by alkaline comet assay, ROS by imaging flow cytometry, apoptosis by flow cytometry, p53 mutations by RSM method, and induction of PFG by RT-qPCR method. Comet assay is a very sensitive technique which can detect damage in DNA at single cell level and widely accepted in genonotoxicity studies worldwide (Garaj-Vrhovac et al., 2002; Guerci et al., 2011; Seidel et al., 2012). Thus, we used comet assay to detect eventual damage caused by different UMTS frequency channels, 1923, 1947.47, and 1977 MHz. Analysis of data by multifactorial ANOVA has shown statistically significant dependence of the comet tail moment on RF exposure but not on duration of exposure. This RF effect was also observed as a higher TM in the samples exposed at the 1977 MHz frequency if the data from 1-h and 3-h exposures were pooled. Analysis of data at other frequencies, 1923 or 1947.47 GHz, did not show statistically significant effect of RF exposure on DNA damage. Thus, we found relatively small but statistically significant induction of DNA damage in dependence on UMTS frequency channel with maximal effect at 1977 MHz. Our comet assay findings are in line with some previous studies (Lai and Singh, 1996, 1997; Garaj-Vrhovac and Orescanin, 2009; Shahin et al., 2013; Gulati and Yadav, 2016) although other studies are in contrast with our data (Sun et al., 2006a, 2006b; Hintzsche and Stopper, 2010; Juutilainen et al., 2011).

Of note, the data from different studies cannot be directly compared due to dependence of the non-thermal RF effects on several biological and physical variables, which significantly vary between studies (Belyaev, 2010; IARC, 2013). In particular, dependence of the non-thermal RF effects on frequency has previously been reviewed (Pakhomov et al., 1998; Belyaev et al., 2000). Frequency-dependent interactions of RF with such targets as cellular membranes, chromosomal DNA, free radicals, proteins and ions in protein cavities may be involved in such effects of RFs (Ismailov, 1987; Chiabrera et al., 2000; Binhi, 2002; Belyaev, 2015).

Cell type was also critical as far as different cell types reacted significantly differently to the same non-thermal RF exposure (Belyaev, 2010; IARC, 2013). So far, very few studies have analyzed genotoxicity of the UMTS signals in human lymphocytes by alkaline comet assay. Sannino et al., (2006) exposed blood leukocytes to 1950 MHz frequency used by UMTS mobile communication for 24 h and didn't find any DNA damage. Ivancsits et al., (2005) also investigated the effect of UMTS exposure using different cell types and didn't reveal any genotoxic effects in lymphocytes. El-Abd et al. (El-Abd and Eltoweissy, 2012) reported time dependent DNA damage in human lymphocytes from UMTS exposure. Intermittent exposure to UMTS as compare to continuous wave exposure resulted in significant effects in fibroblasts but lymphocytes didn't show the same pattern in the study by Schwarz et al., (2008). Al-Serori et al., (2018) studied the role of serum in media with different cell types including lymphocytes for the effects of UMTS exposure. Although DNA damage was serum dependent in glioblastoma cells, no DNA damage was found in lymphocyte by UMTS exposure with or without serum. In line with our results, recent study by Bektas et al. found a link between mobile phone exposure during pregnancy and DNA damage measured with comet assay in UCB lymphocytes (Bektas et al., 2020).

As already mentioned above, results of all these comet assay studies are not directly comparable due to using different biological and physical variables and strong dependence of the RF effects on

Table 2
Expression of MLL2-AF4 and TEL-AML1 preleukemic fusion genes after 1-h and 3-h UMTS exposures as measured by RT-qPCR in cells of three different probands. Number of PFG positive samples out from three tested samples is shown.

	P377 SHAM 1h	P377 UMTS 1h	P377 SHAM 3h	P377 UMTS 3h	P367 SHAM 1h	P367 UMTS 1h	P367 SHAM 3h	P367 UMTS 3h	P320 SHAM 1h	P320 UMTS 1h	P320 SHAM 3h	P320 UMTS 3h
RNA (ng/μl)	149.3	84.2	114.6	97.5	154.7	138.6	172.1	141.1	141.4	98.8	112.1	131.9
Yield (pg/cell)	1.79	1	1.38	1.17	1.66	1.5	1.84	1.5	1.77	1.24	1.2	1.41
c-ABL copies/10^5	36	11.55	27.476	16.55	24.46	12	19.181	20	4.445	12.458	26.236	5.09
MLL2-AF4	1/3	0/3	0/3	1/3	0/3	0/3	0/3	0/3	1/3	0/3	0/3	1/3
TEL-AML1	0/3	0/3	1/3	0/3	0/3	0/3	1/3	1/3	0/3	0/3	1/3	0/3
MLL1-AF9	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3

these variables (Belyaev, 2010). Given such dependence, it should be concluded that RF exposure may or may not affect DNA damage and repair strongly dependent on exposure conditions. In particular, the frequency/frequency channel is of importance as shown previously for GSM (Markova et al., 2005; Belyaev et al., 2009) and now for UMTS mobile phone. Along with other available data on dependence of the non-thermal RF effects on frequency (Belyaev, 2010; IARC, 2013), the obtained here data suggest that each signal for mobile communication should be tested in specially designed experiments before being used in mobile communication.

Except for frequency, apparently controversial findings stemming from different studies on RF-induced DNA damage can be accounted for several other experimental conditions. In particular, background ELF EMF and SMF were consistently reported to affect response to RF exposure (Belyaev, 2010; IARC, 2013), although remain either different or unreported in majority of studies. Thus, background ELF EMF and SMF (0.2 μT and 37 μT in our study) may be one of the reasons underlying eventual inconsistency (Blackman, 2009; Durdik et al., 2019).

Despite significant progress, there is still substantial lack of knowledge in biophysical modeling of RF induced non-thermal biological effects, which would predict effective and respectively inefficient conditions of RF exposure (Belyaev, 2015). A significant number of studies reviewed in (Georgiou, 2010, Yakymenko et al., 2016) suggested the role of oxidative stress (excessive formation of ROS) in RF induced DNA damage. It is generally accepted that stimulation of oxidative stress can generate DNA damage (Moustafa et al., 2001; Stopczyk et al., 2005; Blank and Goodman, 2011; Burlaka et al., 2013; Gulati et al., 2018) and apoptosis (Desai et al., 2009; Shahin et al., 2015).

Lu et al. reported that apoptosis was induced by RF exposure through the mitochondrial pathway mediated by activating ROS and caspase-3, and decreasing the mitochondrial potential (Lu et al., 2012). Friedman et al., studied the link between RF exposure and cancer through ERK-MAPK signaling pathway and found that RF-induced ROS activates ERK cascade by stimulating matrix metalloproteinase (Friedman et al., 2007). Several studies suggested that ROS plays an important role in cell death and signal transduction induced by non-ionizing radiations (De Iuliis, Newey et al., 2009; Kesari et al., 2013; Furtado-Filho et al., 2014). Of note, ROS level may be only temporarily induced by RF expsure due to subsequent activation of the antioxidant defense mechanism (Marjanovic et al., 2015; Durdik et al., 2019). Thus, here we analyzed ROS and apoptosis in UCB lymphocytes upon exposure to UMTS RF. ROS were measured by imaging flow cytometry immediately and 24 h after exposure at two carrier frequencies (1923 and 1977 MHz) for different time durations, 1 and 3 h. Multifactorial ANOVA analysis showed effect of neither RF exposure nor duration of exposure/sham exposure and incubation time. By further analysis, we didn't find any difference in ROS between RF exposed and sham groups for all analyzed time points (ANOVA with Scheffe post-hoc). Of not, exposure at one of these frequencies, 1977 MHz, resulted in weak but statistically significant induction of DNA damage as measured with alkaline comet assay while another frequency, 1923 MHz, was tested ineffective. Vice versa, UMTS exposure at 1947 MHz induced ROS level in identical experiments (Durdik et al., 2019) while did not induce DNA damage as measured in this study. Lack of relationship between induction of ROS and DNA damage revealed in this study may be accounted for adaptive reaction of cells to oxidative stress resulting in time dependent kinetics of ROS, which may be increased at other time points as analyzed in this study. Other possible mechanisms for induction of DNA damage, which do not involve ROS production, deal with impact through RF-induced changes in molecular conformation (Chiabrera et al., 2000; Matronchik and Belyaev, 2008). According to these mechanisms, RF may either affect availability of DNA to DNA-breaks, which are physiologically induced by enzymes such as topoisomerases and endonucleases, or increase activity of these enzymes affecting binding of their active centers with divalent ions such as Zn, Ca, and Mg. We also analyzed apoptosis/cell viability by imaging flow cytometry in the same experiments with ROS but no effect of RF exposure was found. In further experiments we tested by standard flow cytometry whether UMTS exposure at the frequency of 1977 MHz, which was shown to induce DNA damage, also induced apoptosis in UCB lymphocytes. The obtained data solidified our conclusion stemming from analysis by imaging flow cytometry that UMTS exposure did not induce apoptosis in lymphocytes.

While DNA damage is a prerequisite for formation of mutations, it can be efficiently repaired during DNA damage response. Of specific interest are mutations in those genes, which are involved in origination of various types of cancer. TP53 encoding p53 protein is the most commonly mutated gene in human cancers including brain tumors and leukemia. Preleukemic fusion genes TEL-AML1, MLL-AF4 and MLL-AF9 are most frequent in pediatric acute lymphoid leukemia and acute myeloid leukemia, respectively. Thus, we analyzed mutations in *TP53* gene by the RSM method and induction of the aforementioned PFG by the RT-qPCR. No mutations in selected *TP53* gene mutation hotspots were detected with relatively high sensitivity (10^{-4} to 10^{-5}). Neither from the PFG studied here was induced by the UMTS exposure. From obtained results we conclude that UMTS exposure at chosen conditions induced neither TP53 mutations nor TEL-AML1/MLL-AF4/MLL-AF9 preleukemic fusion genes as analyzed by the RSM or RT-qPCR technique, respectively, regardless the ability of UMTS exposure to induce DNA damage as measured by comet assay.

We found decreased yield of RNA per cell upon exposure to UMTS RF. To the best of our knowledge, this is the first report indicating that non-thermal RF exposure from mobile phone can affect a bulk RNA expression. Previous studies focused on analyzing expression of selected genes and transcriptome profiles (Belyaev et al., 2006; Nittby et al., 2008; Fragopoulou et al., 2018), and more recently on miRNA, which play key role in proliferation, differentiation, and apoptosis by suppressing specific target genes (Dasdag et al., 2015a, 2015b; Dasdag et al., 2019). Expression of multiple genes was shown to be either induced or suppressed by RF in these studies. Interestingly, expression of several miRNA was shown to be inhibited. In particular, Dasdag et al. found that long-term exposure of rats to RF at 2.4 GHz inhibited expression of some of the miRNAs such as miR-106b-5p and miR-107 (Dasdag et al., 2015a, 2015b). However, no study has so far provided the yield of RNA per cell to be compared with our results.

As far as non-thermal RF effects were shown to be accumulated during chronic exposures (Belyaev, 2017), further studies with prolonged exposures to different signals of mobile communication are warranted. These should include systems biology studies both *in vitro* and *in vivo*. More specifically, effects in critical biological processes, such as cell cycle, DNA replication and repair, RNA and protein expression, cell death, cell signaling, nervous system development and function, immune system response and carcinogenesis should be studied (Fragopoulou et al., 2018).

5. Conclusion

We found relatively small but statistically significant induction of DNA damage in dependence on UMTS frequency channel with maximal effect at 1977 MHz through alkaline comet assay. We concluded that UMTS RF exposure at the 1923 and 1977 MHz frequency did not induce ROS, apoptosis, selected TP53 mutations and PFG, but inhibited a bulk RNA expression. Our data support a notion that each specific signal used in mobile communication should be tested in specially designed experiments to rule out that prolonged exposure to RF of mobile communication would affect human population and biota.

Statement from authors

All of the authors have read and approved the paper and it has not been published previously nor is it being considered by any other peer-reviewed journal.

Author contributions

I.B. and S.G. conceived the experiments; S.G., P.K., M.D., M.S., L.J., E.M., conducted the experiments; S.G., P.K., M.D., M.S., I.B. analyzed the results; S.G and I.B. wrote the manuscript.

Declaration of competing interest

S.G., P.K., M.D., M.S., L.J., E.M., report no conflict of interest. IB provided expert opinions in the Cell Phone Litigation on link between microwave radiation from mobile phones/base stations and human health.

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Appendix A. Supplementary data

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Research Article

Effects of Long-Term Exposure to L-Band High-Power Microwave on the Brain Function of Male Mice

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Currently, the impact of electromagnetic field (EMF) exposure on the nervous system is an increasingly arousing public concern. The present study was designed to explore the effects of continuous long-term exposure to L-band high-power microwave (L-HPM) on brain function and related mechanisms. Forty-eight male Institute of Cancer Research (ICR) mice were exposed to L-HPM at various power densities (0.5, 1.0, and 1.5 W/m^2) and the brain function was examined at different time periods after exposure. The morphology of the brain was examined by hematoxylin-eosin (HE) and deoxynucleotidyl transferase-mediated dUTP nick-end labeling (TUNEL) staining. Furthermore, cholinergic markers, oxidative stress markers, and the expression of c-fos were evaluated to identify a "potential" mechanism. The results showed that exposure to L-HPM at 1.5 W/m^2 can cause generalized injuries in the hippocampus (CA1 and CA3) and cerebral cortex (the first somatosensory cortex) of mice, including cell apoptosis, cholinergic dysfunction, and oxidative damage. Moreover, the deleterious effects were closely related to the power density and exposure time, indicating that long-term and high-power density exposure may be detrimental to the nervous system.

1. Introduction

Since regular radio broadcasts started in the 1920s, exposure to human-made electromagnetic fields (EMFs) has steadily increased. Nowadays, radio waves come not only from radios but also from a variety of other sources, such as navigation and communication systems, as well as high-voltage transmission and transformation systems. Consequently, a very large fraction of the global population is exposed to EMFs. Unfortunately, the mainstream view in academia is that long-term and high-intensity EMF exposure may disrupt the homeostasis of biological systems and harm human health [1–3]. Although EMF technologies have brought a lot of convenience to human life, there is still insufficient knowledge on the biological effects of EMF. The field of bioelectromagnetic research is still mainly focused on the initial exploration of biological effects. Accordingly, many countries are continuously studying the possible biological effects of various EMF sources and effective protection measures in addition to the application of EMF [4–6].

According to a meta-analysis on the effects of EMF exposure on human health, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers (IEEE) individually declared more stringent guidelines for exposures to EMF from 0 direct current (DC) to 300.0 GHz (IEEE, 2019; ICNIRP, 2020).

As we all know, the physical properties of EMFs are closely related to their frequency. The key parameters of EMF, such as reflectivity, penetration, and absorptivity, vary with its frequency. Therefore, EMFs with different frequencies are defined as multiple bands for particular purposes based on the above characteristics. Over the last 20 years, researchers have compiled increasingly strong evidence that EMFs over the entire frequency range can modify biological processes. There is now solid experimental evidence and a theoretical basis indicating that weak EMFs, especially but not exclusively EMFs at low frequencies, can cause symptoms such as irritability, headache, memory loss, and increased incidence of brain tumors [7, 8]. A large number of animal experiments have also found that electromagnetic radiation with certain parameters can reduce learning ability and memory, affect emotions, and impair the brain structure and function [9–13].

The frequency band of the EMF used in this study was centered around 2.0 GHz, corresponding to the L-band EMF that is widely used in satellite navigation systems. Due to the complexity of operating this kind of navigation system, the operators need to have higher cognitive ability. If the operators have neurocognitive dysfunction, such as difficulty concentrating, slow reaction, and impaired ability to read, it can easily lead to adverse consequences. Therefore, it is critical to investigate whether L-band EMF has an adverse effect on brain function.

According to the different mechanisms through which an EMF exerts its effects on organisms, they can be divided into thermal effects and nonthermal effects. When a biological system is exposed to high-frequency electromagnetic radiation, the heat generated by molecular movement cannot be released in a short time, leading to the thermal effects under the action of dipoles. Furthermore, the balance of the weak EMF of the organism can be disturbed, resulting in nonthermal effects after long-term exposure to low-frequency electromagnetic radiation. If the damage caused by thermal and nonthermal effects cannot be fully repaired, it will accumulate after renewed exposure to EMF radiation [14]. Consequently, diseases might be induced by long-term exposure to EMF because of the accumulation effect, which should be investigated with great care [15]. It has been reported that a thermal effect is induced when the power density of EMF exceeds 100 W/m^2. However, microthermal effects are dominant at power densities of 10–100 W/m^2 and nonthermal effects are dominant at power densities of less than 10 W/m^2 [16]. In the present study, a central frequency of 2.0 GHz and a maximum power density of 1.5 W/m^2 were adopted. Therefore, it can be assumed based on previous results that the treatment with L-band electromagnetic radiations in this study mainly induced nonthermal effects.

There is a weak but stable EMF in the human body, and EMF of a certain intensity could interfere with the bioelectrical activities of the human body and make it unstable. Since the functioning of the nervous system is based on bioelectricity, it is more susceptible to be influenced by external EMF. The nervous system is believed to be an important and sensitive target for electromagnetic exposure. A variety of damaging effects at the whole body, tissue, cell, and gene levels would be induced by long-term exposure to EMF [17–19]. Therefore, to explore the effects of continuous long-term exposure to L-band EMF on brain function and structure, EMFs with an average power density of 0.5, 1.0, and 1.5 W/m^2 were used to irradiate Institute of Cancer Research (ICR) mice for 4 or 8 weeks in the present study. This research provides a biomedical reference for operators of the L-band EMF platform.

2. Materials and Methods

2.1. Animals. All animal care and experimental procedures were in accordance with the University Policies on the Use and Care of Animals and were approved by the Institutional Animal Experiment Committee of Air Force Medical University, Xi'an, China (identification code: IACUC-20180503; date of approval: 21 May 2018). A total of 48 male ICR mice (5–6 weeks old, weighing 18 ± 2 g) were obtained from the Laboratory Animal Center of Air Force Medical University and housed in ten different cages in temperature- and humidity-controlled rooms with ad libitum access to food and water throughout the experimental period.

2.2. L-HPM Exposure Protocol and Experimental Groups. The L-HPM exposure was carried out in a microwave anechoic chamber which included a shielding room and a control room. The shielded enclosure was made of steel plates and had an inner wall covered with a tapered carbon sponge absorbing material to shield from interference by external electromagnetic fields. The L-HPM exposure facility was placed in the shielded room. Animals were placed in a special plastic box in a free position on the animal platform.

The 48 male ICR mice were randomly divided into four groups: sham exposure group, 0.5 W/m^2 L-HPM exposure group, 1.0 W/m^2 L-HPM exposure group, and 1.5 W/m^2 L-HPM exposure group, with 12 mice per group. According to the different exposure times and sampling times, mice from each group were randomly divided into two subgroups with six animals in each subgroup. Animals in the first subgroup were sham exposed or received whole-body exposure to L-HPM for 4 weeks (1 h/day, 09:00 am–10:00 am) and sacrificed 2 weeks after exposure. Animals in the second subgroup were sham exposed or received whole-body exposure to L-HPM for 8 weeks (1 h/day, 09:00 am–10:00 am) and sacrificed 6 weeks after exposure.

2.3. Preparation of Brain Tissue for Analysis. After L-HPM sham exposure or exposure, the whole brains of mice were removed. Three brains from each subgroup of six animals were fixed in 4% paraformaldehyde for 24 h and embedded in paraffin following standard methods for immunohistochemical and histological analyses. The other three brains were quickly dissected on ice and immediately snap frozen and stored at −80°C to be used for the biochemical analyses.

2.4. Hematoxylin and Eosin (HE) Staining. The whole brains were isolated and fixed in 4% paraformaldehyde for 24 h and then rinsed in running water for 24 h. Thereafter, each sample was dehydrated using a standard alcohol series, defatted in xylene, and finally embedded in paraffin. Histological sections, 5 μm thick, were dewaxed, hydrated, and stained with HE. After drying, the histological slides were covered with cover slips. Digital photography of the hippocampus and cerebral cortex was performed under a Leica DMI4000B optical microscope (Leica Biosystems, Heidelberg, Germany) and a Hamamatsu NanoZoomer Scan SQ1.0 (Hamamatsu Photonics, Shizuoka, Japan) with NDP.

2.5. TUNEL Staining. Apoptotic cells in the brains were identified via the terminal deoxynucleotidyl transferase-mediated dUTP nick-end labeling (TUNEL) assay using the in situ Cell Death Detection Kit (Roche, Germany) according to the manufacturer's protocol. Briefly, the brain sections were deparaffinized before rehydration with decreasing concentrations of ethanol. Subsequently, the sections were washed with PBS pH 7.4 and then covered with proteinase K solution for 25 min. Thereafter, the sections were washed with PBS again, covered with the TUNEL reaction mixture, and incubated for 1 h in the dark. DAPI counterstaining of nuclei was followed by a final PBS wash. Florescence micrographs were obtained using a Nikon Eclipse C1 fluorescence microscope (Nikon, Japan) and analyzed using CaseViewer software. The number of TUNEL-positive cells were counted under 400-fold magnification. Cell counting was performed by an investigator blinded to the groups.

2.6. Immunohistochemistry. The brains were cut in the coronal plane into sections with a thickness of 5 μm, which were mounted on slides. Sections at the level of the hippocampus and cerebral cortex were deparaffinized and rehydrated via a decreasing alcohol gradient. Endogenous peroxidase activity was quenched using 3% hydrogen peroxide in methanol for 30 min in darkness, and 0.01 M citrate buffer pH 6.0 was applied for microwave antigen regeneration. The brain sections were washed with PBS and incubated with blocking solution for 1 h at room temperature. Then, the slides were incubated with rabbit anti-c-fos primary antibody (1 : 1000, Servicebio, China) at 4°C overnight. After washing in PBS, a secondary goat anti-rabbit antibody conjugated with horseradish peroxidase (HRP) (1 : 200, Servicebio, China) was incubated with the slides for 1 h at room temperature. Thereafter, the color was developed using DAB (BosterBio, USA). Following hematoxylin counterstaining, slides were sealed with neutral gum. The sections were observed and photographed using a conventional optical microscope (Nikon, Japan). Finally, the positive cells in the hippocampus and cerebral cortex from each mouse were counted at 400-fold magnification in five randomly chosen visual fields.

2.7. C-fos Expression Analysis. Image-Pro Plus 6.0 software was used to analyze the positive cumulative optical density of each image (IOD) and the pixel area of the tissue (AREA). Average optical density (AO) was calculated as IOD/AREA; this AO value was proportional to the positive expression level.

2.8. Assay of Cholinergic Markers. Cholinergic marker levels in brain tissue were measured using commercial assay kits (Nanjing Jiancheng Bioengineering Institute, China). Brain tissue was weighed and homogenized in 9 volumes of ice-cold saline containing a protease inhibitor cocktail (Sigma-Aldrich) and centrifuged at 3000 rpm and 4°C for 20 min to obtain the cleared lysate. The total protein concentration was quantified by the Bradford assay method using the Bio-Rad Dc System (Bio-Rad Laboratories, USA). The cleared lysate was further diluted with the appropriate buffer solutions to measure the activities of choline acetyltransferase (ChAT) and acetylcholinesterase (AChE), according to the manufacturer's instructions. All samples were assessed in triplicate.

2.9. Determination of Oxidative Stress Marker Levels. Oxidative stress marker levels in brain tissue were measured using commercially available assay kits (Nanjing Jiancheng Bioengineering Institute, China). Cleared brain tissue lysate obtained as described in Section 2.8 was used to measure the activities of superoxide dismutase (SOD) and the content of malondialdehyde (MDA) spectrophotometrically using assay kits according to the manufacturer's instructions. All samples were measured in triplicate.

2.10. Statistical Analysis. All data were presented as means ± standard deviations (SD) and analyzed using SPSS 22.0 software (SPSS Inc., USA). Student's t-test followed by homogeneity of the variance test was used to analyze the significance of differences between the sham-exposed group and exposed group. For all statistical analyses, a P value < 0.05 was considered to indicate statistical significance.

3. Results

3.1. Effect of L-HPM Exposure on the Morphology of the Hippocampus and Cerebral Cortex. The brain sections stained with HE did not show any significant morphological and morphometric differences in the hippocampus (CA1 and CA3) and cerebral cortex (the first somatosensory cortex, S1) between the L-HPM-exposed group and the sham-exposure group (Figure 1).

3.2. L-HPM Exposure Aggravated the Cell Apoptosis in the Hippocampus and Cerebral Cortex. To assess the effects of L-HPM exposure on cell apoptosis, TUNEL staining was performed. In the group exposed for 4 weeks, the mice exposed to L-HPM with an intensity of 1.5 W/m^2 showed a significantly increased number of TUNEL-positive cells in the hippocampal CA1 and CA3 and cerebral cortex S1 (Figures 2(a) and 2(b)) than those in the sham exposure group. In the group exposed for 8 weeks, the mice exposed to L-HPM with intensities of 0.5, 1.0, and 1.5 W/m^2 showed a significant increase in the number of TUNEL-positive cells compared with those in the sham exposure group (Figures 2(c) and 2(d)). These results demonstrated that L-

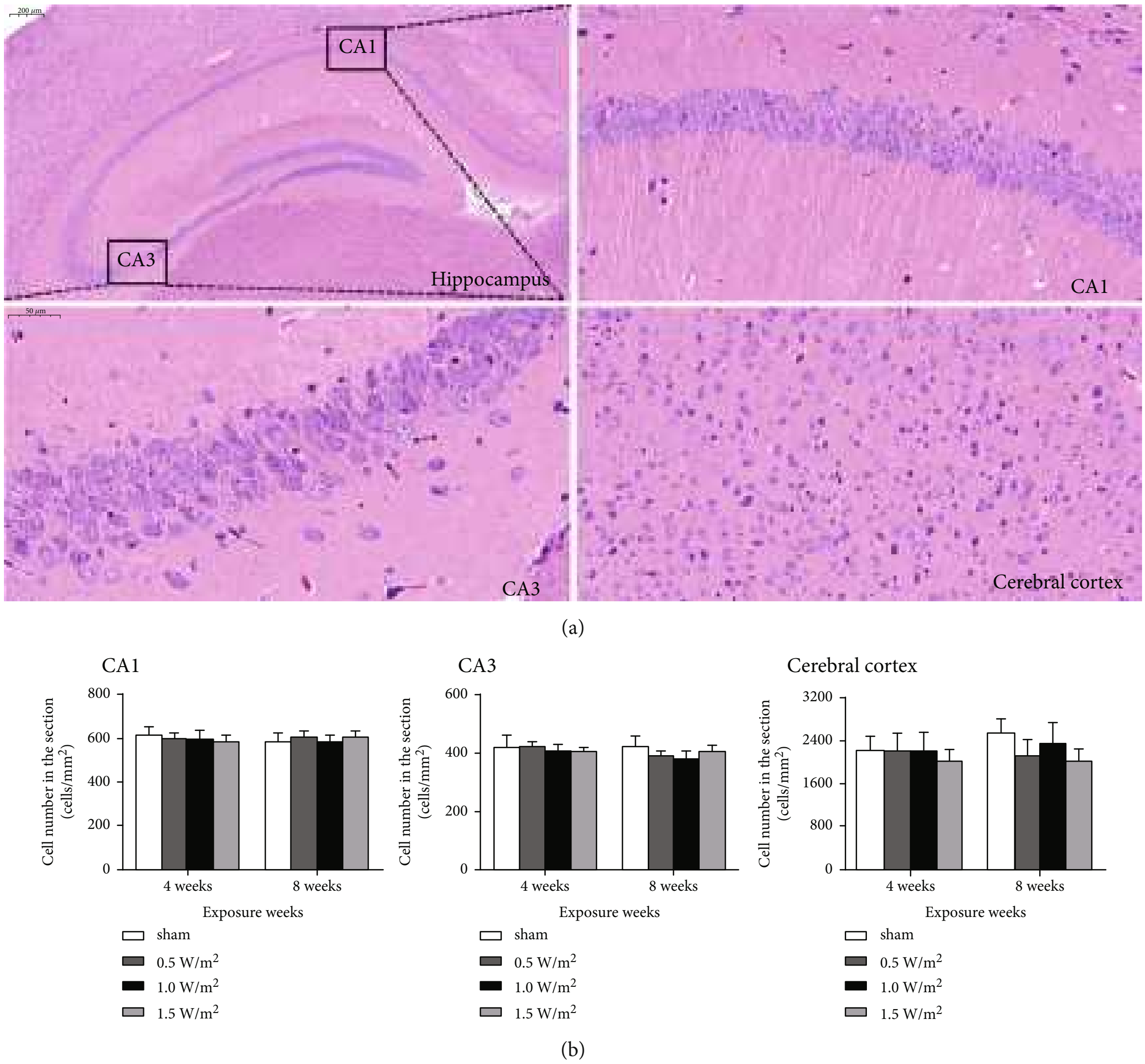

Figure 1: HE stained sections of the mouse hippocampus (CA1 and CA3) and cerebral cortex (S1) after L-HPM exposure for different durations. (a) The histology of the hippocampus and cerebral cortex examined by HE staining. (b) Morphometric analysis of the hippocampus and cerebral cortex. Scale bar = 50 μm. HE: hematoxylin-eosin; L-HPM: L-band high-power microwave.

HPM exposure may aggravate the apoptosis of neurons and glial cells in the hippocampus and cerebral cortex.

3.3. Effect of L-HPM Exposure on c-fos Levels in the Mouse hippocampus and Cerebral Cortex. Immunohistochemical staining was used to evaluate the distribution and expression level of c-fos. The results showed that the distribution of c-fos did not change following L-HPM exposure for different durations (Figure 3(a)). Quantitative analysis revealed that the expression level of c-fos in the hippocampal CA1 and CA3 and cerebral cortex S1 did not exhibit significant differences between the L-HPM-exposed groups and the sham exposure group (Figure 3(b)).

3.4. Effects of L-HPM Exposure on the Activity of AChE and ChAT in the Mouse Brain. Biochemical analyses revealed that the activity of AChE was significantly increased in the mouse brain after 8 weeks of exposure to L-HPM at 1.5 W/m^2 (Figure 4(b)). These results indicate that long-term high-dose L-HPM exposure may cause central cholinergic dysfunction. However, no differences in ChAT and AChE activity were observed between the groups exposed to L-HPM at 0.5 or 1.0 W/m^2 and the sham exposure group (Figures 4(a), 4(c), and 4(d)).

3.5. Effects of L-HPM Exposure on the Activity of SOD and the Content of MDA in the Mouse Brain. Biochemical analyses showed that the activity of SOD in the mouse brain was significantly decreased after 8 weeks of exposure to L-HPM at 1.0 and 1.5 W/m^2 exposure (Figure 5(b)). Furthermore, the MDA levels were significantly elevated after 8 weeks of exposure to L-HPM at 1.5 W/m^2 (Figure 5(d)). However, there were no significant differences in SOD and MDA levels between the other L-HPM exposure groups and the sham exposure group (Figures 5(a) and 5(c)). This indicates that increased oxidative damage was induced by long-term high-dose L-HPM exposure, while shorter and low-dose L-HPM exposure did not induce oxidative damage.

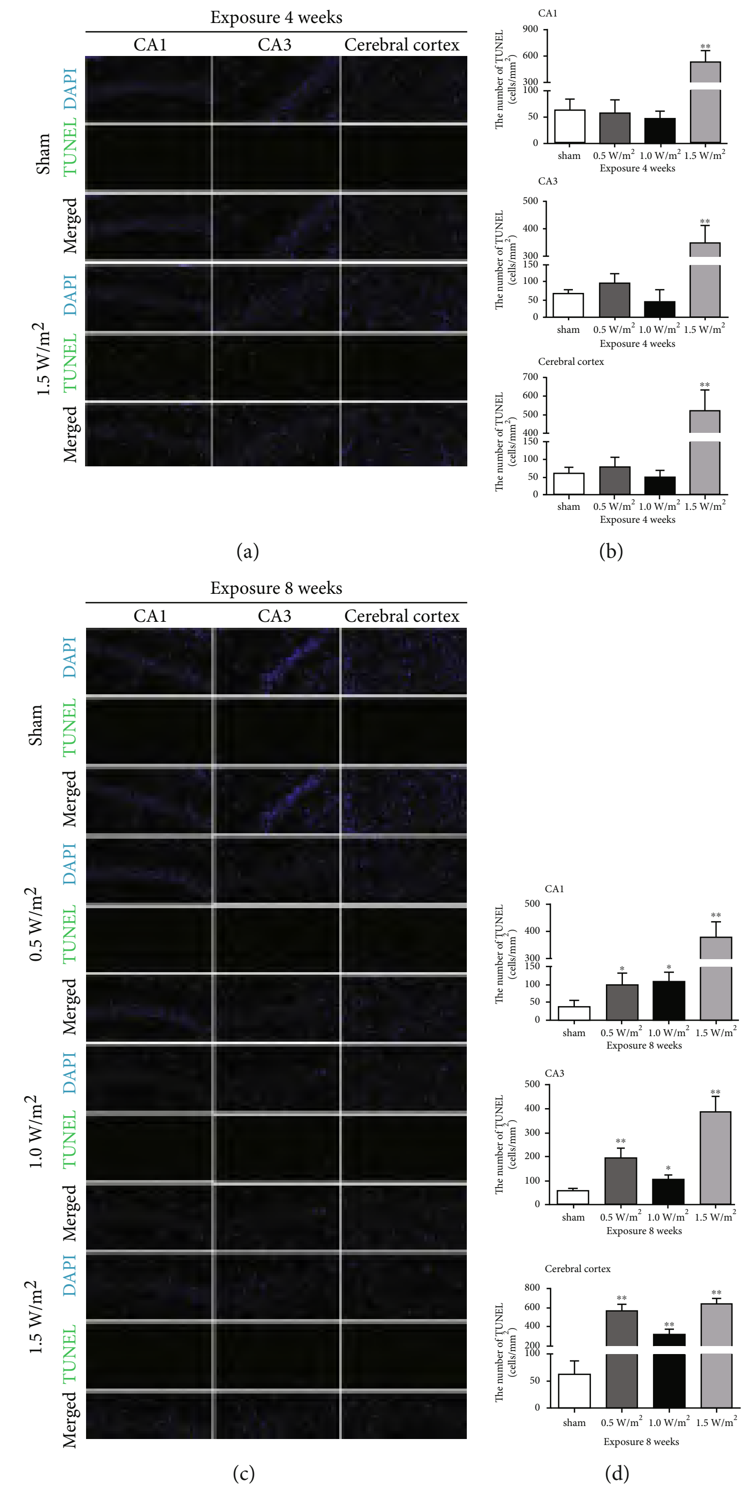

Figure 2: TUNEL staining of the hippocampus (CA1 and CA3) and cerebral cortex (S1) of mice after L-HPM exposure for different durations. Original magnification: ×400. (a) Representative image of TUNEL staining of the hippocampus and cerebral cortex after 4 weeks of L-HPM exposure (scale bar = 50 μm). (b) Quantification of TUNEL-positive cells/mm^2 in the hippocampus and cerebral cortex after 4 weeks of L-HPM exposure. (c) Representative image of TUNEL staining of the hippocampus and cerebral cortex after 8 weeks of L-HPM exposure (scale bar = 50 μm). (d) Quantification of TUNEL-positive cells/mm^2 in the hippocampus and cerebral cortex after 8 weeks of L-HPM exposure. Student's t-test, mean ± SEM, $^*P < 0.05$, $^{**}P < 0.01$ compared with the sham group. TUNEL: deoxynucleotidyl transferase-mediated dUTP nick-end labeling; L-HPM: L-band high-power microwave.

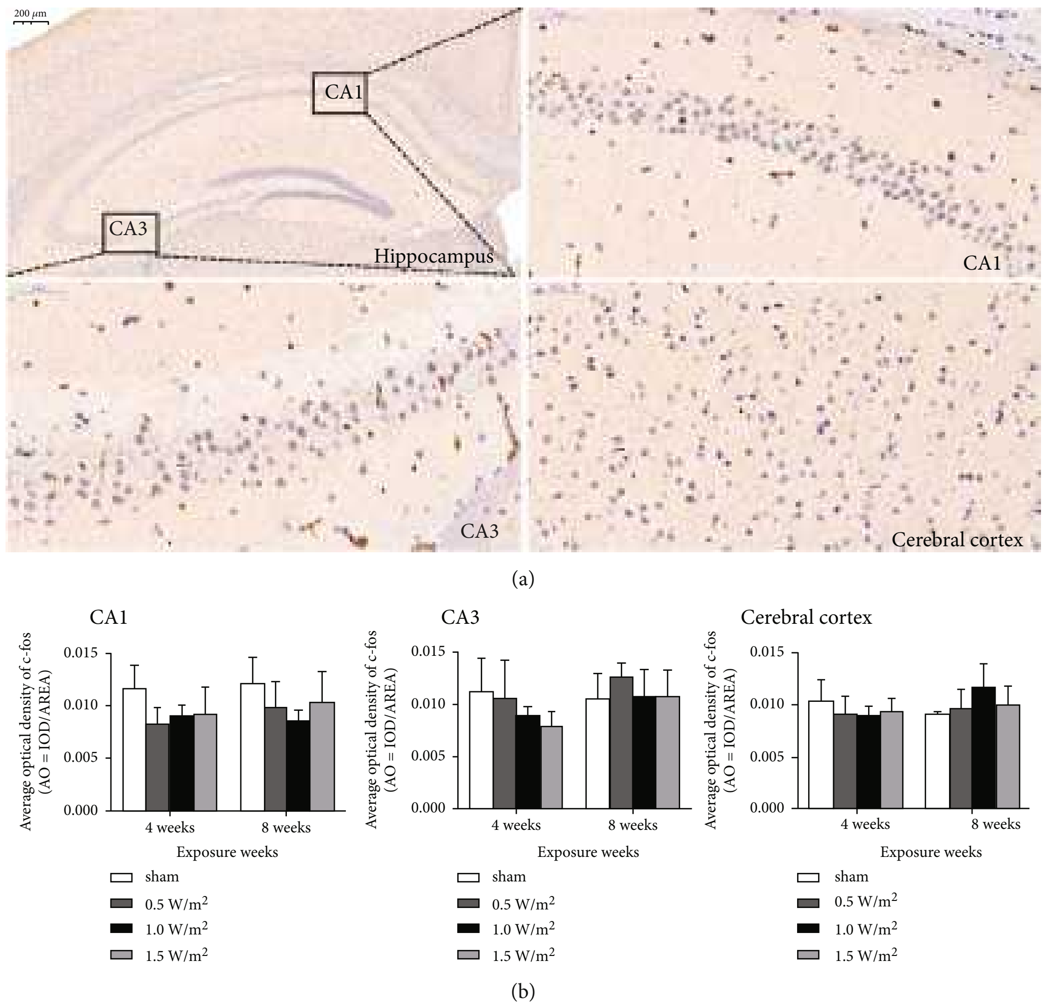

Figure 3: Distribution (a) and expression (b) of c-fos in the mouse hippocampus (CA1 and CA3) and cerebral cortex (S1) after L-HPM exposure for different durations (original magnification: ×400, scale bar = 50 μm). L-HPM: L-band high-power microwave.

4. Discussion

The major finding of the present study is that the exposure to L-HPM at 1.5 W/m^2 can cause generalized injuries in the central nervous system of mice, including cell apoptosis, cholinergic dysfunction, and oxidative damage. Our results demonstrated that the damaging effects are closely related to the power density and exposure time, indicating that long-term L-HPM exposure at high power densities may be detrimental to human health, especially the nervous system.

The cerebral cortex and hippocampus CA1 and CA3 regions are considered to be vulnerable areas of the brain [20], in which selective cell damage or loss is closely related to cognitive impairment [12, 21]. In order to assess possible changes in the morphological structure of the treated mice, we analyzed the morphological structure and cell number in the hippocampus and cerebral cortex after L-HPM exposure. The results of HE staining suggested that the morphological structure of the hippocampal CA1 and CA3 and cerebral cortex S1 did not change in the exposed groups compared with that in the sham exposure group. Next, we examined the effects of L-HPM exposure on the number of hippocampal and cortical cells. Results of TUNEL staining revealed that cell apoptosis in the cerebral cortex S1 and hippocampus CA1 and CA3 regions of mice in the exposed groups significantly increased as compared to those in the sham exposure group. Furthermore, the percentage of apoptotic cells significantly increased in the groups exposed to L-HPM at 1.5 W/m^2 compared to 0.5 and 1.0 W/m^2. Consistent with previous observations, our findings supported the idea that L-HPM exposure could induce neuron and glial cell apoptosis in mice, indicating that it could cause changes in the cognitive function of mice. Our results also confirmed that the degree of reduction in the number of neurons and glial cells was closely related to the power density, which means that the dose-effect relationship of exposure is essential for its safety assessment.

Several studies have shown that c-fos is a major stress-related protein which can be induced by various stimuli such as injury, heat, and exposure to electromagnetic radiation [22–24]. C-fos protein expression in cells is very low and is not significantly affected by stimulation without injury. To some extent, the number of c-fos-positive cells is directly proportional to the intensity of stimulation and the

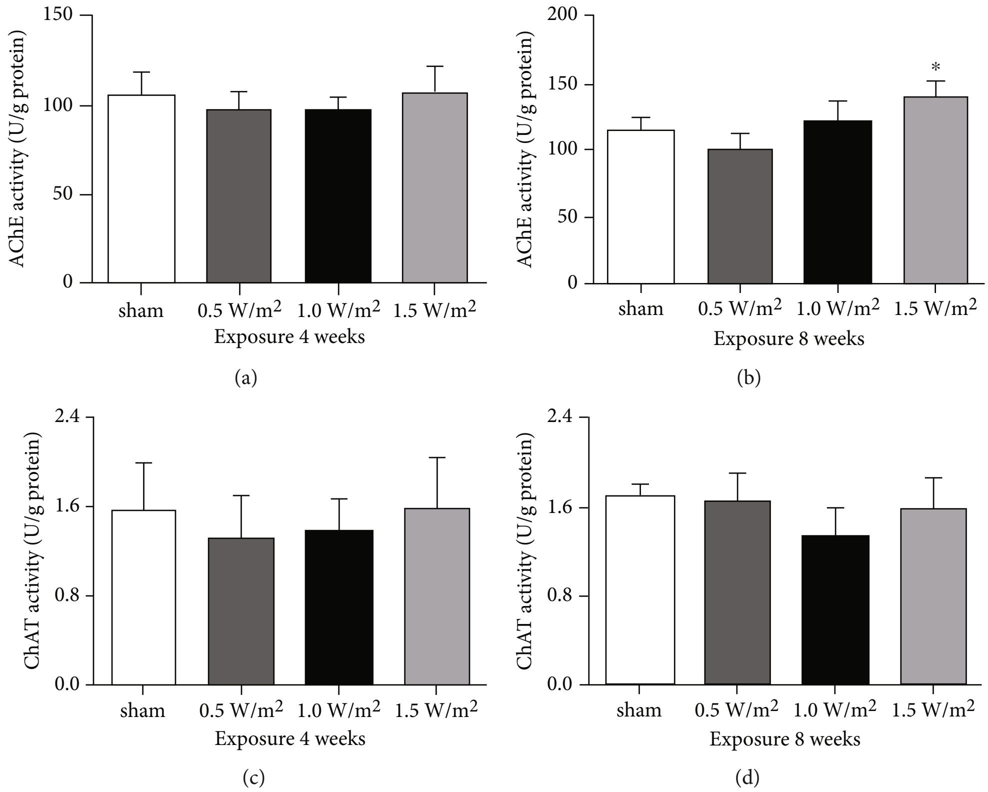

Figure 4: The activity of AChE (a, b) and ChAT (c, d) in mouse brains after L-HPM exposure for different durations. Student's t-test, mean ± SEM, $^{*}P < 0.05$ compared with the sham group. AChE: acetylcholinesterase; ChAT: choline acetyltransferase.

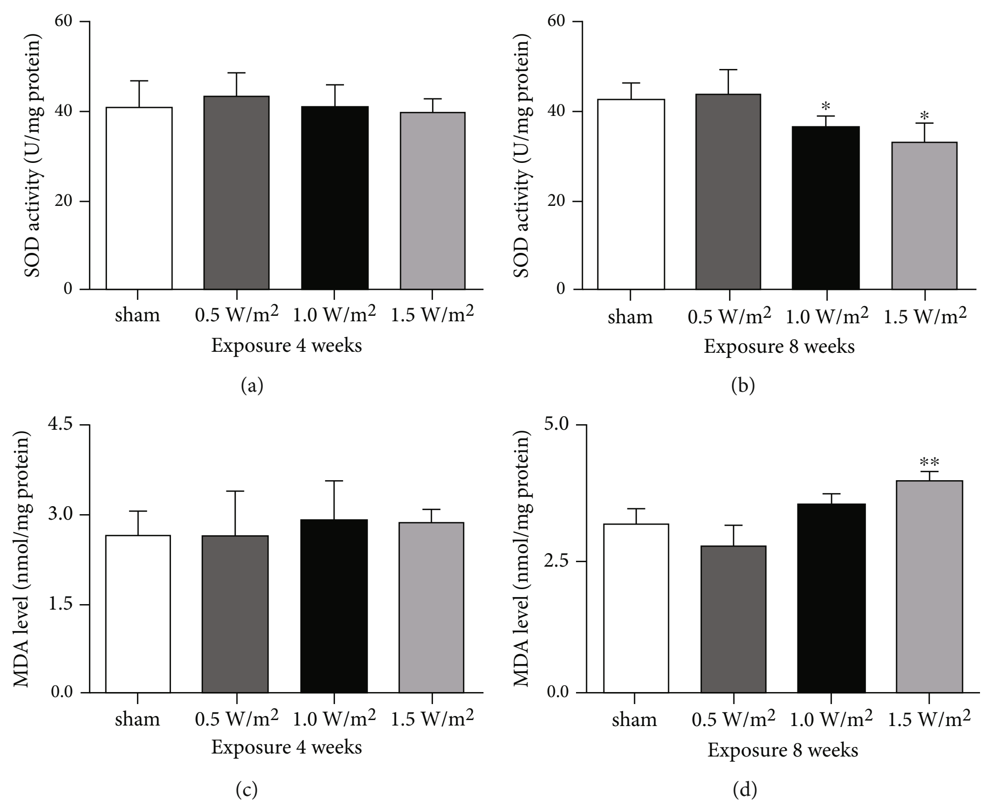

Figure 5: The activity of SOD (a, b) and the content of MDA (c, d) in mouse brains after L-HPM exposure for different durations. Student's t-test mean ± SEM, $^{*}P < 0.05$, $^{**}P < 0.01$ compared with the sham group.

upregulation of c-fos expression often indicates that cells are exposed to noxious stimuli [25]. Thus, the expression levels of c-fos in the cerebral cortex S1 as well as the hippocampal CA1 and CA3 regions were observed to evaluate the effect of L-HPM on neurons and glial cells in mice. Our results showed that there was no significant difference in c-fos protein expression in the hippocampus and cerebral cortex between the exposed groups and the control group.

Although L-HPM exposure could cause cell apoptosis in the cerebral cortex and hippocampus, which may lead to cognitive deficits in mice, the underlying mechanisms are not fully understood. ChAT and AChE are closely related to the metabolism of acetylcholine, a neurotransmitter that plays an important role in learning and memory modulation [26, 27]. In addition, studies have shown that exposure to electromagnetic radiation could decrease ChAT activity and increase AChE activity in the brain, which in turn affects the functioning of the nervous system [13]. Consistent with previous studies, here, we found a marked increase in AChE activity in the brains of mice exposed to L-HPM at 1.5 W/m^2 for 8 weeks. Thus, our results suggested that the destructive effect of L-HPM exposure may stem from reduced central cholinergic function due to the inhibition of the synthesis and release of acetylcholine. Furthermore, recent researches have revealed that central cholinergic dysfunction is related to increased oxidative stress.

SOD is an effective scavenger of free radicals and is one of the most important antioxidative enzymes in the body. MDA is an indicator of lipid peroxidation due to oxidative stress. As oxidative stress is an imbalance between the production of cell-damaging free radicals and the body's ability to neutralize them, in conditions of oxidative stress, SOD activity is usually decreased, while the MDA content is increased. Previous studies have demonstrated that oxidative damage is directly correlated with exposure-induced brain disorders [19, 28, 29]. In our study, we further confirmed that L-HPM exposure could induce oxidative damage, as shown by significantly decreased activity of SOD and increase of lipid peroxidation (MDA) in the brains of mice exposed to L-HPM at 1.5 W/m^2 for 8 weeks. These results therefore indicate that long-term high-intensity L-HPM exposure may substantially increase oxidative damage in the brain.

Several limitations should be considered when interpreting this study. Firstly, we did not perform behavioral tests on the mice, because the purpose of the experiment was to clarify whether L-HPM would lead to nervous system damage, and we did not focus on cognitive function. Nevertheless, further studies should include behavioral tests on animals after L-HPM exposure. Secondly, other potential molecular mechanisms leading to cell apoptosis after exposure to L-HPM remain to be further studied.

5. Conclusions

Taken together, the results of this study demonstrate that L-HPM exposure at certain power densities can lead to oxidative stress in hippocampal and cortical cells and induce brain injury in mice.

Data Availability

The authors confirm that all the data supporting the findings of this study are available within the article.

Disclosure

The funding organization had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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Effects of the Exposure to Mobile Phones on Male Reproduction: A Review of the Literature

Minireview

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ABSTRACT: The use of mobile phones is now widespread. A great debate exists about the possible damage that the radiofrequency electromagnetic radiation (RF-EMR) emitted by mobile phones exerts on different organs and apparatuses. The aim of this article was to review the existing literature exploring the effects of RF-EMR on the male reproductive function in experimental animals and humans. Studies have been conducted in rats, mice, and rabbits using a similar design based upon mobile phone RF exposure for variable lengths of time. Together, the results of these studies have shown that RF-EMR decreases sperm count and motility and increases oxidative stress. In humans, 2 different experimental approaches have been followed: one has explored the effects of RF-EMR directly on spermatozoa and the other has evaluated the sperm parameters in men using or not using mobile phones. The results showed that human spermatozoa exposed to RF-EMR have decreased motility, morphometric abnormalities, and increased oxidative stress, whereas men using mobile phones have decreased sperm concentration, decreased motility (particularly rapid progressive motility), normal morphology, and decreased viability. These abnormalities seem to be directly related to the duration of mobile phone use.

Key words: Sperm parameters, male infertility.

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Cellular phones operate using frequencies that differ by manufacturer and country, and concerns are growing about the possible negative effects of radiofrequency (RF) electromagnetic waves (EMW) emitted by these communication tools on human health. In particular, one of the biggest worries is that these RF-EMW may disturb testicular function and alter conventional and/or nonconventional sperm parameters.

A number of reports have suggested a possible link between cell phone use and decreased semen quality. For example, recently Agarwal et al (2008) suggested that the use of cellular phones adversely affected the quality of semen in 361 men attending an infertility clinic, and Fejes et al (2005) showed that the duration of cellular phone possession and the duration of daily transmission correlated negatively with semen quality in 371 men. These findings have been confirmed, although in a smaller number of men (13 and 27, respectively) (Davoudi et al, 2002; Erogul et al, 2006).

More commonly used cellular phones operate at a frequency of 850 to 1800 MHz; the radiant energy is absorbed by human body tissues and organs by aerial effect and/or coupling the RF signal and/or resonant absorption (D'Andrea et al, 1985). The specific absorption rate (SAR) defines the amount of RF energy absorbed into local tissues and represents a measure for evaluating the emission of transmitters located nearby the body. For cellular phones, SAR varies from 0.12 to 1.6 watts/kg of body weight.

Leydig cells, seminiferous tubules, and spermatozoa are the main targets of the damage caused by mobile phones on the male reproductive tract. In particular, cellular phone exposure reduces testosterone biosynthesis, impairs spermatogenesis, and damages sperm DNA. Scrotal hyperthermia and oxidative stress are the main mechanisms by which the damage is generated (Depinder et al, 2007). It is well known that testicular temperature is 2°C to 3°C lower than rectal temperature, and the optimal temperature for spermatogenesis is considered to be 35°C (Saikhun et al, 1998). From this point of view, the habit of keeping a mobile phone in the trouser pocket or the duration of its use may have an impact on possible generation of hyperthermia and oxidative stress as well.

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Table. *Explanation of some technical acronyms found in the literature*

Acronym	Explanation
W-CMDA	Wideband code division multiple access (W-CDMA) indicates a particular technology of multiple access to radio channel cellular networks of third generation (3G)
FOMA	Freedom of mobile stands for multimedia access (FOMA) is one of the 3G standards that uses W-CDMA transmission interface
SAR	Specific absorption rate (SAR) is a measure of the rate at which energy is absorbed by the body when exposed to a radiofrequency (RF) electromagnetic field; it is defined as the power absorbed per mass of tissue and is measured as W/kg
GSM	Global system for mobile communications (originally groupe spécial mobile; GSM) is a standard set developed by the European Telecommunications Standards Institute to describe technologies for second-generation digital cellular networks
Hz, GHz, and MHz	The Hertz (Hz) is the International System unit of frequency named after the German physicist Heinrich Rudolf Hertz, who made important contributions to the science of electromagnetism; Hz multiples are megahertz (MHz) = 10^6 Hz and gigahertz (GHz) = 10^9 Hz

Many animal studies have shown that EMW negatively interfere with the male reproductive system. However, similar studies are scant in men, and the results obtained in the experimental animal may only be translated to humans with caution. This review presents the main studies exploring the effects of mobile phones on the male reproductive system in various strains of experimental animals and in humans. The Table reports some acronyms used in mobile telephony.

Animal Studies

Studies on Male Sprague-Dawley Rats—One of the first studies on mobile phone exposure investigated the effects of exposure to RF electromagnetic radiation (EMR) on testicular and sperm function. To achieve this objective, rats were confined in Plexiglas cages specially designed for this study, and cellular phones were placed 0.5 cm under the cages (EMW with frequencies between 800 and 1800 MHz, such as those used by mobile phones, can penetrate tissue up to 2 cm). The experimental group was exposed to cellular phones activated for 20 min/d for 1 month, whereas the control rats were exposed to switched-off cellular phones placed beneath the cages for the same length of time. The results of this study showed no statistically significant difference between exposed and control rats as far as sperm count, morphology, lipid composition, malondialdehyde (MDA) concentration (an index of sperm plasma membrane lipid peroxidation), testicular histologic structure, p53 immune reactivity, and rectal temperature (Dasdag et al, 2003). By contrast, Yan et al (2007) reported a significantly higher incidence of cell death in spermatozoa collected from the epididymis in adult rats exposed to RF-EMR compared with unexposed rats. In addition, the former had abnormal clumping of spermatozoa that was not present in unexposed rats (Yan et al, 2007). This apparent discrepancy may be explained by the longer exposure to which the same strain of rats was exposed in this latter study. Indeed, the experimental group was exposed to cellular phone emissions for two 3-hour periods/d for 18 weeks.

The effects of radiation exposure have also been evaluated in young developing male rats. Five-week-old rats were exposed to a 1.95-GHz wide-band code division multiple access signal, which is used for the freedom of mobile multimedia access, with a whole-body exposure for 5 h/d for 5 weeks, corresponding to the period of reproductive maturation in these rats. The whole-body average SAR was designed to be 0.4 W/kg. The control group received sham exposure. There were no differences in body weight gain or weights of the testis, epididymis, seminal vesicles, and prostate among the groups. The number of testicular and epididymal spermatozoa did not decrease in RF-EMR–exposed rats, and no abnormalities in sperm motility or morphology or the histologic appearance of the seminiferous tubules, including the stage of the spermatogenic cycle, were observed. Interestingly, the testicular sperm count increased significantly following exposure to the 0.4-W/kg SAR (Imai et al, 2011).

Lee et al (2010) examined the testicular histologic changes in rats exposed to an RF-EMR of 848.5 MHz for 12 weeks. The exposure schedule consisted of two 45-minute periods, separated by a 15-minute interval, with a whole-body mean SAR of 2.0 W/kg. The authors then investigated sperm counts in the cauda epididymis, MDA concentrations in the testes and epididymis, frequency of spermatogenesis stages, germ cell counts, and appearance of apoptotic cells in the testes. Finally, they performed p53, Bcl2, caspase 3, p21, and poly(adenosine diphosphate–ribose) polymerase immunoblotting of the testes in controls and exposed animals. On the basis of the results found, this study concluded that the subchronic exposure to 848.5 MHz did not have any detectable adverse effects on rat spermatogenesis (Lee et al, 2010).

Studies on adult and developing male Sprague-Dawley rats showed no substantial effects of RF-EMR exposure except for a slightly increased sperm cell death rate.

Studies on Male Wistar Rats—Using adult male Wistar rats, Ribeiro et al (2007) reported that rats exposed to RF-EMR emitted by a global system for mobile communication (GSM) cellular phone (1835–1850 MHz) for 1 h/d for 11 weeks had similar testicular and epididymal weight, lipid peroxidation levels in these organs (evaluated by monitoring the formation of thiobarbituric acid [TBA] reactive substances after the reaction of TBA with MDA), serum total testosterone volume, and epididymal sperm count compared with unexposed control rats. In particular, rectal temperatures before and immediately after RF exposure were 36.9°C ± 0.4°C and 37.1°C ± 0.3°C, respectively, in the control group and 36.9°C ± 0.4°C and 37.0°C ± 0.3°C in the experimental group. Absolute testes weight was 1.72 ± 0.08 g in the control group and 1.77 ± 0.17 g in the experimental group; absolute epididymal weight was 269 ± 19 mg in the control group and 265 ± 25 mg in the experimental group. Finally, the control group had 88 ± 23 × 10^6 sperm/epididymal cauda and the experimental group showed 83 ± 18 × 10^6 sperm/epididymal cauda.

Similarly, no effect on total sperm count was found in rats exposed to RF-EMR, emitted by an active GSM (0.9/1.8 GHz) mobile phone for 1 h/d for 4 weeks, compared with control rats that were exposed to a mobile phone without a battery for the same period. However, sperm motility decreased significantly in exposed rats. The average percent of motile sperm was 72.0% ± 8.7% for controls and 43.1% ± 10.0% in RF-EMR–exposed animals, a reduction of approximately 40%. RF-EMR–exposed rats also had significantly increased lipid peroxidation: endogenous MDA levels were approximately 8% in the testis and approximately 12% in the epididymis. A decreased glutathione content in testis (approximately 10%) and epididymis (approximately 24%) was also reported (Mailankot et al, 2009).

Kesari et al (2010) found a significantly decreased level of protein kinase C (an enzyme present in human sperm head, neck, and tail that is strongly associated with motility and the acrosomal reaction) and total sperm count along with increased apoptosis in adult rats exposed to RF-EMR in Plexiglas cages for 2 h/d for 5 weeks, with an SAR estimated to be 0.9 W/kg. Subsequently, these researchers investigated the production of free radicals following mobile phone exposure and the effects on fertility pattern using the same length of exposure and the same strains of rats. The levels of the antioxidant enzymes glutathione peroxidase and superoxide dismutase decreased, whereas the level of catalase increased significantly. MDA concentration increased significantly from 0.16 ± 0.01 vs 0.08 ± 0.01 TBA-reactive substances in experimental group and controls, respectively. Micronuclei evaluated as the ratio of polychromatic erythrocyte to normochromatic erythrocyte by flow cytometry was significantly lower in the mobile phone–exposed group (0.67 ± 0.15) as compared with the sham-exposed group (1.36 ± 0.07). Finally, histone kinase volume decreased significantly in exposed rats (3659.1 ± 1399.4 and 5374.9 ± 1366.9 P_{32} counts/mg of protein, respectively, in the EMR-exposed and sham-exposed groups). A significant change in testicular sperm cell cycle of G_0–G_1 and G_2/M was recorded. Free radical production increased significantly (Kesari et al, 2011).

Finally, hypospermatogenesis was found in 3 of 16 male Wistar rats (18.7%) exposed to mobile phone radiation for 60 min/day (whole body) for 3 months, whereas another 3 rats (18.7%) had maturation arrest. In contrast, no spermatogenesis abnormalities were found in rats exposed to mobile phone radiation for 30 min/day for 3 months (Meo et al, 2011).

With some discrepancies, studies on Wistar male rats have shown that mobile phone exposure results in decreased sperm count and motility and increased oxidative stress.

Studies on Male Mice—A single study has been reported on mice. The experimental animals were exposed to 900-MHz RF-EMR at an SAR of approximately 90 mW/kg inside a waveguide for 12 h/d for 1 week, and the rate of DNA damage in spermatozoa of the caudal epididymal was assessed by quantitative polymerase chain reaction and alkaline and pulsed-field gel electrophoresis. The exposed mice were clearly normal, and sperm number, morphology, and vitality were not significantly affected. Gel electrophoresis revealed no evidence of increased single-stranded or double-stranded DNA breakage in spermatozoa taken from treated animals. However, a detailed analysis of DNA integrity using quantitative polymerase chain reaction revealed statistically significant damage in both the mitochondrial genome and the nuclear β-globin locus. This study suggested that although RF-EMR does not have a dramatic impact on male germ cell development, a significant genotoxic effect can be detected in epididymal spermatozoa (Aitken et al, 2005). However, it should be pointed out that the SAR used in this study was approximately 10-fold lower than that used in the study by Kesari et al (2010) in rats. The different experimental conditions and the different strains used may be partly responsible for the contrasting outcome. In fact, mice are much smaller than rats. Mice weigh approximately 30 to 50 g and have bodies that are 3 to 4 inches long with 3- to 4-inch tails. Rats, on the other hand, are far heavier and longer: they can weigh 10 times as much, averaging 450 to 650 g for males, and have 9- to 11-inch long bodies and 7- to 9-inch tails.

Studies on Male Rabbits—Rabbits have also been used as an experimental model to evaluate the effect of mobile phone exposure on testicular function. In the study by Salama et al (2009), 30 individually caged, adult male New Zealand White rabbits, aged 20 weeks and weighing 3.15 to 3.25 kg, were used. They were randomly divided into 3 groups. The first one was the mobile phone group, with members individually placed in cages specifically designed (50 × 25 × 35 cm) for this study. These cages could accommodate plastic partitions according to the animals' dimensions (average, 30 × 16 × 18 cm) to restrict movement. Therefore, the animals rested throughout the period of the daily phone exposure with their genitalia opposing the antennae of the mobile phones, which were fixed to the cage bottoms. Mobile phones were conventional GSM handsets (900 MHz) that were turned to the standby position with a 2.92-V/m average strength of the electric field estimated at 0.5 cm away from the phone and 0.487 V/m at the most distant region inside the cage. The whole-body average SAR was 0.43 W/kg. Phone exposure was applied for 8 hours (9:00 AM–5:00 PM) daily for 12 weeks. Following this daily mobile phone exposure, the animals were returned to their individual standard cages (90 × 60 × 40 cm). Because of the restriction of animal movement and the possibility of stress-related outcome, 2 control groups were added for the measurement of fructose or citrate levels under stressful conditions. Animals of the first control group were the sham or stress controls (n = 11). They were placed in identical cages for 8 hours with the phones switched off. The animals in the second control group provided an additional control (n = 8) throughout the duration of the study and were housed in conventional cages provided by the animal room. In both control groups, the cages were positioned 7 m away from the phone group where the average strength of the electric field detected was equivalent to background radiation (0.18 V/m). Rectal temperature assessment was conducted for all animals in this study 2 times per week. The measurements were made both before and after phone exposure. A significant decline in both fructose concentrations (250 ± 8.4 mg% in the mobile phone group, 499 ± 7.3 mg% in stress controls, and 497 ± 4.1 mg% in ordinary controls) and number of motile spermatozoa (52% ± 2.3% in the phone group, 63% ± 2.0% in stress controls, and 73.4% ± 3.4% in ordinary controls) was observed in the phone group at the 10th week. However, no correlation was found between the 2 values. The stress control animals showed a similar but significantly less marked decline in motility. Citrate concentrations (one of the most important anions present in human semen and the major regulator of ionized calcium levels in seminal plasma) and the other parameter studied did not differ significantly among groups (Salama et al, 2009).

Subsequently, these researchers, using a mobile phone emitting at 800 MHz, evaluated the longitudinal effect of RF-EMR on adult rabbits using a similar experimental design and protocol of exposure. Sperm analysis, sperm functional tests (viability, hypo-osmotic swelling, and acridine orange staining), histologic testicular sections, and serum total testosterone level were evaluated weekly. A decrease in the sperm concentration appeared after 6 weeks of exposure. This became statistically significant at week 8, compared with the 2 control groups (stress and ordinary) and the initial sperm count found in the phone group. Sperm motility was similar among the 3 groups until week 10, when it declined significantly, and thereafter in rabbits exposed to mobile phones and in the stress control group, with more significant decline in the phone group. Histologic examination also showed a significant decrease in the diameter of seminiferous tubules in the phone group vs that in the stress and ordinary controls. The other end points did not show any statistically significant differences (Salama et al, 2010). In conclusion, the 2 studies in rabbits conducted by the same group of researchers with the identical experimental design showed that RF-EMR exposure decreased sperm concentration and motility.

Human Studies

Human Spermatozoa Exposed to Mobile Phone Radiation In Vitro—A number of studies have attempted to elucidate the effects of cellular phone radiation on human sperm function using a direct approach that consisted of exposure of raw or selected spermatozoa to RF-EMR for a variable length of time. Erogul et al (2006) exposed an aliquot of unprocessed raw spermatozoa to the RF-EMR emitted by an activated cellular phone (900 MHz), and another aliquot of the same ejaculate served as control. RF-EMR exposure caused a slight decrease in the rapid progressive and slow progressive sperm movement; by contrast, it increased the percentage of immotile spermatozoa (Erogul et al, 2006). A similar in vitro experimental approach was conducted on semen samples from healthy donors (n = 23) and infertile patients (n = 9). After liquefaction, the semen samples were divided into 2 aliquots; an aliquot was exposed to a Sony Ericsson w300i cellular phone in talk mode for 1 hour. This phone emitted at 850 MHz with a maximum power <1 W and an SAR of 1.46 W/kg. This model had a loop shape and omnidirectional antenna placed on the top back of its handset. The distance between the phone antenna and each specimen was kept at 2.5 cm. The second aliquot (unexposed) served as the control sample under identical conditions. Spermatozoa exposed to RF-EMR showed a significant decrease in sperm motility and viability, increase in radical oxygen species (ROS) production, and a reduced ROS total antioxidant capacity (TAC) score. The seminal plasma has an effective antioxidant system that can provide spermatozoa with a protective environment. The seminal plasma TAC is the sum of enzymatic (eg, superoxide dismutase, catalase, and glutathione peroxidase) and nonenzymatic (eg, ascorbate, urate, vitamin E, pyruvate, glutathione, taurine, and hypotaurine) antioxidants.

Levels of TAC and sperm DNA fragmentation in the exposed spermatozoa showed no significant differences compared with unexposed spermatozoa (Agarwal et al, 2009). These results suggested that RF-EMR emitted from cellular phones may increase the oxidative stress in human semen.

Different than the previous 2 in vitro studies exploring the direct effects of RF-EMR exposure on unselected spermatozoa, Falzone et al (2008) exposed density-purified spermatozoa to pulsed 900-MHz GSM mobile phone radiation at 2 SARs (2.0 and 5.7 W/kg) and compared the effects observed with controls over time. No effects of RF-EMR were found on sperm mitochondrial membrane potential, an early apoptotic event evaluated by flow cytometry following staining with JC-1, and on all sperm kinematic parameters (evaluated by computer-assisted sperm analysis) at an SAR of 2.0 W/kg. However, over time, the 2 kinematic parameters straight-line velocity and beat-cross frequency decreased significantly after exposure at an SAR of 5.7 W/kg (Falzone et al, 2008). Subsequently, using a similar approach, these researchers examined the effects of the radiation on the induction of apoptosis-related features in human spermatozoa. For this purpose, ejaculated, density-purified, highly motile human spermatozoa were exposed to mobile phones at SARs of 2.0 and 5.7 W/kg. At various times after exposure, flow cytometry was used to examine caspase 3 activity (caspase 3 is the major effector enzyme causing cell disruption during apoptosis; caspase 3 activity has been detected in the midpiece of ejaculated human sperm and has been shown to be significantly associated with low sperm motility or with decreased normal sperm concentration, motility, and morphology), phosphatidylserine externalization (phosphatidylserine translocation from the cytosol to the outer leaflet of the plasma membrane is an early apoptotic event), DNA fragmentation, and generation of ROS. RF-EMR had no statistically significant effect on any of the parameters studied (Falzone et al, 2010). Therefore, a stimulatory effect of mobile phone exposure on oxidative stress seemed to be present only in unprocessed semen and not in density-purified spermatozoa. However, the lack of effect reported by Falzone et al (2011) may relate to different SARs. De Iuliis et al (2009) exposed purified human spermatozoa to RF-EMR tuned to 1.8 GHz and covering a range of SAR from 0.4 W/kg to 27.5 W/kg. Sperm motility and vitality decreased significantly, whereas the mitochondrial generation of ROS and DNA fragmentation increased significantly with increases in the SAR. In addition, highly significant relationships among SAR, oxidative DNA damage biomarker (8-hydroxy-2′-deoxyguanosine), and DNA fragmentation after RF-EMR exposure were also observed (De Iuliis et al, 2009).

Finally, Falzone et al (2011) evaluated sperm-fertilizing competence following exposure to RF-EMR. To accomplish this, highly motile human spermatozoa collected from 12 healthy, nonsmoking donors were exposed for 1 hour to 900-MHz mobile phone radiation at an SAR of 2.0 W/kg, and the acrosome reaction was evaluated at various intervals after exposure by using the viability probe (7-aminoactinomycin, a fluorescent chemical compound) to assess the acrosome reaction in live spermatozoa only. The acrosome was assessed with *Pisum sativum* agglutinin fluorescein isothiocyanate, and specimens were gated by light scatter properties (size and granularity) of spermatozoa and analyzed for dual-color fluorescence using flow cytometry. The radiation did not affect sperm acrosome reaction rate. Morphometric evaluation, appraised by computer-assisted sperm analysis, showed a significant decrease of the sperm head area and acrosome percentage of the head area among exposed compared with unexposed spermatozoa. The sperm competence to bind the zona pellucida following RF-EMR exposure decreased significantly compared with that of unexposed spermatozoa (Falzone et al, 2011). Therefore, the results of this study showed that although RF-EMR exposure does not seem to negatively affect the rate of the acrosome reaction, it significantly alters sperm morphometry and decreases the capability of spermatozoa to bind to the zona pellucida.

Together, in vitro studies suggested that following RF-EMR exposure, human spermatozoa show motility reduction, morphometric abnormalities, and increased oxidative stress. These alterations are somewhat dependent upon the SAR administered directly to spermatozoa.

Clinical Studies—One of the first clinical studies on the effects of RF-EMR on conventional sperm parameters was conducted in 52 men aged 18 to 35 years. The results of this study showed that men who carried a mobile phone in their hip pockets or on their belts had a lower sperm concentration than men who either did not carry a mobile phone or who stored it elsewhere in the body (Kilgallon and Simmons, 2005). A much larger number of men (n = 371) was asked questions concerning cellular phone use habits, including possession, daily standby position, and daily transmission times before sperm analysis was performed. The results showed that the duration of possession and the daily transmission length correlated negatively with the percentage of rapid progressive motile spermatozoa and positively with the percentage of slow progressive motile spermatozoa. The low transmitter group of men had a significantly higher percentage of rapid progressive motile spermatozoa compared with high transmitters (Fejes et al, 2005).

Wdowiak et al (2007) examined the conventional sperm parameters of 304 men divided into 3 groups on the basis of their habits using mobile phones. One group (n = 99) did not use mobile phones, a second group (n = 157) used mobile phones sporadically for 1 to 2 years, and the third group (n = 48) regularly used mobile phones for more than 2 years. Analysis of the effect of RF-EMR exposure on sperm parameters revealed that an increase in the percentage of spermatozoa with abnormal morphology was associated with the duration of exposure to the radiation emitted by cellular phone. The results also confirmed a decrease in the percentage of spermatozoa with progressive motility in the semen that correlated with the frequency of mobile phone usage (Wdowiak et al, 2007). Similarly, Agarwal et al (2008) reported significantly lower sperm count, motility, and viability and normal morphology in 3 groups of men using cellular phones for variable lengths of time (<2 h/d, 2–4 h/d, and >4 h/d), compared with men who did not use them.

Overall, clinical studies showed that cellular phone use is associated with decreased sperm concentration, decreased motility (particularly rapid progressive motility), normal morphology, and decreased viability. These abnormalities seem to be directly related to the duration of mobile phone use.

Conclusions

In aggregate, the literature has suggested that mobile phone use alters sperm parameters in both experimental animals and humans. Sperm motility and morphology seem to be the 2 parameters more frequently affected. There is evidence that mobile phone radiation results in increased oxidative stress, with subsequent sperm membrane lipid and DNA damage. These abnormalities seem to be directly related to the duration of mobile phone use. Nevertheless, more studies are necessary to provide stronger evidence that cellular phone use disturbs sperm and testicular function because the existing literature has several limitations. These include dishomogeneity in terms of RF wavelength used, depth of penetration, and length of radiation exposure.

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Review

Electrohypersensitivity as a Newly Identified and Characterized Neurologic Pathological Disorder: How to Diagnose, Treat, and Prevent It

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Abstract: Since 2009, we built up a database which presently includes more than 2000 electrohypersensitivity (EHS) and/or multiple chemical sensitivity (MCS) self-reported cases. This database shows that EHS is associated in 30% of the cases with MCS, and that MCS precedes the occurrence of EHS in 37% of these EHS/MCS-associated cases. EHS and MCS can be characterized clinically by a similar symptomatic picture, and biologically by low-grade inflammation and an autoimmune response involving autoantibodies against O-myelin. Moreover, 80% of the patients with EHS present with one, two, or three detectable oxidative stress biomarkers in their peripheral blood, meaning that overall these patients present with a true objective somatic disorder. Moreover, by using ultrasonic cerebral tomosphygmography and transcranial Doppler ultrasonography, we showed that cases have a defect in the middle cerebral artery hemodynamics, and we localized a tissue pulsometric index deficiency in the capsulo-thalamic area of the temporal lobes, suggesting the involvement of the limbic system and the thalamus. Altogether, these data strongly suggest that EHS is a neurologic pathological disorder which can be diagnosed, treated, and prevented. Because EHS is becoming a new insidious worldwide plague involving millions of people, we ask the World Health Organization (WHO) to include EHS as a neurologic disorder in the international classification of diseases.

Keywords: electrohypersensibility; multiple chemical sensitivity; neurologic disease; oxidative stress; melatonin; O-myelin; inflammation; histamine; radiofrequency; extremely low frequency; electromagnetic fields

1. Introduction

The term electromagnetic hypersensitivity or electrohypersensitivity (EHS) was first proposed in 1991 by William Rea to identify the clinical condition of patients reporting health effects while being exposed to an electromagnetic field (EMF) [1]. This term was then used in 1997 in a report provided by a European group of experts for the European Commission to clinically describe this unusual pathology, which may imply EMF exposure [2].

In 2002, Santini et al. in France reported similar symptomatic intolerance in users of digital cellular phones and among people living near wireless communication base stations [3,4]. In 2004, because of the seemingly worldwide prevalence increase in EHS, the World Health Organization (WHO) organized an international scientific workshop in Prague to define and characterize EHS. Although not acknowledging EHS as being caused by EMF exposure, the Prague working group clearly defined EHS as "a phenomenon where individuals experience adverse health effects while using or being in the vicinity of devices emanating electric, magnetic, or electromagnetic fields" [5]. WHO then acknowledged EHS as an adverse health condition [6]. However, according to a previous 1996 International Program on Chemical Safety (IPCS)-sponsored conference in Berlin on multiple chemical sensibility (MCS) [7], it was recommended to qualify such unknown new pathological conditions under the term of "idiopathic environmental intolerance (IEI)". Thus, following the Prague workshop, instead of using the term EHS, it was proposed to use the term "idiopathic environmental intolerance attributed to EMF (IEI-EMF)" to name this particular pathological condition, because of the lack of a proven causal link between EHS and EMF exposure, and no proven physiopathological mechanism linking EMF exposure with clinical symptoms.

That is indeed what WHO officially stated in its 2005 fact sheet 296 [6], indicating that "EHS resembles MCS, another disorder associated with low-level environmental exposure to chemicals ... " and that because of "non-specific symptoms" and "no clear diagnostic criteria", this "disabling condition" could not be diagnosed medically. In addition, in 2002 and 2013, WHO classified extremely low frequencies (ELF) and radiofrequencies (RF) respectively as possibly carcinogenic (group IIB), meaning that EMFs may cause cancer. This past scientific evolution is summarized in Table 1.

Table 1. Electrohypersensitivity (EHS)/multiple chemical sensitivity (MCS) and cancer statements including those of the World Health Organization (WHO) or on behalf of WHO. COST—European action for co-operation in the field of science and technological research on biological effects of electromagnetic fields; EMF—electromagnetic field; IARC—international agency for research on cancer.

1996	Berlin: WHO-sponsored workshop; MCS classified as idiopathic environmental intolerance (IEI)
1997	Stockholm: Possible health implication of electromagnetic field exposure; a report prepared by a European group of experts for the European Commission
1998	Austria: COST 244 bis international workshop on EHS
1998	Atlanta (US): MCS 1999 consensus meeting
2002	IARC: Extremely low frequency (ELF) EMFs classified as possibly carcinogenic (Group IIB)
2004	Prague: WHO workshop; identification of idiopathic environmental intolerance attributed to EMF
2005	WHO: WHO fact sheet n° 292 aiming at defining EHS
2013	IARC: Radiofrequency (RF) EMFs classified as possibly carcinogenic (Group IIB)
2015	Brussels: Fourth Paris Appeal Colloquium; a focus on electromagnetic fields and EHS

However, since the 2005 WHO statement on EHS and a more recent 2014 WHO report on mobile phone exposure and public health [8], much clinical and biological progress has been made in identifying and characterizing EHS, as summarized during the international scientific consensus meeting on EHS and MCS which we organized in May 2015 in Brussels at the Royal Belgium Academy of Medicine [9].

Because we suspected that EHS prevalence was increasing worldwide, since 2009, we constituted and maintained a database which was registered by the French Committee for the protection of persons (CPP), under the registration number 2017-A02706-47, as well as in the European Clinical *Trials* Database (*EudraCT*), under the registration number 2018-001056-36. This database presently includes more than 2000 EHS and/or MCS cases. All the patients included in this series gave their informed consent for clinical and biological research investigations. In addition, all these patients were anonymously registered in the database.

By querying this database, we showed for the first time that EHS is frequently associated with MCS [10], and that EHS and MCS are characterized by a common similar clinical picture which can be identified objectively by the detection of similar biomarkers in the peripheral blood and urine [10,11], and by similar pulsometric abnormalities in the brain [10,12]. Thus it finally appears that EHS and MCS could in fact be two etiopathogenic aspects of a unique pathological disorder [10]. We would like here to overview our original data and discuss the possibility that EHS is part of a true pathologic neurologic disorder resulting from a comprehensive physiopathologic mechanism, in common with MCS. We conclude that EHS—whatever its causal origin—is becoming a worldwide plague. Thus, as we showed that it can be diagnosed, treated medically, and eventually prevented, we ask WHO to include EHS in the international classification of diseases (ICD).

2. Demography

In a prospective study involving systematic face-to-face questionnaire-based interviews and clinical physical examinations of many patients constituting part of the database, we reported that EHS is a well-defined clinico-biological entity [10].

Table 2 presents the demographic data we obtained from the serial analysis of the first 726 consecutive cases included in the database. No children were included. Median and mean ages were 48 years for the EHS group, 48 and 47 years, respectively, for the MCS group, and 46 years for the EHS and MCS-associated group. Sex ratio shows a clear predominance of women among patients, reaching two-thirds in the EHS group and the MCS group, while it was three-quarters in the group of patients presenting with both disorders. This strongly suggests that women are genetically more susceptible than men to the environmental intolerance attributed to EMFs and/or chemicals.

Table 2. Age and sex ratio in EHS and/or MCS self-reported patients, according to Reference [10].

Demographic Data	EHS	MCS	EHS/MCS
n (%)	521 (71.7%)	52 (7.1%)	154 (21.2%)
Age (mean ± SD)	48.2 ± 12.9	48.5 ± 10.3	46.7 ± 11.2
Age (median (range))	48 (16–83)	47 (31–70)	46 (22–76)
Sex ratio (women/men)	344/177	34/18	117/37
Female (%)	66	65	76

3. Clinical Description

Table 3 presents the detailed symptomatic picture that we obtained during face-to-face interviews and clinical examinations for the groups of (1) EHS self-reported patients, (2) MCS self-reported patients, and (3) both disorder self-reported patients. Symptoms in patients with EHS were compared with those from a series of apparently healthy control subjects that showed no clinical evidence of EHS and/or MCS. As indicated in the table, EHS is characterized by the occurrence of neurologic symptoms including headache, tinnitus, hyperacusis, dizziness, balance disorder, superficial and/or deep sensibility abnormalities, fibromyalgia, vegetative nerve dysfunction, and reduced cognitive capability, including immediate memory loss, attention–concentration deficiency, and eventually tempo-spatial confusion. These symptoms were associated with chronic insomnia, fatigue, and depressive tendency, in addition to emotional lability and sometimes irritability. A major observation is that symptoms were repeatedly reported by the patients to occur each time they reported being exposed to presumably EMF sources, even of weak intensity, and to regress or even disappear after they left these presumed sources. With the exception of arthralgia and emotivity, which were observed at a similar frequency range in the control group, all clinical symptoms occurring in EHS patients were found to be significantly much more frequent than those in apparently normal controls.

Contrary to what was claimed from studies reporting clinical symptoms in EHS patients [2,5,6,13], these symptoms were not all subjective. In many cases, they were confirmed by family members; moreover, we were able to detect, at physical examination, a Romberg sign (objective posture test) in 5% of the cases and to observe the presence of cutaneous lesions in 16%. Overall, although many of these symptoms are considered as non-specific in the scientific literature, the general clinical picture resulting from their association and frequency strongly suggests that EHS can in fact be recognized and identified as a typical neurologic disorder as it is also the case for MCS and MCS-associated EHS.

Table 3. Clinical symptoms in EHS self-reported patients in comparison with those in normal controls and in comparison with those in MCS and EHS/MCS self-reported patients *, according to Reference [11].

Clinical Symptoms	EHS (%)	Normal Controls (%)	p **	MCS (%)	p ***	EHS/MCS (%)	p ****
Headache	88	0	<0.0001	80	0.122	96	0.065
Dysesthesia	82	0	<0.0001	67	0.0149	96	0.002
Myalgia	48	6	<0.0001	48	1	76	<0.0001
Arthralgia	30	18	0.067	24	0.611	56	<0.001
Ear heat/otalgia	70	0	<0.0001	16	<0.0001	90	<0.001
Tinnitus	60	6	<0.0001	35	<0.001	88	<0.0001
Hyperacusis	40	6	<0.0001	20	<0.001	52	0.118
Dizziness	70	0	<0.0001	52	0.0137	68	0.878
Balance disorder	42	0	<0.0001	40	0.885	52	0.202
Concentration/attention deficiency	76	0	<0.0001	67	0.210	88	0.041
Loss of immediate memory	70	6	<0.0001	56	0.040	84	0.028
Confusion	8	0	0.007	0	0.0038	20	0.023
Fatigue	88	12	<0.0001	72	0.0047	94	0.216
Insomnia	74	6	<0.0001	47	<0.0001	92	0.001
Depression tendency	60	0	<0.0001	29	<0.0001	76	0.022
Suicidal ideation	20	0	<0.0001	9	0.027	40	0.003
Transitory cardiovascular abnormalities	50	0	<0.0001	36	0.046	56	0.479
Ocular deficiency	48	0	<0.0001	43	0.478	56	0.322
Anxiety/panic	38	0	<0.0001	19	0.003	28	0.176
Emotivity	20	12	0.176	16	0.461	20	1
Irritability	24	6	<0.001	14	0.071	24	1
Skin lesions	16	0	<0.0001	14	0.692	45	<0.0001
Global body dysthermia	14	0	<0.0001	6	0.236	8	0.258

* These data result from the clinical analysis of 150 consecutive clinically evaluable cases issued from the database including an already published series of EHS and/or MCS patients who were investigated for biological markers [10]. Symptoms in EHS self-reported patients were compared with symptoms obtained from a series of 50 apparently normal subjects used as controls. These symptoms were also compared to those occurring in MCS and EHS/MCS self-reported patients. Percentage of patients with symptoms were compared by using the chi-square independence test. ** Statistical difference between EHS self-reported patients and normal controls. *** Statistical difference between EHS self-reported patients and MCS self-reported patients. **** Statistical difference between EHS self-reported patients and EHS/MCS self-reported patients.

Table 3 reveals that between EHS and MCS there is no statistically significant difference in types and frequencies of clinical symptoms for headache, myalgia and arthralgia, balance disorder, concentration/attention deficiency, emotivity and irritability, skin lesions and global body dysthermia, whereas dysesthesia, ear heat/otalgia, tinnitus, hyperacusis, dizziness, loss of immediate memory, insomnia and fatigue as well as depression tendency and suicidal ideation appear to be statistically more frequent in EHS than in MCS. Moreover, in the case of EHS associated with MCS, most of the symptoms—such as headache, dysesthesia, myalgia and arthralgia, tinnitus, and, above all, cognitive capability, including loss of immediate memory, concentration/attention deficiency, and tempo-spatial confusion—were found to be significantly more frequent than in EHS alone, suggesting that the presence of an additional chemical intolerance component to the intolerance attributed to EMF exposure is associated with a more severe pathology. This was especially the case for skin lesions which were found in 45% of the cases, as well as for physical and mental suffering and depressive tendency with underlying suicidal ideation in 40%.

Note that cutaneous lesions were more frequent on the superior members than on the inferior members of the patients, and more frequent on the hands, particularly on the hand which held the mobile phone (as exemplified in Figure 1A). Note also that the cutaneous lesions were not only more frequent in the group of patients with EHS- and MCS-associated disorders (45%) than in the group of attributed to EMF exposure is associated with a more severe pathology. This was especially the case for skin lesions which were found in 45% of the cases, as well as for physical and mental suffering and depressive tendency with underlying suicidal ideation in 40%.

Note that cutaneous lesions were more frequent on the superior members than on the inferior members of the patients, and more frequent on the hands, particularly on the hand which held the mobile phone (as exemplified in Figure 1A). Note also that the cutaneous lesions were not only more frequent in the group of patients with EHS- and MCS-associated disorders (45%) than in the group of patients with only EHS (16%), but also that they were more extensive and persistent in the cases of both associated disorders than in the case of EHS alone (Figure 1B).

Figure 1. Examples of skin lesions observed on the hand of an EHS-bearing patient (**A**) and of an EHS/MCS-bearing patient (**B**). (Photographs are issued from the database).

These clinical observations strongly suggest that EHS and EHS/MCS are objective somatic disorders, which can neither be claimed as originating from some psychologic or psychiatric-related conditions, nor from nocebo effects [11] (see further).

4. Identification of Biomarkers

On the basis of previously published experimental data, we selected and identified several biomarkers in the peripheral blood and urine of EHS and/or MCS patients which allow physicians to objectively characterize EHS and MCS as true somatic pathological disorders [10], discarding the hypothesis that EHS and MCS could be caused by a psychosomatic-related process [11]. As indicated in Table 4, there is a similar increase in low-grade inflammation-related biomarkers in the peripheral blood of patients with EHS, MCS, or both associated disorders. In addition, as far as frequency is concerned, we found hypersensitive C-reactive protein (hs-CRP) to be increased in 12–15% of the cases, histamine in 30%–40%, immunoglobulin E (IgE) in 20%–25%, and heat-shock protein 27 (Hsp27) and Hsp70 in 12%–30%. Note that, among these markers, IgE and histamine were found to be increased in patients with no allergy; thus, in the case of no associated allergy, histamine appears to be the most frequently involved biomarker in EHS, as well as in MCS, suggesting a low-grade inflammatory process involved in the genesis of these two disorders. Consequently, it is believed that, as an inflammation mediator, histamine could play a major contributing role in the physiopathologic mechanism which may account for the occurrence of the two disorders [11,14] (see further). Note also that, with the exception of Hsp 70, which was found to be less frequently increased in the MCS group, there was no significant difference between the three groups of patients for the percentage of patients with values above normal, nor any significant difference in mean increased values in comparison with normal values for all biomarkers in the three groups studied, meaning that EHS, MCS, and the association of both disorders may share a common low-grade inflammation-related physiopathologic mechanism for genesis.

Table 4. Increase in low-grade inflammation-related biomarker mean blood level values in the peripheral blood of patients with EHS and/or MCS, according to References [9,10]. SE—standard error; hs-CRP—hypersensitive C reactive protein; IgE—immunoglobulin E; Hsp—heat-shock protein.

	Patient Groups							
Marker Normal Values	**EHS Mean ± SE**	**Above Normal (%)**	**MCS Mean ± SE**	**Above Normal (%)**	***p* ***	**EHS/MCS Mean ± SE**	**Above Normal (%)**	***p* ****
hs-CRP < 3 mg/L	10.3 ± 1.9	15	5.3 ± 1.7	12	0.50	6.9 ± 1.7	14.3	0.36
Histamine < 10 nmol/L	13.6 ± 0.2	37	23.5 ± 4.5	33	0.91	13.6 ± 0.4	41.5	0.52
IgE < 100 UI/mL	329.5 ± 43.9	22	150.9 ± 18.3	20	0.23	385 ± 70	24.7	0.53
Hsp 70 < 5 ng/mL	8.2 ± 0.2	18.7	5.9 ± 0.5	12	0.03	8 ± 0.3	25.4	0.72
Hsp 27 < 5 ng/mL	7.3 ± 0.2	25.8	6.8 ± 0.1	6 ***	0.59	7.2 ± 0.3	31.8	0.56

* Comparison between the EHS and MCS groups of patients for marker mean level values was done using the two-tailed *t*-test. Except for Hsp 70, there is no statistically significant difference between EHS and MCS patients for increased mean level values of the different biomarkers analyzed, suggesting that EHS and MCS share a common physiopathological mechanism for genesis. ** Comparison between the EHS and EHS/MCS groups of patients by using the two-tailed *t*-test. There is no statistically significant difference between EHS and EHS/MCS patients for increased mean level values of the different biomarkers analyzed. *** With the exception of MCS, for which there is a statistically significantly lower frequency percentage value for Hsp 27, the frequency percentage values obtained in EHS and EHS/MCS for all the other investigated parameters do not differ significantly on the basis of the chi-square independence test.

Moreover, as indicated in Table 5, we were able to show that, in peripheral blood, there is an increase in S100B protein in 15–20% of the patients and an increase in nitrosative stress-related nitrotyrosine (NTT) in 8–30% in the EHS and/or MCS groups, suggesting that these biomarkers may reflect opening of the blood–brain barrier (BBB) in these patients, whatever the patient group considered, since it was shown that S100B protein [15,16] and nitrotyrosine [17–20] are markers associated with BBB opening. In addition, we detected the presence of autoantibodies against O-myelin in about 20% of all cases, whether EHS, MCS or both; meaning that an autoimmune response against the white matter of the nervous system occurres in patients; a finding that may in fact be the consequence of the occurrence of oxidative/nitrosative stress [10,21].

Table 5. Increase in mean blood level values of peripheral blood S100B protein, nitrotyrosine (NTT), and O-myelin autoantibodies in EHS and/or MCS patients, according to References [10,11].

	Patient Groups							
Markers Normal Values	**EHS Mean ± SE**	**Above Normal (%)**	**MCS Mean ± SE**	**Above Normal (%)**	***p* ***	**EHS/MCS Mean ± SE**	**Above Normal (%)**	***p* ****
S100B < 0.105 µg/L	0.20 ± 0.03	14.7	0.25 ± 0.05	21.15	0.56	0.17 ± 0.03	19.7	0.69
NTT * > 0.9 µg/ml	1.36 ± 0.12	29.7	1.26 ± 0.13	8	0.85	1.40 ± 0.12	28.9	0.86
O-myelin (qualitative test)	Positive	22.8	Positive	13.6	_	Positive	23.6	_

* Comparison between the EHS and MCS groups of patients using the two-tailed *t*-test. There is no statistically significant difference between the two groups of EHS and MCS patients for increased mean level values of the two different biomarkers analyzed, suggesting that EHS and MCS share a common physiopathological mechanism for genesis. ** Comparison between the EHS and EHS/MCS groups of patients using the two-tailed *t*-test. There is no statistically significant difference between EHS and EHS/MCS patients for increased mean level values of the different biomarkers analyzed, suggesting here too that EHS and MCS share a common physiopathological mechanism for genesis.

Moreover, more recently, we measured different oxidative and nitrosative stress-related biomarkers such as thiobarbituric acid reactive substances (TBARS), oxidized glutathione (GSSG), and NTT in the peripheral blood of EHS patients. As reported in Figure 2, we found that nearly 80% of EHS patients presented with an increase in oxidative/nitrosative stress-related biomarkers—more precisely, with only one of these three studied biomarkers in 43% of the patients, two of these biomarkers in 21% of them, and all three in 15% [22]. This clearly indicates that, in addition to low-grade inflammation and an anti-white matter autoimmune response, EHS can also be diagnosed by the presence of oxidative/nitrosative stress.

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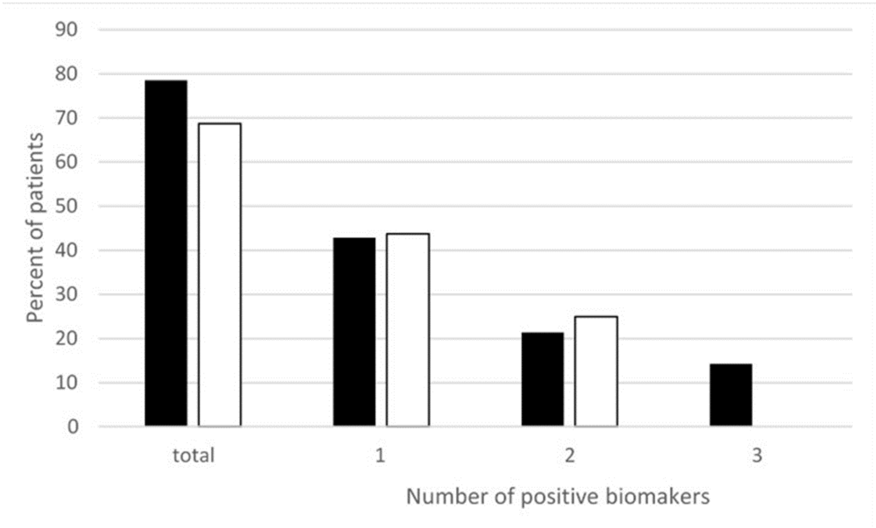

Figure 2. Percentage of EHS self-reported patients having positive thiobarbituric acid reactive substances (TBARS), oxidized glutathione (GSSG), and/or NTT oxidative stress biomarkers measured in the peripheral blood, according to Reference [22]. ■ Corresponds to NTT, TBARS, and GSSG, i.e., all three biomarkers measured in 14 of the 32 included patients. □ Corresponds to TBARS and GSSG analyzed in all 32 included patients. "Positive" biomarkers correspond to patients having one, two, or three markers with levels above the upper normal limits, and "total" corresponds to patients having at least one positive biomarkers, i.e., having one, two, or possibly three positive biomarkers.

Finally, we also found that, in comparison with normal reference values, the 24-h urine 6-hydroxymelatonin (6-OHMS)/creatinine ratio was normal or significantly decreased in 88% of cases, while, due to a still unexplained process, it was significantly increased in 12%, whatever the group of patients considered. 6-OHMS is a melatonin metabolite. Decrease in melatonin production as a consequence of prolonged EMF exposure was experimentally evidenced both in animals and in humans [23,24]. However, since EMF exposure was also reported not to alter melatonin synthesis and secretion [25], an alternative plausible explanation could be that a decrease in the excretion of 6-OHMS in the urine may result from a decrease in melatonin metabolic bioavailability due to its increased intake and utilization of melatonin as a free radical scavenger [26,27]. This indeed could be the case in patients with a decrease in the 24-h urine 6-OHMS/creatinine ratio level, since, as shown above, most EHS patients present with oxidative/nitrosative stress. Thus, a decrease in 6-OHMS in the urine may in fact be a consequence of the antioxidative stress effect of this hormone rather than its decreased synthesis in the pineal gland. Consequently, such reduction in bioavailability may contribute not only to clinical sleep disturbance in these patients, but also to a decrease in host defense mechanisms, possibly putting these patients at risk of neurodegenerative disease and cancer [28,29].

Moreover, the development of oxidative/nitrosative stress-related autoimmune response may also contribute to weakening the putative protective health effect of the chaperone proteins Hsp 70 and Hsp 27 [30]. There is presently no clear explanation why, in 12% of the cases, instead of having a normal or significant decrease in the 24-h urine 6-OHMS/creatinine ratio, this ratio was significantly increased in comparison with normal control values. As indicated in Table 6, this may be due in some cases to an increased production of serotonin in the brain, since serotonin is a precursor neurotransmitter of melatonin.

As indicated in Table 6, changes in neurotransmitter levels revealed that EHS is associated with different abnormal neurotransmitter profiles, confirming EHS is a well-established new brain-related neurologic disorder.

Table 6. Preliminary unpublished data based on the measurement of neurotransmitters and their metabolites in the urine of 42 EHS-bearing patients. 3-4 DOPAC—3,4-Dihydroxyphenylacetic acid.

Neurotransmitters	Patients	%
Dopamine increase	17/42	31
3-4 DOPAC decrease	18/42	43
Noradrenaline increase	11/42	26
Adrenaline increase	8/42	19
Adrenaline decrease	12/42	22
Serotonin increase	4/42	9.5
Serotonin decrease	5/42	12

5. Radiological Identification of Cerebral Neuro-Vascular Abnormalities

Classical brain imaging techniques including brain computerized tomography (CT) scans, brain magnetic resonance imaging (MRI), and brain angioscans are usually normal in EHS patients and in MCS or EHS/MCS patients, meaning that the normality of these investigations is not an argument against the diagnosis of these pathological disorders. Fortunately we have shown that development and use of other imaging techniques could be greatly helpful to increase our ability of objectively characterizing EHS and MCS, should they show abnormal function. In fact, as indicated in Table 7, by using transcranial Doppler ultrasound (TDU) in patients with EHS, we showed a decrease in the mean pulsatility index in one or both middle cerebral arteries, i.e., for one artery in 25% and 31% of the cases respectively for the right and left artery, and for both arteries in 50%. Moreover, for the dual EHS/MCS group of patients, it was for one artery in 20% of the cases and for both arteries in 50%. In addition, as far as resistance in the blood flow (BBF) is concerned, we found that, in EHS patients, BBF resistance was increased for one artery in 6.25% of the cases and for both arteries in 18.75%, while in EHS/MCS patients, it was 5–10% for one artery and 25% for both arteries. Note also that mean blood flow velocity was below normal values in 9.75% to 40% of the cases, while it was above normal values in 5% to 18.75%, depending on the EHS and EHS/MCS group considered (see Table 7). This suggests that, in EHS and/or MCS, BBF may be decreased in one or both of these brain arteries.

Table 7. Results of resistance index, pulsatility index, and mean flow velocity in comparison with normal values in the right and left middle cerebral arteries using transcranial Doppler ultrasound in 32 EHS cases and 20 EHS/MCS cases (unpublished data).

	EHS n = 32								
	Normal Value	**Mean ± SE**		**Below Normal (%)**			**Above Normal (%)**		
	Right and Left	**Right**	**Left**	**Right Only**	**Left Only**	**Both**	**Right Only**	**Left Only**	**Both**
Resistance index	<0.75	0.62 ± 0.03	0.65 ± 0.04	_	_	_	6.25	6.25	18.75
Pulsatility index	>0.60	0.55 ± 0.02	0.55 ± 0.03	25	31.25	50	_	_	_
Mean flow velocity	62 ± 12	59.56 ± 5.98	61.35 ± 5.27	9.75	9.75	31.25	3.12	9.25	18.75
	EHS/MCS n = 20								
	Normal values	**Mean ± SE**		**Below Normal (%)**			**Above Normal (%)**		
	Right and Left	**Right**	**Left**	**Right only**	**Left only**	**Both**	**Right only**	**Left only**	**Both**
Resistance index	<0.75	0.79 ± 0.09	0.64 ± 0.04	_	_	_	5	10	25
Pulsatility index	>0.60	0.48 ± 0.03	0.61 ± 0.02	20	0	65	_	_	_
Mean flow velocity	62 ± 12	53.03 ± 9.09	51.77 ± 7.63	20	20	40	10	10	5

Resistance index	<0.75	0.79 ± 0.09	0.64 ± 0.04	–	–	–	5	10	25
Pulsatility index	>0.60	0.48 ± 0.03	0.61 ± 0.02	20	0	65	–	–	–
Mean flow velocity	62 ± 12	53.03 ± 9.09	51.77 ± 7.63	20	20	40	10	10	5

Moreover, by using ultrasonic cerebral tomosphygmography (UCTS) applied to the temporal lobes [12], we showed there is a significant decrease in mean pulsometric index in the middle cerebral artery-dependent tissue areas of these lobes, especially in the capsulo-thalamic area, which corresponds to the limbic system and the thalamus [12]. As exemplified in Figure 3, this tissue hypo-pulsation—mainly detected in the capsulo-thalamic area of these lobes—suggests that EHS and/or MCS are associated with a capillary BBF decrease in these two brain structures, thus leading to the hypothesis that they may be associated with some vascular and/or neuronal dysfunction [10–12]. Although these abnormalities are not specific, since they may be similar to those found in Alzheimer's disease and other neurodegenerative disorders, we recently confirmed that UCTS could presently be one of the most accurate imaging techniques to be used to diagnose EHS and/or MCS and to follow objectively treated patients [12].

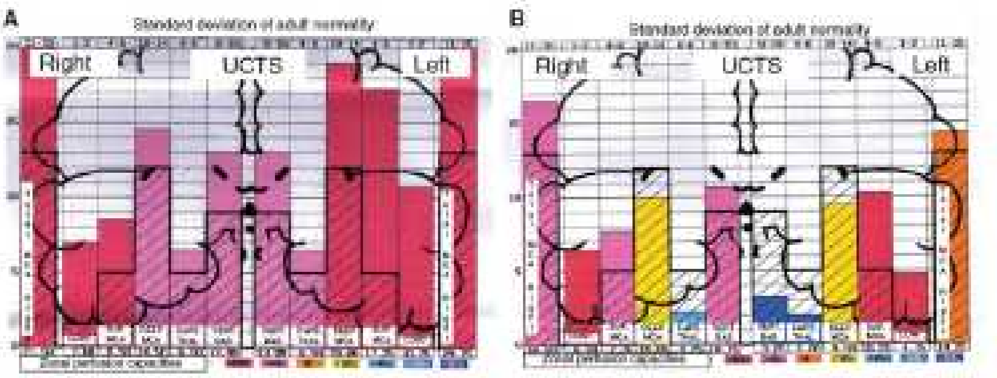

Figure 3. Examples of diagrams obtained from the database by using ultrasonic cerebral tomosphygmography (UCTS), exploring the global centimetric ultrasound tissue pulsatility in the two temporal lobes of a normal subject (**A**) and of an EHS self-reported patient (**B**), according to References [11,12]. Measurements are expressed as pulsometric index (PI). Note that, in A and B, mean values of PI in each explored area are recorded from the cortex to the internal part of each temporal lobe (i.e., from left to right for the right lobe, and from right to left for the left lobe). In addition, note that, in A (normal subject), all values are over the median normal PI values, whereas, in B (EHS self-reported patient), values in the so called capsulo-thalamic areas (the fifth and the second column for the right and left temporal lobes, respectively) are significantly under the median normal values, suggesting that the limbic system and the thalamus in each temporal lobe may be involved in EHS, as exemplified in this patient.

It appears, however, that these brain abnormalities are not restricted to the limbic system and the thalamus, since, by using TDU as indicated above, we showed that, in EHS and/or MCS patients, BBF in the middle cerebral arteries may be abnormal. Moreover, by using functional MRI (fMRI) in EHS patients exposed chronically to extremely low-frequency (ELF) radiation, regional BBF changes were also reported by Heuser and Heuser, but mainly in the frontal lobes, as an abnormal default mode network (DMN) (particularly as hyper-connectivity of this DMN), in association with a decrease in cerebral BBF and metabolic processes in the two so far individualized fragment hyper-connected components [31]. For example, in Figure 4, abnormal DMN is represented with fragmented hyper-connectivity of the anterior component and posterior component, which may lead to decreased BBF and/or metabolism in the bi-frontal lobes.

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Figure 4. Abnormal functional MRI brain scan in patients complaining of EHS after long-term exposure to EMF, according to Reference [31].

6. Diagnostic Criteria

On the basis of the above clinical, biological, and radiological reported investigations, it appears that there is presently sufficient comprehensive and relevant data allowing the objective characterization and identification of EHS as a well-defined new neurologic pathological disorder. As a result, patients who self-report that they suffer from EHS should be investigated utilizing presently available objective tests, including the use of the above-reported blood and urine biomarkers and imaging techniques.

At a clinical level, isolated symptoms such as headache, tinnitus, dizziness, or cognitive defects, although they may be referred by the patients as being due to EMF or chemical exposure, are indeed not sufficient for the diagnosis to be made, as they may reflect another pathology. Clinical arguments for EHS could nevertheless be the following: (1) absence of known pathology accounting for the observed clinical symptoms; (2) the characteristic association of symptoms such as those we identified, with the association of headache, tinnitus, hyperacusis, dizziness, loss of immediate memory, and attention/concentration deficiency being the most characteristic and reproducible; (3) reproducibility of symptoms under the said influence of EMFs; (4) regression or disappearance of symptoms in the case of said EMF avoidance; (5) finally and most importantly, the association with MCS. As we showed that MCS is associated with EHS in 30% of the cases, and as MCS was well defined during a 1999 international consensus meeting [32], this latter association may in fact be the best clinical criterion for the diagnosis of EHS.

However, because many of these clinical criteria are subjective, they are not sufficient to objectively prove the disease and, thus, establish the diagnosis. Among biological markers, histamine in the blood is presently the best available marker in the case of no associated allergy and the easiest to measure routinely in medical practice. Moreover, detection in the blood of an increase in protein S100B and oxidative/nitrosative stress-related biomarkers such as GSSG and NTT may also be objective contributing elements for the diagnosis. Note, however, that, in 30% of the cases, there were no positive detectable biomarkers in the blood; thus, in addition to the availability of clinical criteria, the EHS diagnosis could be made by using imaging techniques, such as TDU, fMRI, and, if possible, UCTS. Overall, by using this approach, we were able to objectively diagnose EHS in about 90% of EHS self-reported patients.

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7. Treatment and Prognostic Evolution

There is, at the moment, no recognized standardized treatment of EHS. There are, however, some treatments that could be indicated, on the basis of biological investigations. We showed, for example, that patients with EHS present frequently with a profound deficit in vitamins and trace elements, especially in vitamin D and zinc, which should be corrected [10,11,22]. Anti-histaminics should also be used in the case of increased histamine in the blood. Furthermore, antioxidants such as glutathione and, more specifically, anti-nitrosative medications should also be used in case of oxidative/nitrosative stress. Moreover, as exemplified in Figure 5, we showed that natural products such as fermented papaya preparation (FPP) and ginkgo biloba can restore brain pulsatility in the various middle cerebral artery-dependent tissue areas of temporal lobes, thereby improving brain hemodynamics and, consequently, brain oxygenation [33]. Since FPP was shown to possess some antioxidant, anti-inflammation, and immune-modulating properties [34–36], we recommend the use of this widely available natural product.

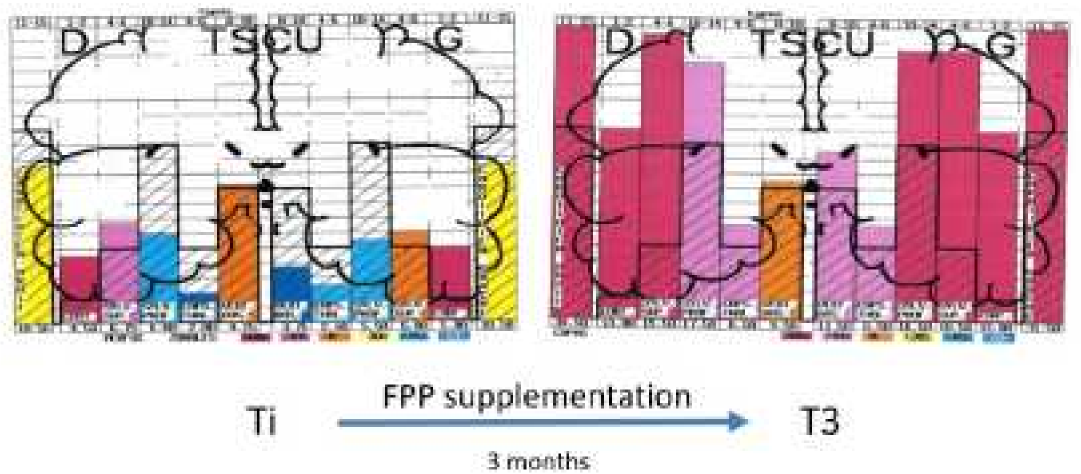

Figure 5. Example of diagrams obtained from the database by using UCTS exploring the global centimetric ultrasound pulsatility in the two temporal lobes of an EHS subject at inclusion (Ti) and three months later (T3) after fermented papaya preparation (FPP) supplementation (9 g per day in two divided doses), according to Reference [33].

In the case of no treatment and no protection against environmental stressors such as EMF and multiple chemicals, EHS may evolve toward some neurodegenerative and psychiatric disorders, possibly including some seemingly Alzheimer's disease-related states. However, in treating and protecting patients as soon as possible, we never observed the occurrence of true Alzheimer's disease in any patient included in the database. By contrast, regression and even disappearance of symptoms of intolerance may occur after treatment and protection of patients. However, in our experience and to our knowledge, hypersensitivity to EMF and/or MCS-related chemical sensitivity never disappears, meaning – unlike symptomatic intolerance – EHS and MCS appear to be associated with some irreversible neurologic pathological state, requiring strong and persistent prevention. So, contrary to some recent claims, we believe these disorders cannot be merely reduced to some type of functional impairment.

8. Proposed Physiopathological Mechanism

In its 2005 official statement on EHS, WHO indicated there is "no scientific basis to link EHS symptoms to EMF exposure" meaning there is no accepted physiopathological mechanism to link environmental cause to disease. This is no longer the case. The basic low-grade inflammation and oxidative/nitrosative stress-related states we showed in EHS patients [10,11,22] are remarkable since they confirm the detrimental health effects of (1) non-thermal or weak thermal non-ionizing radiation, which were proven experimentally in animals [37–39] and in humans [11] exposed to different environmental stressors including ELF and RF EMFs, and (2) multiple man-made environmental chemicals [40–42], especially in the brain [43,44].

Figure 6 summarizes the different steps of the model we have so far been able to construct from the presently available published data, including our own. On the basis of the inflammation and oxidative/nitrosative stress processes which we evidenced in EHS and/or MCS patients, this model accounts for the mechanisms via which physiopathological effects could take place in the brain and, consequently, how EHS and/or MCS genesis can occur.

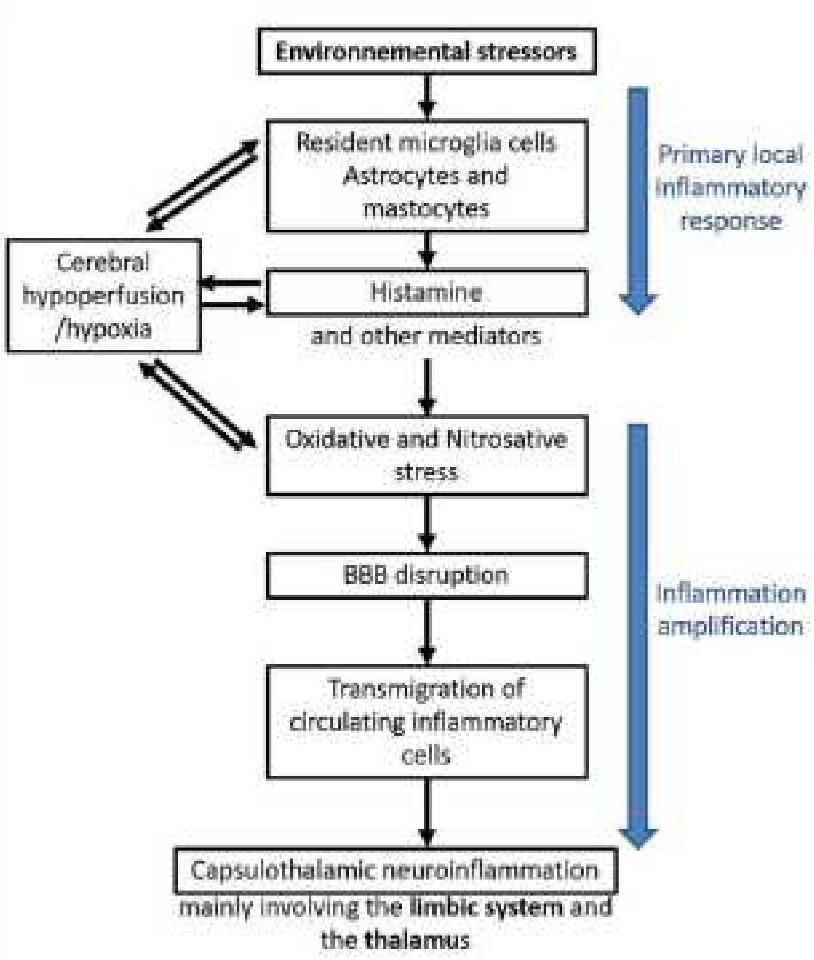

Figure 6. EHS/MCS physiopathological model based on low-grade neuroinflammation and oxidative/nitrosative stress-induced blood–brain barrier disruption, according to Reference [10].

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In a first step, there could be an initial local inflammatory response to environmental stressors, whatever they may be. Resident microglia cells, astrocytes, and mastocytes could be the first cells in the brain locally involved in the inflammatory process, releasing inflammatory mediators such as histamine. On the basis of our data [10–12,22,33], it is speculated that histamine is a key mediator contributing to the induction of oxidative/nitrosative stress and, consequently, to cerebral hypoperfusion, thereby leading to some local cerebral hypoxia.

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In a second step, amplification of inflammation could occur, including oxidative/nitrosative stress-related BBB disruption, allowing transmigration of circulating inflammatory cells from the blood to the brain. Finally, neuroinflammation in the brain would occur, mainly involving the capsulo-thalamic area of temporal lobes, i.e., the limbic system and the thalamus.

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may account for both the emotional and cognitive pathological alterations (in particular memory loss), while the thalamic involvement may explain sensibility-related abnormalities, both superficial and deep. Naturally, the possible extension of neuroinflammation into the frontal lobes and possibly into the hypothalamus [45] may, in addition, account for the other associated clinical symptoms.

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9. Etiopathogenesis and Prevention

The causal origin of EHS is still debated, and the present current institutional message is that there is no proof that EHS genesis is causally related to EMF exposure. There is, however, great confusion in the present scientific literature in addressing this problem, since there is presently no clear distinction between the cause of clinical symptoms occurrence in EHS patients, i.e., after EHS has already occurred, and the environmental causal origin of EHS itself. In fact, as reported in Table 8, by querying the database and analyzing retrospectively previous exposure to EMFs and/or chemicals in EHS- and EHS/MCS-bearing patients, we found there are presently several direct and indirect arguments which strongly suggest that EMF exposure and even chemicals may cause or contribute to cause EHS.

Table 8. Clinical analysis of self-reported excessive presumed EMF and chemical exposure preceding the occurrence of electrohypersensibility (unpublished data). DECT—digital enhanced cordless telecommunications; RF—radiofrequency; ELF—extremely low frequency.

Sources	EHS (%)	Frequency Bands
Mobile phone	37	RF
Mobile phone/DECT	8	
DECT	7	
Cathode-ray screen	9	
WiFi	16	
Relay antenna towers	3	
Energy-saving lamps/mobile phone *	1.4	RF and ELF
High-voltage power lines	2.7	ELF
Power transformer	1.7	
Railway	0.8	
Chemicals	11	
Idiopathic **	2.4	

* Presumed excessive source exposure concern both low frequencies (LF) and radiofrequencies (RF); ** possible genetic susceptibility.

Moreover, a further distinction should be made between the general term of intolerance, which refers to the clinical symptoms and/or the biological abnormalities occurring in a particular environmental situation, and the term hypersensitivity, which should in fact be defined as a particular endogenous physiopathological state characterized by a decrease in the environmental tolerance threshold to such a critical point that patients become intolerant to low-dose stressors. Such a distinction is already made in medicine as, for example, the individualization of atopy in allergic patients.

Thus, if we agree on the distinction between the concept of intolerance and that of EHS, EHS should be characterized by definition as a particular decrease in the intolerance threshold according to which patients become intolerant to low-dose-intensity EMF exposure, while MCS (as already indicated by the MCS consensus meeting report in 1999 in Atlanta) was defined by a similar physiopathological state in which patients become intolerant to low-dose multiple chemicals [32]. This distinction may explain why most studies using provocation tests aiming to reproduce the clinical symptoms which may occur under EMF exposure in EHS self-reported patients report negative findings. Indeed, these negative results may in fact be due to different, unacceptable scientific flaws: (1) the lack of objective inclusion criteria, because objective biomarkers were not used to define EHS in so-called EHS-self reported patients; (2) EHS patients may be sensitive to certain frequencies and not necessarily to others; (3) duration of exposure was generally too short and assessment too early; (4) association with MCS was not considered; (5) as reported above, EHS patients have cognitive defects and, thus, can make mistakes in distinguishing EMF exposure from sham exposure; (6) and above all, patients may respond positively in the case of sham exposure because of a decrease in environmental tolerance threshold, as well as because of psychologic conditioning from their past history of suffering.

Hence, on this basis, and because of the experimental evidence provided by studies in animals [37–39,43,44] and in humans [11,14,23,24] have shown the detrimental impact of EMF on health we believe, there is presently no sufficiently robust scientific data to refute a role of EMF exposure in inducing the previously described clinical symptoms and biological alterations in EHS patients.

Therefore, the causal origin of EHS should be established with a different scientific approach. RF and ELF were found to cause persistent adverse biological effects not only in animals [46,47] but also in plants [48,49] and microorganisms [50]. Here too, such observations certainly dismiss the hypothesis of a nocebo effect as the initial cause of EHS. In fact, the inflammation and oxidative/nitrosative states we showed in EHS patient are remarkable since they confirm the data obtained experimentally in animals exposed to these two types of non-ionizing frequencies [37–39], especially in the brain [43,44]. Furthermore, the limbic system-associated capsulo-thalamic abnormalities that we showed to characterize these patients [12,33] may likely correspond to the hippocampal neuronal alterations caused by EMF exposure in rats [51–53].

We therefore consider that the biological effects we observed in EHS patients may be due to both the pulsed and the polarized characteristics of man-made EMF emitted by electric or wireless technologies, as opposed to terrestrial non-polarized and continuously emitted natural EMFs [54–56].

In addition, as indicated in Table 9, we showed that, in 30% of the EHS cases, EHS was associated with MCS, with MCS preceding the occurrence of EHS in 37% of these EHS/MCS-associated cases; meaning that in this group of patients, EHS evolved toward MCS in 63% of the cases. As reported in Table 8, we thus speculate that man-made environmental chemicals may also be causally involved in EHS genesis in around 11% of the cases.

Table 9. Percentage of MCS patients who later suffered from EHS and vice versa.

	Total EHS/MCS Patients	Total EHS Patients Including EHS/MCS Patients *
Percentage of MCS patients that later suffered from EHS	37	11
Percent of EHS patients that later suffered from MCS	63	19

* EHS/MCS patients represent 30% of the total number of EHS patients.

These various considerations should not be neglected, since to avoid risks, knowledge of them could lead to protective measures in EHS and/or MCS patients. Such measures should include as much as possible EMF and chemical avoidance, use of anti-EMF clothes, and earthing-related electric charge detoxication. In addition, public preventive measures for the most vulnerable people—particularly pregnant women, infants, children, and adolescents—should be taken by limiting or even totally avoiding the use of wireless technology in these conditions. Such protective measures should also be taken and carried out in vulnerable patients, i.e., in cardiac patients with pacemakers, in patients with auditive prothesis, and in patients with neurodegenerative diseases.

10. The Worldwide Health Plague

Another argument incriminating the role of new wireless technology and possibly man-made chemicals introduced in the environment [57,58] is that, as indicated in Table 10, the increase in EHS prevalence is not restricted to a single country but is presently a worldwide plague, which started as soon as these industrial technologies became widespread. Prevalence of EHS occurrence is estimated to range from 0.7% to 13.3%, mainly affecting about 3% to 5% of the population in many countries (Table 10), meaning that millions of people may in fact be affected by EHS worldwide.

Table 10. Estimated prevalence of people with self-reported EHS in different worldwide countries. USA—United States of America.

Country	Date	Sample Size	People Contribution Rate (%)	Estimated % of People with EHS	References
Sweden	1997	15,000 (19–80) *	73	1.5	Hillert et al., 2002 [59]
Sweden	2010	3406	40	2.7	Palmquist et al., 2014 [60]
Swiss	2004	2048 (>14) *	55.1	5	Schreier et al., 2006 [61]
Swiss	2008	1122 (30–60) *	37	8.6	Roosli et al., 2010 [62]
Swiss	2009	1122 (30–60) *	37	7.7	Roosli et al., 2010 [62]
Germany	2004	30,047	58.6	10.3	Blettner et al., 2009 [63]
Germany	2004	30,047	58.4	8.7	Kowall et al., 2012 [64]
Germany	2006	30,047	58.4	7.2	Kowall et al., 2012 [64]
USA (California)	1998	2072	58.3	3.2	Levallois et al., 2002 [65]
Finland	2002	6121	40.8	0.7	Korpinen et al., 2009 [66]
Great Britain	Before 2007	3633	18.2	4	Eltiti et al., 2007 [67]
Taiwan	2007	1251	11.5	13.3	Tseng et al., 2011 [68]
Austria	Before 2008	460	88	3.5	Schröttner and Leitgeb, 2008 [69]
Japan	Before 2009	2472	62.3	1.2	Furubayashi et al., 2009 [70]
Holland	2011	5789	39.6	3.5	Batiatsas et al., 2014 [71]
Holland	Before 2013	1009	60	7	Vabn Dongen et al., 2014 [72]

* When precised, age intervals of included patients are indicated in brackets.

Furthermore, although these reported EHS prevalence figures are only estimations, not critically evaluated due to a lack of objective criteria to clearly define EHS, it is possible—as speculated in Figure 7—that the EHS prevalence will continue to grow in the future, in as much as the manufacture of wireless technology and industrial chemicals will continue to develop.

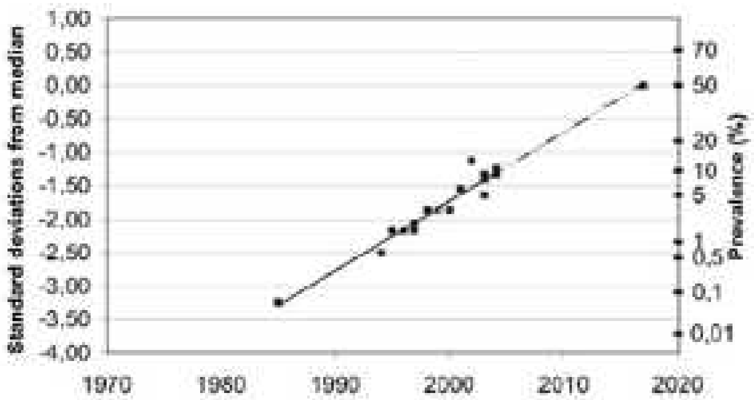

Figure 7. Estimated prevalence (%) of people around the world who consider themselves to be electrohypersensitive, plotted over time in a normal distribution graph, according to Reference [73].

11. Conclusions

In summary, we showed that there are presently sufficient clinical, biological, and radiological data for EHS to be acknowledged as a well-defined, objectively identified, and characterized pathological neurologic disorder. As a result, patients who self-report they suffer from EHS should be diagnosed and treated on the basis of presently available biological tests, including the detection of peripheral blood and urine biomarkers and the use of imaging techniques such as fMRI, TDU, and, when possible, UCTS. Moreover, because we showed for the first time that EHS is frequently associated with MCS and that both clinico-biological entities may be associated with a common physiopathological mechanism for genesis, it clearly appears that they can be identified as a unique neurologic pathological syndrome, whatever their causal origin. Moreover; as it was shown that MCS genesis may be attributed to toxic chemical exposure, and EHS genesis to potentially excessive EMF and/or chemical exposure; protective measures against these two environmental stressors should be taken.

Whatever its causal origin and mechanism of action, EHS should therefore be from now on recognized as a new identified and characterized neurological pathological disorder. As it is already a real health plague potentially involving millions of people worldwide it should be acknowledged by WHO, and thus be included in the WHO ICD. As stated during the international scientific consensus meeting on EHS and MCS that we have organized in 2015 in Brussels, scientists unanimously asked WHO to urgently assume its responsibilities, by classifying EHS and MCS as separate codes in the ICD; so as to increase scientific awareness of these two pathological entities in the medical community and the general public, and to foster research and train medical practitioners to efficiently diagnose, treat, and prevent EHS and MCS–, which in fact constitute a unique, well-defined, and identifiable new neurologic disease.

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Abbreviations

6-OHMS	6-hydroxymelatonin
BBB	blood–brain barrier
BBF	brain blood flow
CT scan	computerized tomography (CT) scan
DECT	digital enhanced cordless telecommunications
DMN	default mode network
EHS	electrohypersensitivity
EHS/MCS	electrohypersensitivity and multiple chemical sensitivity
EMF	electromagnetic field
ELF	extremely low frequencies
fMRI	functional magnetic resonance imaging
GSSG	oxidized glutathione (GSSG)
Hs-CRP	hypersensitive C reactive protein
ICD	international classification of disease
IEI-EMF	idiopathic environmental intolerance attributed to EMF
IgE	immunoglobulin E
IPCS	International Program on Chemical Safety
MCS	multiple chemical sensitivity
MRI	magnetic resonance imaging
NTT	nitrotyrosine
PI	pulsometric index
RF	radiofrequencies
TBARS	thiobarbituric acid reactive substances

TDU	transcranial Doppler ultrasound
UCTS	ultrasonographic cerebral tomosphygmography
WHO	World Health Organization
WiFi	Wireless Fidelity

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Electromagnetic field exposure-induced depression features could be alleviated by heat acclimation based on remodeling the gut microbiota

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A R T I C L E I N F O

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A B S T R A C T

Background: Electromagnetic pollution cannot be ignored. Long-term low-dose electromagnetic field (EMF) exposure can cause central nervous system dysfunction without effective prevention.

Materials/Methods: Male C57BL/6J mice (6–8 weeks, 17–20 g) were used in this study. Depression-like and anxiety-like behaviors detected by behavioral experiments were compared among different treatments. 16S rRNA gene sequencing and non-targeted liquid chromatography-mass spectrometry (LC-MS) metabolomics were used to explore the relationship between EMF exposure and heat acclimation (HA) effects on gut microbes and serum metabolites.

Results: Both EMF and HA regulated the proportions of *p_Firmicutes* and *p_Bacteroidota*. EMF exposure caused the proportions of 6 kinds of bacteria, such as *g_Butyricicoccus* and *g_Anaerotruncus,* to change significantly ($p < 0.05$). HA restored the balance of gut microbes that was affected by EMF exposure and the proportion of probiotics (*g_Lactobacillus*) increased significantly ($p < 0.01$). Serum metabolite analysis suggested that HA alleviated the disturbance of serum metabolites (such as cholesterol and D-mannose) induced by EMF exposure. Both the metabolic KEGG pathways and PICRUSt functional analysis demonstrated that tryptophan metabolism, pyrimidine metabolism and amino acid biosynthesis were involved.

Conclusions: EMF exposure not only led to depression-like neurobehavioral disorders, but also to gut microbiota imbalance. HA alleviated the depression features caused by EMF exposure. Based on the analysis of gut microbiota associated with serum metabolites, we speculated that gut microbiota might play a vital role in the cross-tolerance provided by HA.

1. Introduction

Electromagnetic fields (EMFs) are widely used in communication, smelting, medicine and other industries. The impact of electromagnetic pollution on health has attracted public attention. EMF regulation (2016) clearly noted that long-term low-dose electromagnetic radiation exposure can lead to central nervous system dysfunction (Van, 2000; Wijngaarden, 2000). EMF exposure can cause neurobehavioral disorders, including circadian imbalance, headache, fatigue, depression and anxiety. However, it is difficult to verify the conclusions of epidemiological studies on the mechanism of nerve injury induced by EMF exposure, especially low-dose EMF exposure. Some of the obtained results have even been contradictory. One reason might be that researchers analyzed the bioeffects of EMFs based on the levels in cells or tissues and neglect to look at the experimental animals as a whole.

The gut microbiota is a complex microecological system that colonizes the intestine. Studies have shown that gut microbes are closely related to health (Wang et al., 2012). They regulate host energy homeostasis, material metabolism, blood glucose balance and the immune response. More importantly, gut microbes also play an essential role in maintaining brain physiological function, participating in neuropsychiatric behavior, brain development, aging and neurodegenerative processes (Sun et al., 2020). Chronic environmental stimulation could lead to anxiety, depression and other mental and behavioral disorders based on gut microbes (Neufeld et al., 2014; Sharon et al., 2016). As a physical environmental factor, EMFs might also lead to central nervous

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0147-6513/

system disorders by affecting gut microbes. Currently, there are few reports about the bioeffects of gut microbes under EMF exposure. In 2020, Yee. et al. found that the gut microbiome ratio of *Firmicutes/Bacteroidetes* decreased with pulsing electromagnetic field (PEMF) exposure (Yee et al., 2020). Therefore, EMF exposure could be able to affect the gut microbiota composition.

Heat acclimation (HA) refers to a series of adaptive physiological responses to long-term repeated exposure to moderately high environmental temperatures. Studies have confirmed that HA could not only alleviate central nervous system injury caused by heatstroke (Yi et al., 2017),but also enhance the protective effect of other stimuli besides high temperature (such as hypoxia, ischemia and reperfusion injury) on injury (Umschweif et al., 2013). This cross reinforcement is called "cross tolerance". Our previous study also revealed that HA could regulate microglial inflammatory activation with EMF exposure (Genlin et al., 2020). Moreover, long-term exposure to high environmental temperature has been shown to affect the gut microbiome in mice (Yang et al., 2021). According to the "cross tolerance" of HA, we hypothesize that HA might play a protective role in disorders of the central nervous system against EMF exposure by remodeling the gut microbiota.

Our study used a mouse model of intermittent long-term EMF exposure to explore the adverse biological effects of EMFs. Additionally, a mouse model of HA was used. Central nervous system dysfunction was confirmed by animal behavior experiments. 16S rRNA gene sequencing was used to explore variations in the gut microbiome and combined with non-targeted liquid chromatography–mass spectrometry (LC-MS) metabolomics to elucidate the potential mechanism by which HA alleviates the depression features caused by EMF exposure.

2. Methodology and materials

2.1. Experimental animal model

2.1.1. Heat acclimation model

All experimental animals were[1] 8-week-old male nice purchased from the Animal Centre of Army Medical University (Chongqing, China). The breeding conditions for mice were 28 degrees Celsius, 50% humidity and a 12:12 h light:dark cycle with food and water provided ad libitum. The mice were randomly divided into four groups: the control group (Control), electromagnetic field exposure group (EMF), electromagnetic field exposure with heat acclimation group (EMF+HA) and heat acclimation group (HA). All animal model included two stages. The first stage was 28 days and the mice in the control group (Control) and electromagnetic field exposure group (EMF) were housed at ambient temperature (28 ± 0.5 °C), while the heat acclimation group (HA) and electromagnetic field exposure with heat acclimation group (EMF+HA) were housed at 35 ± 0.5 °C with 60 ± 5% humidity (Fig. 1A). During this period, the basal metabolism and heart rate of mice in HA group were lower and the heat resistance was better.

2.1.2. Electromagnetic field (EMF) exposure model

To keep the temperature and humidity constant in the EMF exposure environment, pulsed electromagnetic field (2450 MHz, 2 μs/pulse, 500 pulses/s) were employed. Experimental animals were deposited in a special plexiglass cage that allowed for transmission of electromagnetic waves and the long axis of the mouse body was perpendicular to the long axis of the electromagnetic field-emitting antenna. Whole bodies of mice were exposed to EMF (specific absorption rate, SAR: 2.5 W/kg) for 4 h a day for 5 weeks. After exposure, the EMF+HA group was returned to an artificial climate simulation cabin with continued HA (temperature: 35 ± 0.5 °C, humidity: 60 ± 5%), while the EMF group was returned to ambient temperature (temperature: 28 ± 0.5 °C, humidity: 50 ± 5% humidity). Eliminating the environmental interference caused by EMF exposure, the HA group was also placed in a plexiglass cage with sham EMF exposure for 4 h a day for 5 weeks. When animals underwent EMF exposure, the environmental temperature was 28 ± 0.5 °C, and the humidity was 50 ± 5% (Fig. 1B). All animal laboratories involved in this study not only strictly followed the recommendations in the National Institutes of Health's Laboratory Animal Care and Use Guidelines but were also approved by the Laboratory Animal Welfare and Ethics Committee of Army Medical University.

2.2. Methods

2.2.1. Sample collection and processing

After behavioral testing, mice were anesthetized, and blood was collected from the eyeballs. Serum samples were immediately frozen in liquid nitrogen and then stored at − 80 °C. Fresh feces from each animal were collected at the end of the experiment. Each mouse was placed separately in a metabolic cage. The samples were immediately frozen in liquid nitrogen and then stored at − 80 °C until DNA extraction.

2.2.2. Behavioral experiments

All assays to monitor behavior commenced 12 h after the end of EMF exposure. The mice were kept in the same room in which the experiments were to be performed for a minimum of 30 min before each test. Furthermore, the less stressful test (open-field test) was conducted before the more stressful tests (elevated plus-maze, light–dark transitions, forced swim test, tail suspension test).

2.2.3. Open-field test

The open-field test allowed for the assessment of behavior and locomotor activity by recording the free movements of the mice. The open field maze consisted of a square chamber (40 cm (length) × 40 cm (width) × 25 cm (height)) made of nonporous plastic placed in a quiet environment free of clues. The mouse was placed in the middle of the maze and could freely move for 5 min. Locomotion was automatically recorded using an EthoVision XT15 (Noldus, Wageningen, The Netherlands) video tracking system attached to a pole above the field. During the test, the total distance and central square duration were all obtained from the tracking system with a video camera mounted above the apparatus. After each subsequent test, the entire apparatus was cleaned with 75% ethanol.

2.2.4. Elevated plus-maze test

The apparatus consisted of two sets of arms: two open arms and two closed arms. The dimensions of both the open and closed arms were 30 cm × 6 cm × 15 cm. Each of the arms was associated with a common central platform having dimensions of 6 cm × 6 cm. Individual mice were placed on the central platform with their heads pointed toward the open arm of the apparatus. Subsequently, the ratios of open-arm time to total arm time and open-arm frequency to total arm frequency were calculated for a period of 10 min. Prior to each test, the platform was cleaned using 75% ethanol.

2.2.5. Light/dark transition test

The apparatus used comprised a light side and a dark side having identical dimensions of 20 cm × 15 cm × 25 cm. The experiments were initiated by placing mice on the light side of the chamber first. After 10 min of recording, the time spent in the dark side of the chamber and the total number of transitions were recorded. Prior to each test, the platform was cleaned using 75% ethanol.

2.2.6. Tail suspension test

This test was carried out by suspending each mouse by its tail with the help of bands from a hook placed 50 cm above floor level. The animals being tested were isolated from each other both acoustically and visually. The hanging was continued for 6 min. The entire period was recorded by a camera and the immobility times were monitored by an

[1] 6-8-week-old male nice.

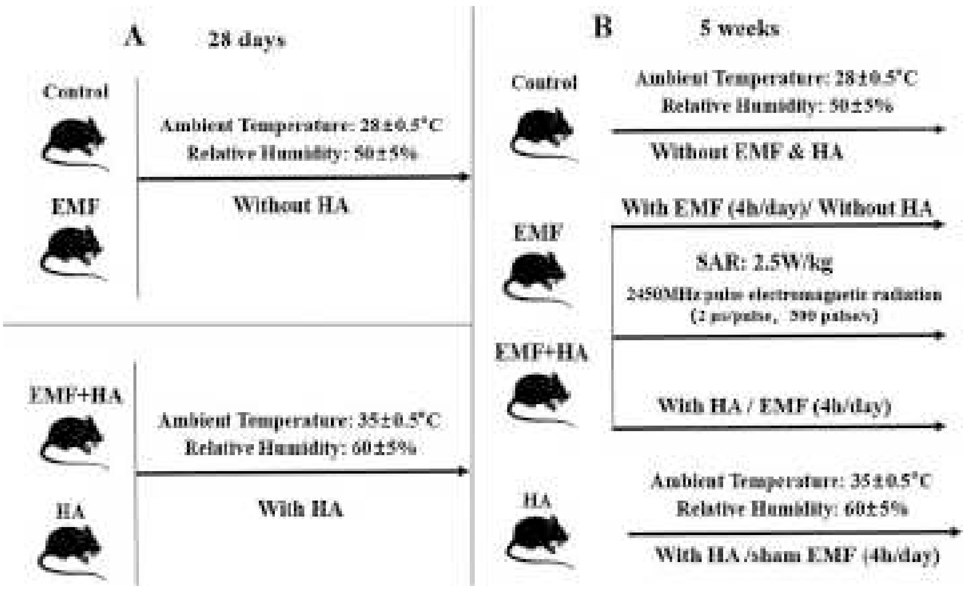

Fig. 1. Research design. A. Mice were randomly divided into four groups: the control group (Control), electromagnetic field exposure group (EMF), electromagnetic field exposure with heat acclimation group (EMF+HA) and heat acclimation group (HA). The process of heat acclimation was 28 days. Mice in the control group (Control) and electromagnetic field exposure group (EMF) were housed at ambient temperature (28 ± 0.5 °C), while heat acclimation group (HA) and electromagnetic field exposure with heat acclimation group (EMF+HA) at the temperature of (35 ± 0.5 °C) with 60 ± 5% humidity reared. B. After the 28 days HA, 5-week EMF exposure model was conducted. The pulsed electromagnetic fields (2450 MHz, 2 μs/pulse, 500 pulses/s) were employed. Experimental animals deposited in a special plexiglass cage that could transmit electromagnetic waves and the long axis of the mouse body should be perpendicular to the long axis of the EMF emitting antenna. Whole body of mice were exposed to EMF (specific absorption rate, SAR: 2.5 W/kg) for 4 h a day with 5 weeks. After exposure, EMF+HA group were returned to artificial climate simulation cabin continuing heat acclimation (temperature: 35 ± 0.5 °C, humidity: 60 ± 5%), while EMF group were returned to ambient temperature (temperature: 28 ± 0.5 °C, humidity: 50 ± 5% humidity). Eliminating the environmental interference caused by the EMF exposure, HA group was also placed in plexiglass cage with sham EMF exposure for 4 h a day with 5 weeks. When animals underwent EMF exposure, the environmental temperature was 28 ± 0.5 °C and humidity was 50 ± 5%.

uninformed observer.

2.2.7. *Forced swimming test*

A glass cylinder with a diameter of 10 cm and height of 20 cm was filled with water up to a level of 10 cm. Temperature was maintained at 23 ± 2 °C. The mice were placed in the middle of the given cylinder and allowed to swim for 6 min. Swimming was monitored for the entire period. However, only the 4-min period toward the end was taken into consideration for result analysis. The duration of immobility was measured by an observer unaware of the groups.

2.3. *16S rRNA gene sequencing & analysis*

DNA was isolated from fecal pellets using an EZNA stool DNA kit according to the instructions of the manufacturer (Omega Biotek, Inc., Norcross, GA). DNA was amplified using universal primers (iTRU-A 515F and iTRU-1 806R) to target the V4 regions of bacterial 16S rRNA. Individual samples were barcoded, pooled to construct the sequencing library and then sequenced (Illumina MiSeq) to generate paired-end 250 × 250 reads. Analysis of 16S rRNA sequencing data was performed by Shanghai Majorbio Biopharm Technology Co., Ltd.

2.4. *Serum metabolomics profiling*

LC-MS analyses were performed using a Vanquish UHPLC system (Thermo Fisher, Waltham, MA, USA) coupled with an Orbitrap Q Exactive series mass spectrometer (Thermo Fisher, Waltham, MA, USA). For the serum samples, mobile phase A was water mixed with 0.1% formic acid, while mobile phase B was 70% isopropanol and 30% acetonitrile containing 0.1% formic acid. The serum samples were eluted under gradient conditions at a flow rate of 400 μl/min with 1% B, which was held for 1 min and then ramped up from 1% to 40% B for 2 min, from 40% to 75% B for 5 min, from 75% to 85% B for 4 min and from 85% to 99% B for 6 min, held at 99% B over 4 min and then returned to 1% B for 3 min. The volume of the sample injected onto the column was 1000 μl.

3. Results

3.1. *EMF exposure did not cause anxiety-like behavior in mice*

We used the open-field test (OFT), elevated plus maze (EPM) and light/dark transition (LDT) test to determine whether there was anxiety-like behavior in mice. The results of the open-field test for distance covered in 5 min travel time by the different groups of animals were analyzed (Fig. 2A). There was no significant effect of the total distance traveled (F = 0.000, $p > 0.05$, Fig. 2B) observed. Moreover, the central square duration (F = 0.132, $p > 0.05$, Fig. 2C) in each group was not significantly different. Time spent by the animals on the open arm of the EPM was considered inversely related to anxiety. Mice in each group spent the same time in the open arms (F = 0.880, $p > 0.05$) and had an equal percentage of entries in the open arms (F = 1.342, $p > 0.05$, Fig. 3A). The light/dark transition (LDT) revealed no significant differences in time in the dark (F = 0.008, $p > 0.05$) with no significant differences in transitions (F = 0.165, $p > 0.05$, Fig. 3B) among the four groups in our study. These results did not indicate anxiolytic-like behavior.

3.2. *EMF exposure caused depression-like behavior, while HA alleviated it*

The tail suspension test (TST) and forced swimming test (FST) were used to assess depressive-like behaviors in mice. Enhanced immobility in both the TST and FST was considered a measure of behavioral despair. TST results revealed significant differences in mobility among the four groups of mice (F = 23.484, $p < 0.001$). Data analyses proved that mice with EMF exposure demonstrated significantly more immobility (49.071 s (31.34–66.79 s)) during the TST than control mice ($p < 0.001$). Administration of HA significantly decreased the immobility period (−36.66 s (−55.06 s to −18.27 s)) compared to that of the EMF group ($p < 0.001$, Fig. 3C). To confirm the TST results, we analyzed immobility duration using the FST and found that there were significant differences between the four groups in the FST (F = 80.254, $p < 0.001$). Analyses showed that mice with EMF exposure remained immobile for a significantly longer period of time than control mice ($p < 0.001$).

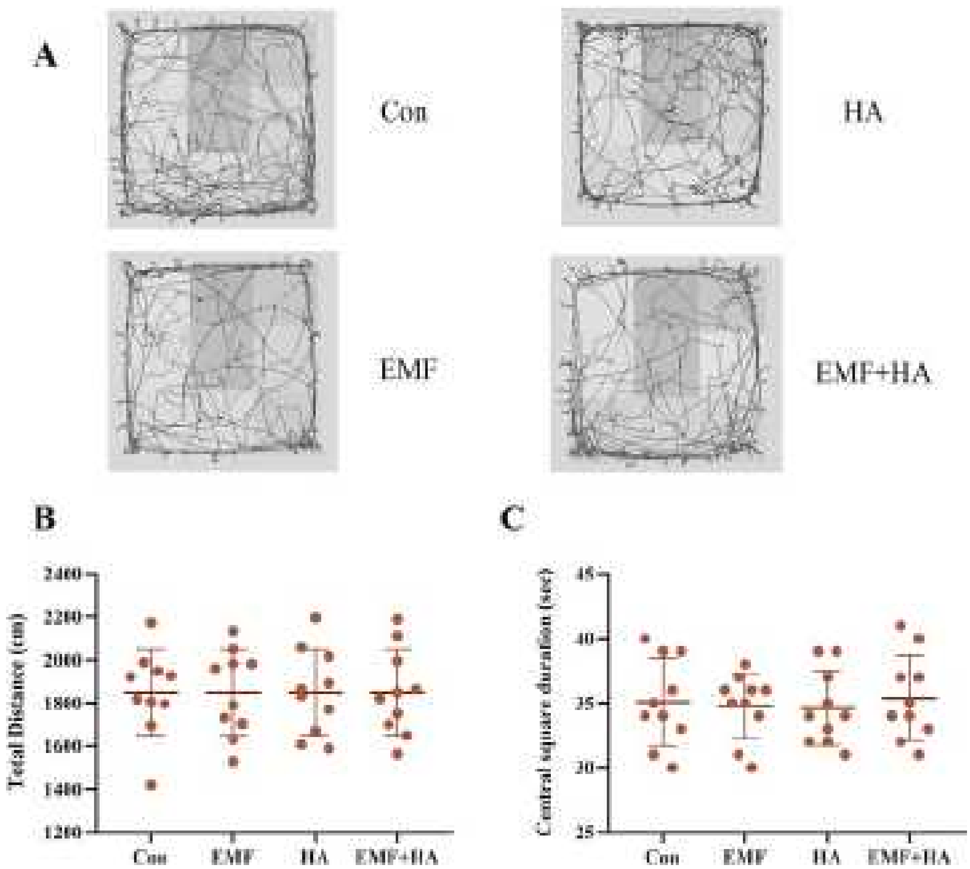

Fig. 2. Effects of HA on mice with EMF exposure in the open-field test (OFT). A. The open-field test for distance covered in 5 min travel time by the different groups. The locomotion track in the four groups. B. The total distance of each group had no significant differences (F = 0.000, $p > 0.05$). C. The central square duration in each group had no significant difference (F = 0.132, $p > 0.05$). Data represented as mean ± SEM (n = 10).

Administration of HA markedly reduced the duration of immobility in the FST in the EMF+HA group ($p < 0.001$, Fig. 3D). Therefore, HA ameliorated depression-like mental behavior disorder caused by chronic exposure to electromagnetic radiation.

3.3. EMF exposure causes disorder of the gut microbiome and increases depression-related metabolites

3.3.1. EMF induced changes in the gut microbiota

The OTU sequence number of each sample was normalized according to the minimum quantity of OTU sequences (CON_1:35149). Alpha diversity was determined by the analysis of species diversity in a single sample, including community diversity and richness. Shannon and Simpson indices were used to describe community diversity. There was no significant difference in community diversity between the control group and EMF group ($p > 0.05$, Wilcoxon sum test). ACE and Chao 1 indices were used to describe community richness. There was no significant difference in community richness between the control group and EMF group ($p > 0.05$, Wilcoxon sum test). Alpha diversity showed no significant difference between the control group and EMF group. Nonmetric multidimensional scaling (NMDS), based on Bray-Curtis distance, showed that EMF subjects were clearly separated from control subjects ($p = 0.003$, stress = 0.074, R = 0.48, ANOSIM for Bray-Curtis distances).

At the phylum level, the dominant bacteria in the control group were *p_Bacteroidota* (accounting for 77.5%), followed by *p_Firmicutes* (accounting for 22.4%). The dominant bacteria in the EMF group were *p_Bacteroidota* (accounting for 56.8%), followed by *p_Firmicutes* (accounting for 43.0%). The genus level analysis showed that *f_Muribaculaceae* and *g_Lactobacillus* were significantly decreased, while *g_Lachnospiraceae_NK4A136* and *g_Bacteroides* were significantly increased in EMF subjects (Fig. 4D, E).

Differentially abundant taxa were further confirmed by LEfSe analysis (Segata et al., 2011). The results are shown in Fig. 5B, and multiple genera were present in significantly different abundances in the gut microbiome between the EMF and control groups. These included *g_Butyricicoccus* (LDA = 3.65, $p = 0.032$), *g_Lachnospiraceae_NK4A136_group* (LDA = 4.94, $p = 0.022$), *g_Anaerotruncus* (LDA = 3.84, $p = 0.032$), *g_Lachnospiraceae_UCG-006* (LDA = 3.84, $p = 0.032$), *g_Bilophila* (LDA = 3.83, $p = 0.045$), and *g_Tuzzerella* (LDA = 3.80, $p = 0.022$, Fig. 5B).

3.3.2. EMF induced disturbance in the metabolite profiles of serum samples

Since 16S rRNA sequencing revealed that the gut microbiome had significantly changed with EMF exposure, we further examined whether the serum metabolomes were perturbed with EMF exposure using untargeted LC-MS in both positive ion (ES+) and negative ion (ES-) modes. To identify the differential metabolites associated with EMF exposure, we calculated fold changes (FCs), p values and PLS-DA variable importance in the projection (VIP) scores for all metabolic features in EMF vs. control. In total, 22 significant metabolic features (FC ≥ 2 or ≤ 0.5, $p \leq 0.05$, and VIP > 1) were found (Table 1), including cholesterol, ketoleucine, formylanthranilic acid, maleic acid, D-fructose, fumaric acid, phenylacetylglycine, dodecanoic acid, 4-hydroxycinnamic acid and sedoheptulose 7-phosphate. Except for fumaric acid, which was significantly downregulated in the EMF group, the other 9 different metabolites were significantly upregulated with EMF exposure (Table 1). Fig. 6A presents 20 differential metabolites.

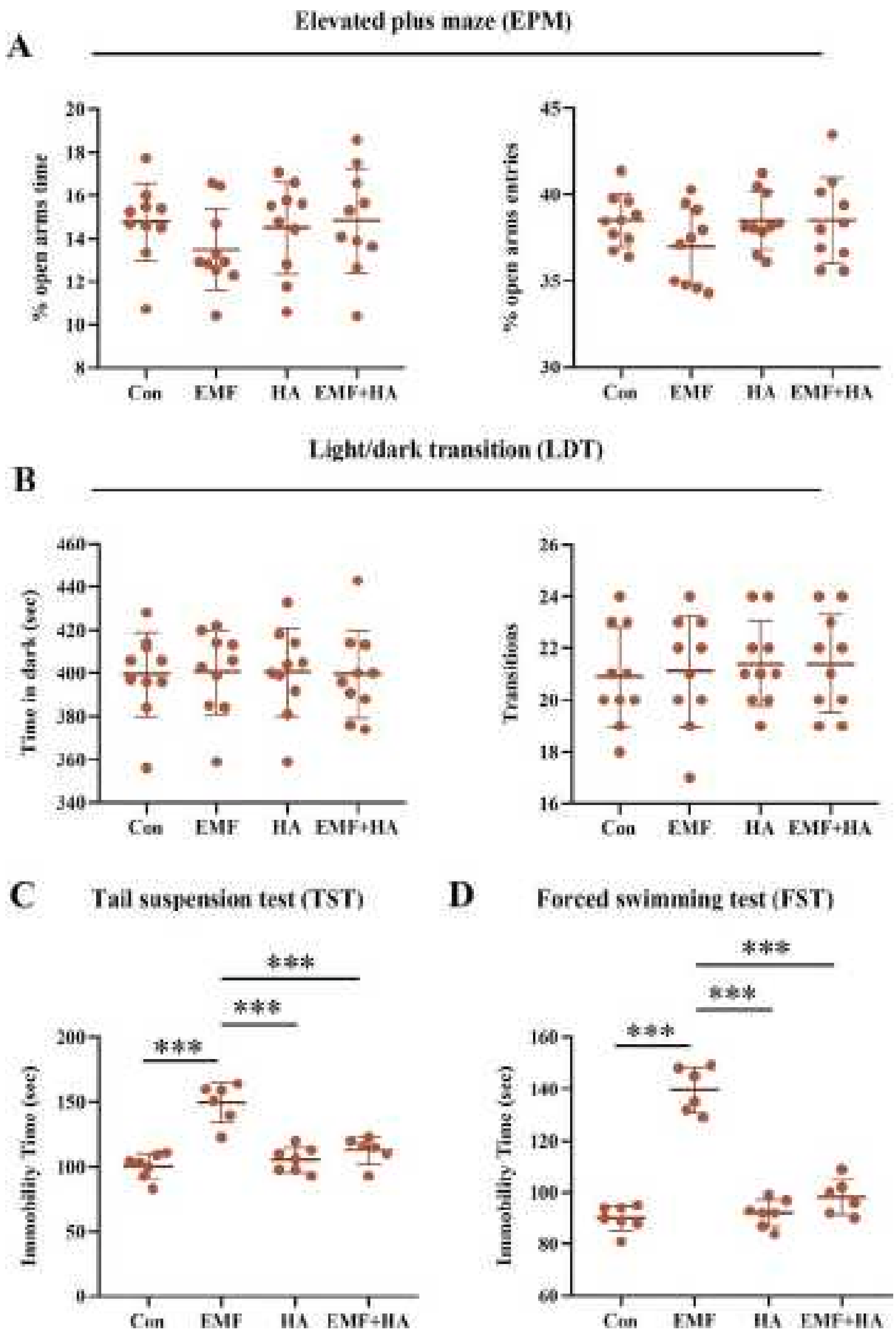

Fig. 3. Effects of HA on mice with EMF exposure in the behavioral experiments. A. Behavior shown by the four groups of animals in the elevated plus-maze test (EPM) test. Mice in each group spent same time in the open arms and had equal percentage of entries in the open arms. B. Behavior shown by the four groups of mice in the light/dark transition (LDT) test. There were no significant differences in time in the dark with no significant differences in transitions among the four groups. C. The mice with EMF exposure exhibited more immobility time on the TST, and this effect could be reversed by treatment with HA. D. The immobility time of mice with EMF exposure was more on the FST and this effect could be reversed by treatment with HA. Data are represented as mean ± SEM (n = 10). ***, $p < 0.001$.

3.4. HA remodeling of gut microbiota disorders caused by EMF exposure

3.4.1. Community composition analysis of the gut microbiota

Phylum level. The predominant bacterial phyla in all the samples were *p_Firmicutes* and *p_Bacteroidota*. Fig. 4A shows the percent abundance range for *p_Firmicutes* and *p_Bacteroidota* for various experimental groups. EMF exposure caused a significant reduction in *p_Bacteroidota*. Treatment with HA inhibited these changes. NMDS based on Bray-Curtis distances showed that different groups were clearly separated ($p = 0.001$, stress = 0.173, R = 0.563, ANOSIM for Bray-Curtis distances, Fig. 4B). To explore the relationship between the gut microbiota community composition and environmental characteristics, redundancy analysis (RDA) was used. RDA revealed that the gut microbiota community composition was formed by environmental characteristics, including temperature (T) and EMF exposure (E). Compared with temperature (T, $R^2 = 0.11$, $p = 0.267$), the effect of the EMF (E, $R^2 = 0.44$, $p = 0.002$) was more significant (Fig. 4C).

3.4.2. Community composition differences in the gut microbiota

The genus-level analysis showed that HA could balance the community composition under exposure to the EMF (Fig. 4E). *g_Lactobacillus* (a major probiotic, $p = 0.01842$, *corrected p-value* = 0.1413), *g_norank_f_norank_o_Clostridia_UCG-014* ($p = 0.003405$, *corrected p-value* = 0.0893), *g_norank_f_Oscillospiraceae* ($p = 0.02681$, *corrected p-value* =

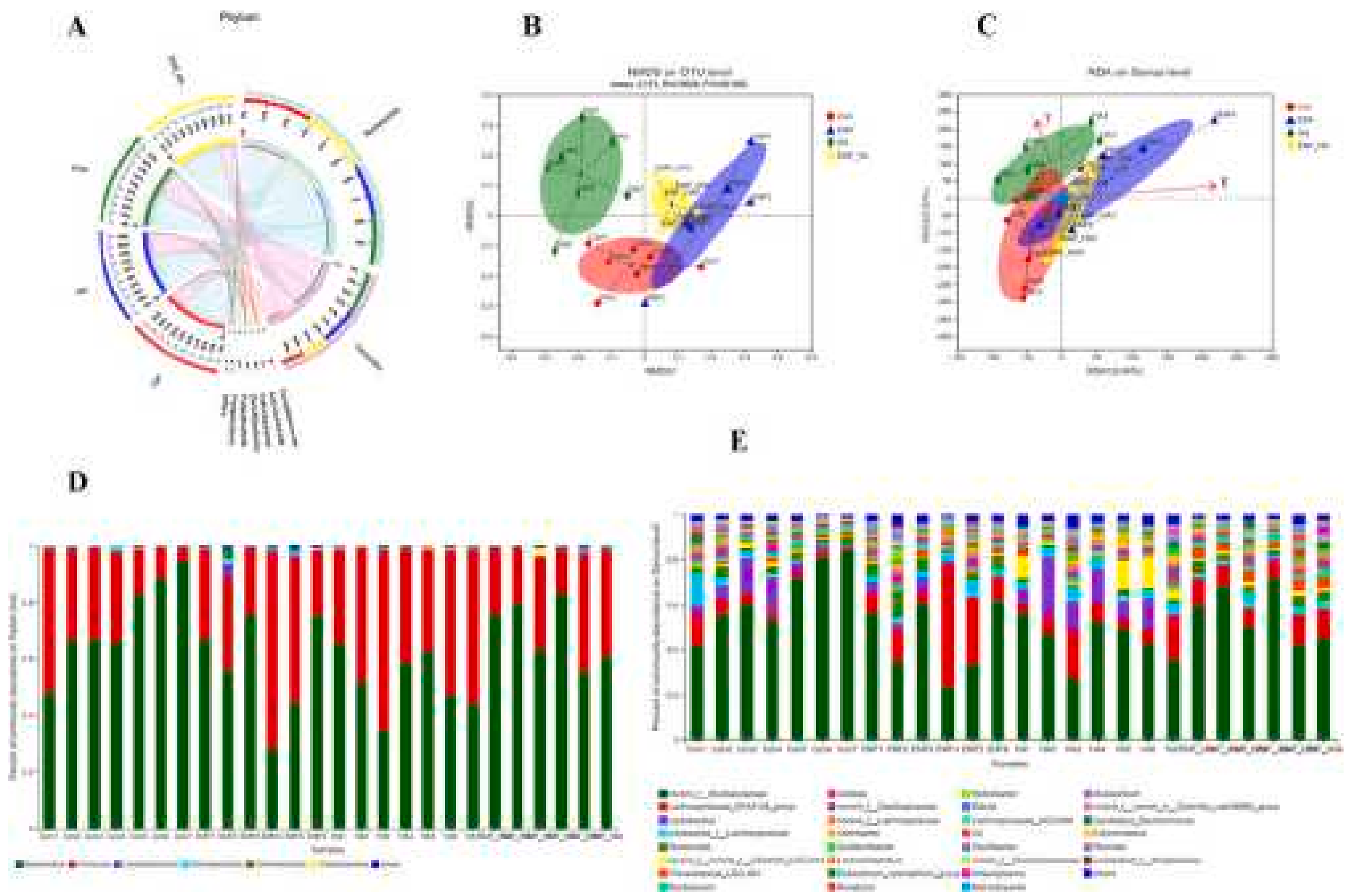

Fig. 4. Community composition of the gut microbiota. A. Relative abundance at the phylum level in each group. B. Beta diversity assessed by Nonmetric Multidimensional Scaling (NMDS), based on Bray-Curtis. Anosim tests show statistically significant differences among these groups. C. Redundancy analysis (RDA) of gut microbiota (symbols) and environmental characteristics (arrows). D. Relative community abundance at the phylum level in each sample. E. Relative community abundance at the genus level in each sample.

0.1413), *g_Odoribacter* ($p = 0.03832$, *corrected p-value* $= 0.1413$), and *g_Colidextribacter* ($p = 0.008133$, *corrected p-value* $= 0.1066$) were significantly increased, while *g_Alistipes* ($p = 0.003405$, *corrected p-value* $= 0.0893$) was significantly decreased in the EMF+HA group compared with the EMF group (Fig. 5C).

3.5. HA alleviated depression-related serum metabolite disturbance caused by EMF exposure

To identify the differential metabolites between the EMF and EMF+HA groups, we calculated fold changes (FCs), *P* values and PLS-DA variable importance in the projection (VIP) scores for all metabolic features in EMF vs. EMF+HA. In total, 56 significant metabolic features (FC ≥ 2 or ≤ 0.5, P ≤ 0.05, and VIP > 1) were found (Table 2). Compared with EMF exposure, HA balanced serum metabolite disturbance (Fig. 6A). These metabolites were classified as Kyoto Encyclopedia of Genes and Genomes (KEGG) compounds. The hormone and transmitter groups included 4 kinds of neurotransmitters and 2 kinds of steroid hormones. Lipids involved were eicosanoids and fatty acids. Among them, there was 1 eicosanoid and 16 fatty acids. Organic acids are carboxylic acids and there were 18 such compounds in the analysis. The peptides included amines, amino acids and peptides. Among them, there were 3 kinds of amine compounds, 23 kinds of amino acid compounds and 2 kinds of peptide compounds (Tables 1, 2).

To further understand these metabolic changes at the pathway level, we performed pathway enrichment analysis. The following metabolic pathways were significantly changed: Metabolic pathways (map01100, Number of metabolite: 42); ABC transporters (map02010, Number of metabolite: 8); Protein digestion and absorption (map04974, Number of metabolite: 5); Vitamin digestion and absorption (map04977, Number of metabolite: 5); Tryptophan metabolism (map00380, Number of metabolite: 4); Central carbon metabolism in cancer (map05230, Number of metabolite: 4); Fructose and mannose metabolism (map00051, Number of metabolite: 3); Pyrimidine metabolism (map00240, Number of metabolite: 3); Cysteine and methionine metabolism (map00270, Number of metabolite: 3); Histidine metabolism (map00340, Number of metabolite: 3); Tyrosine metabolism (map00350, Number of metabolite: 3); Phenylalanine metabolism (map00360, Number of metabolite: 3); Metabolism of xenobiotics by cytochrome P450 (map00980, Number of metabolite: 3); Carbon metabolite (map01200, Number of metabolite: 3); Biosynthesis of amino acids (map01230, Number of metabolite: 3) and other related pathways (Fig. 6C).

The markedly different metabolic pathways ($Q < 0.05$) were analyzed with PICRUSt and include the following: energy production and conversion, carbohydrate transport and metabolism, amino acid transport and metabolism, nucleotide transport and metabolism, lipid transport and metabolism, inorganic ion transport and metabolism (Fig. 6B). Both the metabolic pathway analysis of differential metabolites and the PICRUSt functional prediction of gut microbiota results highlighted tryptophan metabolism, pyrimidine metabolism, cysteine and methionine metabolism, histidine metabolism, tyrosine metabolism and phenylalanine acid metabolism, amino acid biosynthesis and other related pathways. This result suggested that changes in these metabolic pathways may be an important way in which HA improves depression-like behaviors caused by EMF exposure and that the gut microbiota plays an essential role.

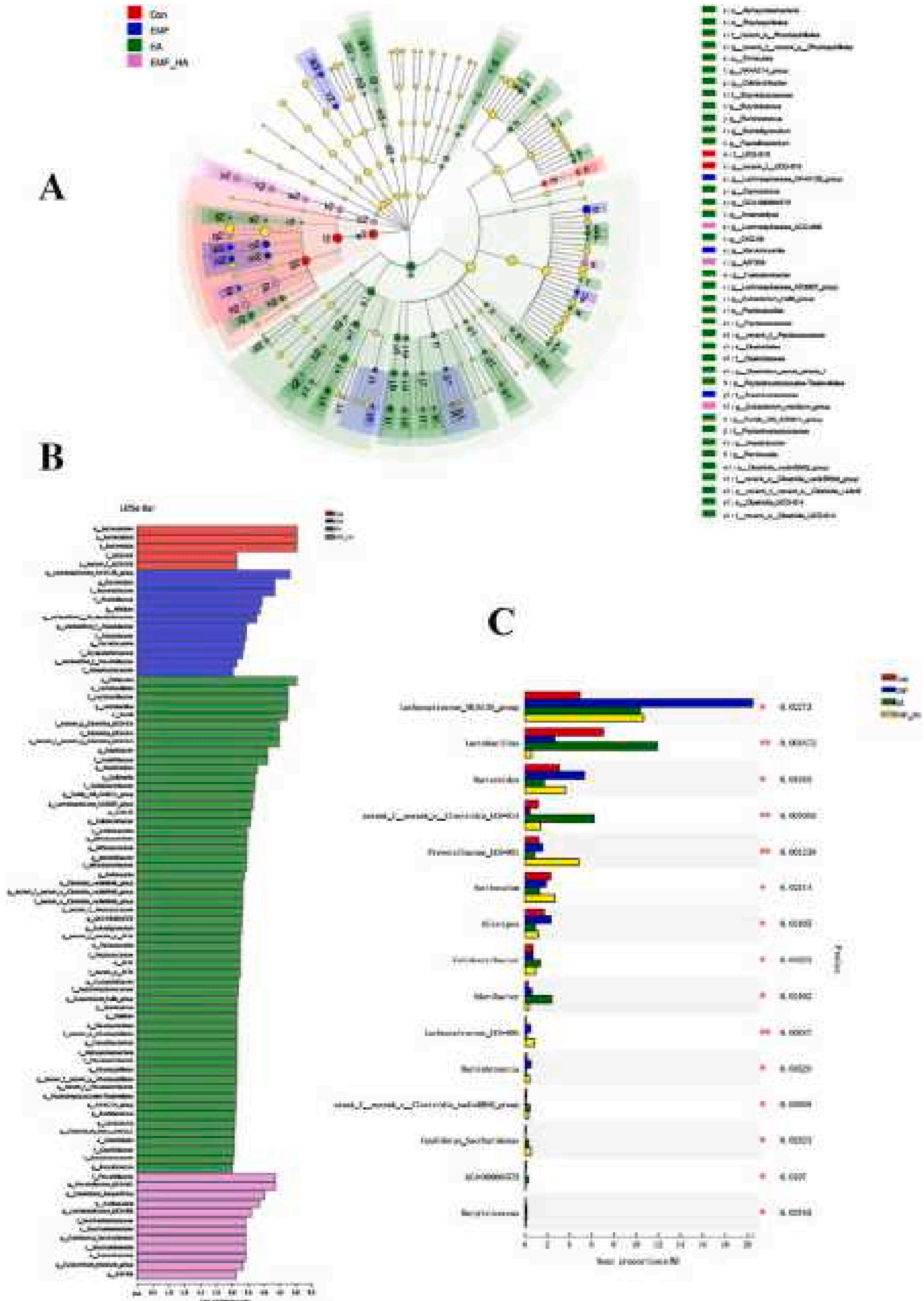

Fig. 5. The composition difference of gut microbiota in each group. A. The composition cladogram with microbial differences in each group. B. Differential bacterial taxonomy selected by LEfSe analysis with LDA score > 2 in microbiota. C. Differentiated gut microbiome in each group.

Table 1
List of significantly changed metabolites in the EMF group.

	mean_Con	sd_Con	mean_EMF	sd_EMF	Fold Change	log2 (FC)	p.value	FDR
Ketoleucine	13557745	9987354	42109179	9537258	0.322	-1.635	0.000275	0.0764
Formylanthranilic acid	1060665	225981.3	2230218	610776.3	0.476	-1.072	0.000618	0.0859
D-Fructose	7438820	2747047	29549500	15186521	0.252	-1.99	0.00291	0.269
Dodecanoic acid	1.22E+08	30865425	1.95E+08	43748231	0.629	-0.669	0.00512	0.356
Cholesterol	205.492	0	3.67E+08	3.04E+08	0	-20.767	0.00826	0.428
Gluconic acid	4.91E+08	1.04E+08	3.3E+08	86494554	1.489	0.574	0.0119	0.428
Phenylacetic acid	4336659	1443703	6517230	1183502	0.665	-0.588	0.0134	0.428
Sedoheptulose 7-phosphate	2293697	703223.3	3551024	859243.1	0.646	-0.631	0.0143	0.428
Maleic acid	1.44E+08	43019261	3E+08	1.36E+08	0.479	-1.061	0.0146	0.428
Fumaric acid	3976940	1435102	2105986	748998.8	1.888	0.917	0.0154	0.428
D-Mannose	5409433	517759.6	6458740	831366.2	0.838	-0.256	0.0179	0.451
Pimelic acid	1.39E+08	8320126	1.5E+08	4905277	0.929	-0.106	0.0195	0.451
2-Dehydropantoate	8187159	1024773	6864637	741629	1.193	0.254	0.0238	0.509
4-Hydroxycinnamic acid	82988153	71290206	3.15E+08	2.42E+08	0.263	-1.927	0.033	0.53
Phenylacetylglycine	41457716	13219368	79187282	39815664	0.524	-0.934	0.0369	0.53
N-Formyl-L-glutamic acid	4688155	1287652	6814099	1942447	0.688	-0.54	0.0377	0.53
Imidazole-4-acetaldehyde	8653720	1207952	6375274	2228077	1.357	0.441	0.0389	0.53
Oxalacetic acid	1.02E+08	39997079	62312192	9522185	1.631	0.706	0.0394	0.53
Quercetin	46502840	2510558	51005127	4429505	0.912	-0.133	0.0419	0.53
(R)-3-Hydroxybutyric acid	36030298	15803514	50875887	3442919	0.708	-0.498	0.0465	0.53
1-Methylxanthine	1318483	117432.8	1097146	230844.3	1.202	0.265	0.0473	0.53
Lathosterol	99675324	60531305	3.15E+08	2.51E+08	0.316	-1.662	0.0487	0.53

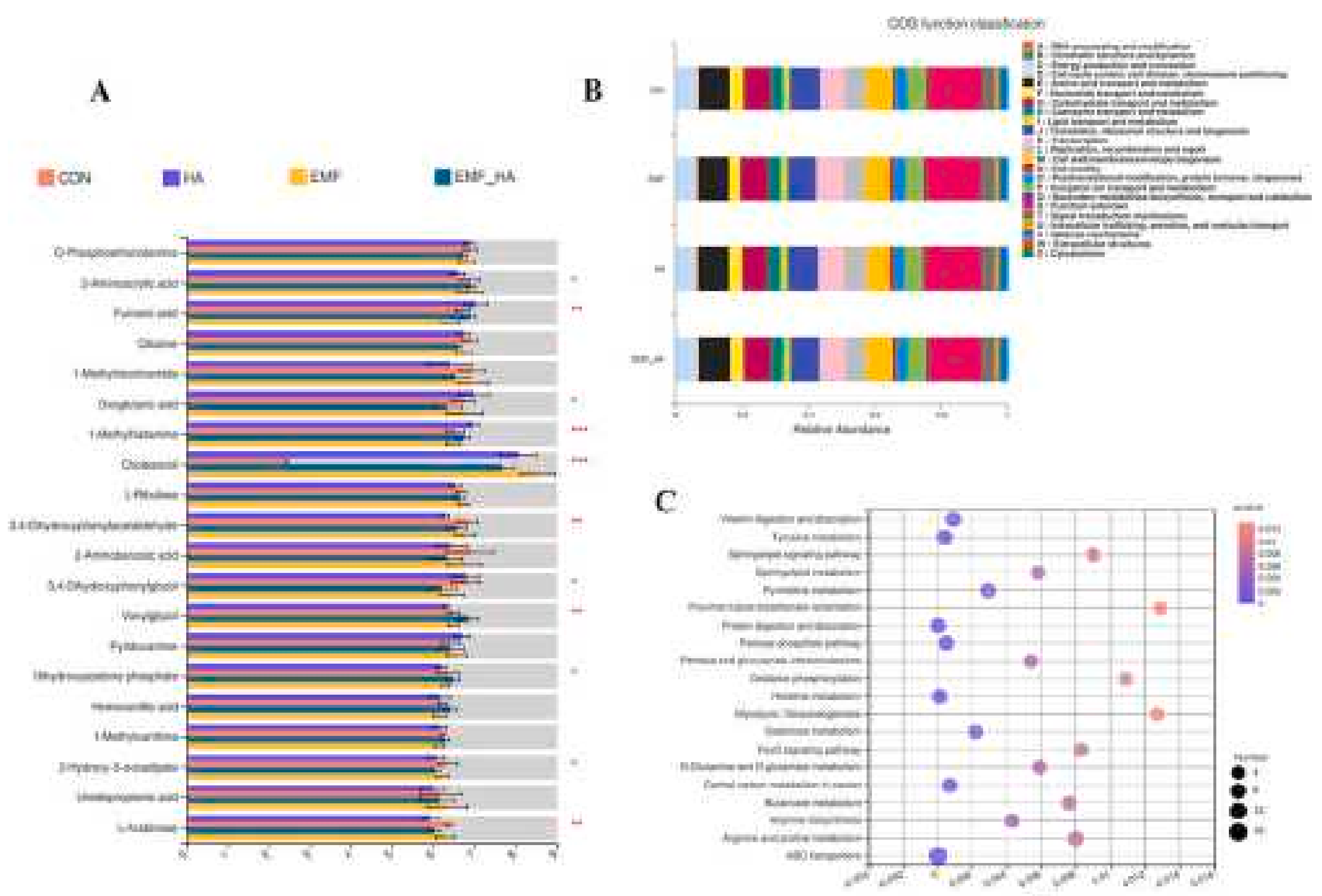

Fig. 6. Differential serum metabolites. A. The Kruskal-Wallis H test of differential serum metabolites. B. Prediction of serum metabolite function with PICRUSt. C. KEGG pathway enrichment analysis.

Table 2
List of significantly changed metabolites in the EMF with HA group.

	mean_EMF	sd_EMF	mean_EMF+HA	sd_EMF+HA	Fold Change	log2 (FC)	*p*.value	FDR	VIP
Ketoleucine	3.15E+08	2.51E+08	22499470	20838811	14.017	3.809	0.0173	0.171	1.566
Putrescine	3.67E+08	3.04E+08	40404925	50035431	9.077	3.182	0.0269	0.191	1.483
2-Dehydropantoate	42109179	9537258	5448375	5481740	7.729	2.95	9.86E-06	0.00274	2.181
Thymidine	40458846	28798503	6037831	2374788	6.701	2.744	0.0154	0.164	1.586
Eicosadienoic acid	46970616	33948237	8995730	4033056	5.221	2.384	0.0215	0.191	1.525
4-Oxoproline	9701122	6380189	2626945	1936913	3.693	1.885	0.0265	0.191	1.485
Guanidoacetic acid	2.84E+08	2E+08	77066743	58174506	3.688	1.883	0.0353	0.202	1.426
Se-Methylselenocysteine	3.43E+08	2.09E+08	96155905	1.12E+08	3.57	1.836	0.0286	0.192	1.47
Methyl beta-D-galactoside	1687451	795802	635411.2	194344.6	2.656	1.409	0.0104	0.147	1.649
2-Keto-6-aminocaproate	21348132	11432262	8619585	1509186	2.477	1.308	0.0222	0.191	1.52
L-Kynurenine	24448917	12510853	11058313	2259951	2.211	1.145	0.0274	0.191	1.478
Niacinamide	54441030	26016108	25079263	12984822	2.171	1.118	0.0329	0.199	1.441
Folic acid	4.88E+08	2.4E+08	2.28E+08	42018380	2.143	1.099	0.026	0.191	1.489
N-Carbamoylputrescine	5387896	2550829	2521743	1359418	2.137	1.095	0.0355	0.202	1.425
4-Guanidinobutanal	13839849	2462334	7057165	3035022	1.961	0.972	0.00169	0.0938	1.876
Cytidine	1377753	449631.9	712025.4	245448	1.935	0.952	0.00976	0.147	1.659
2-Hydroxy-3-oxoadipate	3E+08	1.36E+08	1.55E+08	64794517	1.932	0.95	0.0404	0.218	1.396
L-Arabinose	65129673	12166214	37213701	13348391	1.75	0.807	0.00357	0.115	1.795
N-Formyl-L-methionine	1.63E+08	67209803	93652299	22805217	1.745	0.803	0.0368	0.205	1.417
D-Ribose	71996977	22522340	44191264	11552218	1.629	0.704	0.0227	0.191	1.516
Fumaric acid	18900531	2273132	11732775	852645	1.611	0.688	2.82E-05	0.00392	2.143
D-Mannose	1.69E+10	3.65E+09	1.05E+10	5.75E+09	1.607	0.684	0.0441	0.219	1.377
Hydrogen phosphate	12767309	3903506	7983098	2324926	1.599	0.677	0.0274	0.191	1.478
Sucrose	15545286	2399047	9826436	1733432	1.582	0.662	0.000801	0.0556	1.945
Palmitic acid	27529590	7928625	17579666	7004914	1.566	0.647	0.044	0.219	1.377
Inosine	3.36E+08	75144817	2.17E+08	63989019	1.548	0.63	0.0144	0.16	1.597
3-Hydroxyphenylacetic acid	2283694	200400.5	1505173	633303.3	1.517	0.601	0.0166	0.171	1.572
Lathosterol	52099839	15188176	34790758	10354949	1.498	0.583	0.0438	0.219	1.378
UMP	3551024	859243.1	2373671	559849	1.496	0.581	0.0184	0.171	1.554
Sedoheptulose 7-phosphate	10939302	1133576	7827837	2910869	1.397	0.483	0.0349	0.202	1.429
2-Naphthol	21169437	3179682	15803033	942038.5	1.34	0.422	0.00267	0.115	1.828
Guanosine	58177826	8563157	44352192	11692339	1.312	0.391	0.0416	0.218	1.39
Adenosine	23831609	4779105	18183600	2847463	1.311	0.39	0.0322	0.199	1.446
L-Carnitine	12244273	1664254	9384327	1173027	1.305	0.384	0.00633	0.126	1.722
Acetylphosphate	3.43E+08	63240912	2.63E+08	54761929	1.304	0.383	0.0408	0.218	1.394
Indolepyruvate	92445158	11648876	72398594	9294820	1.277	0.353	0.00808	0.14	1.687
1-Methylnicotinamide	16228129	2964455	12780440	1301690	1.27	0.345	0.0261	0.191	1.488
Cholesterol	50490032	8482762	39758450	6148101	1.27	0.345	0.031	0.196	1.454
Uric acid	7059540	932662.2	5565286	900114.7	1.268	0.343	0.018	0.171	1.558
GMP	92901461	15309906	73397248	5042699	1.266	0.34	0.0142	0.16	1.599
Butyric acid	68166162	7702257	55443384	6496494	1.23	0.298	0.0114	0.147	1.635
Phthalate	6458740	831366.2	5265719	471670.4	1.227	0.295	0.0121	0.147	1.626
3-Dehydroshikimate	14919402	487154.1	13062847	1120240	1.142	0.192	0.00396	0.115	1.782
Pseudouridine	6.99E+09	7.25E+08	6.16E+09	2.3E+08	1.134	0.182	0.0236	0.191	1.508
(R) 2,3-Dihydroxy-3-methylvalerate	8301519	156105.6	8931539	585565	0.929	-0.106	0.029	0.192	1.467
N-Acetyldemethylphosphinothricin	7.55E+08	2.17E+08	1.08E+09	57775876	0.697	-0.521	0.00495	0.115	1.754
CMP	6864637	741629	10098170	1077362	0.68	-0.557	0.000123	0.0114	2.073
Quinolinic acid	2586033	1207668	4792935	1236533	0.54	-0.89	0.0107	0.147	1.645
3,4-Dihydroxyphenylacetaldehyde	688405.7	306227.6	1565816	633233.5	0.44	-1.186	0.0121	0.147	1.625
Saccharopine	2105986	748998.8	4892561	2078362	0.43	-1.216	0.0115	0.147	1.634
Maleic acid	5020768	2269353	15262667	7194074	0.329	-1.604	0.00767	0.14	1.695
L-Histidine	67750704	26377973	2.08E+08	87563726	0.326	-1.617	0.00378	0.115	1.788
all-trans-Retinoic acid	2977815	1700889	9817480	4266513	0.303	-1.721	0.00448	0.115	1.767
Citric acid	1656431	447281.5	5653697	2687767	0.293	-1.771	0.0049	0.115	1.756
Pyrrolidonecarboxylic acid	11538653	9665587	49547858	25283399	0.233	-2.102	0.00634	0.126	1.722
Dehydroepiandrosterone	15965241	13747287	82655531	63204907	0.193	-2.372	0.0301	0.195	1.459

4. Discussion

Our living environment has been increasingly polluted by EMFs, while the central nervous system is vulnerable to these adverse effects. Epidemiological studies suggest that long-term EMF exposure could cause sleep disorders, headaches, fatigue, memory loss (Jiang et al., 2015). EMF exposure could even lead to cognitive behavior disorders, such as depression and anxiety (Genuis, 2008). It was not clear whether EMFs, as a physical environmental factor, could cause central nervous system dysfunction in experimental animals. In our study, after 5 weeks of continuous intermittent EMF exposure, we found that the mice had depression-like neurobehavioral changes (Fig. 2). Additionally, 16S rRNA gene sequencing was used to reveal the community composition of the gut microbiota. EMF exposure significantly influenced the beta diversity instead of alpha diversity of the gut microbiota.

The correlation between the gut microbiota and depression has been scientifically confirmed (Collins and Bercik, 2009; Kleiman et al., 2017). The community composition of the gut microbiota in depressed patients or animals is significantly different from that in regular control groups. Fecal microbiota transplantation (FMT) from donors of depression patients can even induce depression-like behavior in sterile rats. This further proves that gut microbiota and depression have a direct relationship. In Jiajia Duan's research, depressed animals exhibited gut microbiomes that were depleted in members of the family *Lactobacillaceae* (Jiajia et al., 2021). In our study, EMF exposure not only caused depression-like neurobehavioral disorders but also significantly depleted g_*Lactobacillus*. We speculated that an imbalanced composition of the gut microbiota with EMF exposure might be one of the most important factors for depression-like symptom occurrence.

It has not been previously reported that HA can alleviate central nervous system dysfunction associated with EMF exposure. In our study, HA alleviated depression-like factors (Fig. 3) and the EMF exposure lasted 5 weeks. To maintain the community composition of the gut microbiota established by HA, we continued to maintain the HA environment after daily EMF exposure.

Both EMF and HA regulated the ratio of *p_Firmicutes* and *p_Bacteroidota*. LEfSe was carried out to identify differentially abundant bacterial taxa among all groups. EMF exposure caused the proportion of 6 kinds of bacteria to change significantly, including those of *g_Butyricicoccus* and *g_Anaerotruncus*. HA restored the imbalance of gut microbes caused by EMF exposure, and the proportion of probiotics (*g_Lactobacillus*) increased significantly. RDA revealed that as an environmental characteristic, the effect of EMF was more significant than that of temperature. Yang et al. found that long-term exposure to high environmental temperature could affect the gut microbiome in mice. In their study, genus-level analysis showed that the genus Lactobacillus (a major probiotic) was significantly increased, which was consistent with our findings. *Bacillus subtilis* has been used for the prevention of heat stress by maintaining intestinal permeability and microbial structure, as well as reducing bacterial translocation (Moore et al., 2014; Sorokulova et al., 2016). In our study, *Bacillus subtilis* was not found, but *Clostridia* was found to be increased.

Growing evidence indicates that the gut microbiota affects not only gastrointestinal function but also central nervous system (CNS) physiology and behavior by regulating the microbiota-gut-brain axis (Evrensel and Ceylan, 2015; Foster and Mcvey Neufeld, 2013; Leclercq et al., 2020; Luna and Foster, 2015; Luna et al., 2015). Concerning the metabolome, existing data on depression have uncovered altered metabolic pathways and metabolites in urine, plasma and hippocampal samples from clinical subjects and animal models (Su et al., 2011, 2014; Zheng et al., 2012). Several metabolites that have been shown to be altered with depression include hippuric acid, tryptophan, phenylalanine (Machado et al., 2012; Bansal et al., 2018). These are metabolic byproducts of the gut microbiota. In our study, EMF induced disturbance in the metabolite profiles of serum samples. Significantly different metabolites included cholesterol, D-fructose and fumaric acid and these were associated with depression (Xiong et al., 2020). Based on KEGG classification, the metabolites involved in neurotransmitters and steroids were altered significantly. HA alleviated depression-related serum metabolite disturbance caused by EMF exposure. Metabolic pathways involved in HA were protein digestion and absorption, vitamin digestion and absorption, tryptophan metabolism, pyrimidine metabolism, tyrosine metabolism, phenylalanine metabolism, amino acid biosynthesis. Valine, leucine and isoleucine are essential branched-chain amino acids, and their biosynthetic pathways play an important role in the stress response and energy metabolism balance. Both the metabolic pathway analysis of differential metabolites and the PICRUSt functional prediction of gut microbiota pointed to tryptophan metabolism, pyrimidine metabolism, cysteine and methionine metabolism, histidine metabolism, tyrosine metabolism and phenylalanine acid metabolism, amino acid biosynthesis and other related pathways as being important. This result suggested that changes in these metabolic pathways may be an important factor in the improvement of depression-like behaviors caused by EMF via HA and that the gut microbiota plays an essential role.

This study had limitations. To characterize the effects of HA on depression-like disorders linked to the gut microbiota, fecal and serum samples were collected and sequenced only at the end of the experiment. However, both EMF exposure and HA were long-term chronic processes. The gut microbiomes and serum metabolites might have been explored at additional time points for more reliable and precise results using both comparative and longitudinal analyses. Although 16S rRNA gene sequencing technology was beneficial for microbiome studies, it provided low resolution at the species level and insufficient discriminatory power for some genera. Ideally, whole-metagenome shotgun sequencing would be a better choice for obtaining more accurate information. Although we found depression-related gut microbiota and serum metabolites, exploration of the correlation between the gut microbiota and serum metabolites was lacking and should be performed in the future. The findings in this study were correlational and did not support a causal relationship between gut microbiota and EMF exposure or HA, indicating a lack of sufficient evidence to distinguish the gut microbiota as a cause or consequence of the effects following EMF exposure or HA. Future studies using strategies such as fecal microbiota transplantation (FMT) are necessary to elucidate the underlying causality.

Nevertheless, our study demonstrated that EMF exposure could not only lead to neurobehavioral disorders such as depression, but also cause gut microbiota imbalance. HA alleviated the depression features caused by EMF exposure, providing an example of cross-tolerance. Based on the analysis between gut microbiota and serum metabolites, we speculated that gut microbiota might play an important role in the cross-tolerance of HA.

5. Conclusion

Depression- and anxiety-like behaviors were detected by behavioral experiments. EMF exposure could lead to depression-like neurobehavioral disorders. HA alleviated the depression features caused by EMF exposure. Both EMF and HA regulated the ratio of *p_Firmicutes* and *p_Bacteroidota*. EMF exposure caused the proportion of 6 kinds of bacteria, such as *g_Butyricicoccus* and *g_Anaerotruncus,* changing significantly. HA restored the imbalance of gut microbes caused by EMF exposure and the proportion of probiotics (*g_Lactobacillus*) increased significantly. Serum metabolite analysis suggested that HA alleviated the disturbance of serum metabolites (such as cholesterol and D-mannose) induced by EMF exposure. Both the metabolic KEGG pathways and PICRUSt functional analysis indicated that tryptophan metabolism, pyrimidine metabolism and amino acid biosynthesis were involved.

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Author statement

Manuscript by Xueyan Huang, Zhen Luo, Zeze Wang, Genlin He, Yulong Tan, Boyi Zhang, Huan Zhou, Ping Li, Tingting Shen, Xueting Yu, Xue Luo, Xuesen Yang and entitled "Electromagnetic fields exposure induced depression features could be alleviated by heat acclimation base on remodeling gut microbiota", which is submitted for possible publication in *Environmental Pollution.* This paper is new. Neither the entire paper nor any part of its content has been published or has been accepted elsewhere. It is not being submitted to any other journal.

Code availability

Not applicable.

Authors' contributions

The Author X.L. and XS.Y. conceived the study, designed and performed the experiments, analyzed the data and wrote the manuscript; Z. L., GL.H., ZZ.W., YL.T. and XY.H. performed experiments, and analyzed the data; YL.T., BY.Z., H.Z., P.L., TT.S., ZZ. W., and XT.Y. were involved in data generation. X.L. conceived the study and revised the manuscript. XS.Y. supervised experimental design and revised the manuscript. All authors reviewed the manuscript.

Ethics approval

The animal study was reviewed and approved by the Experimental Animal Ethics Committee of Army Medical University.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and material

The raw sequences used in this study were stored on the Sequence Read Archive (SRA) of NCBI, and the SRA accession number was SRP329366. Bioproject accession number was PRJNA748853.

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Review

Electromagnetic radiation as an emerging driver factor for the decline of insects

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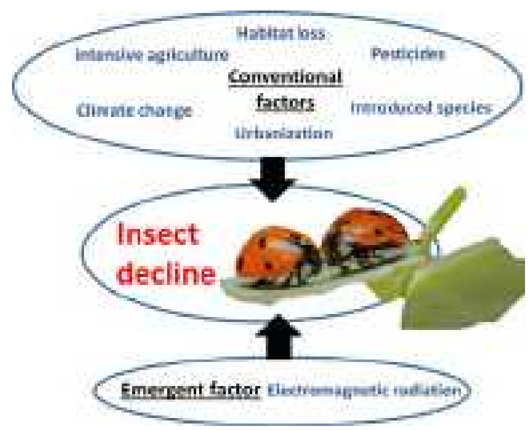
HIGHLIGHTS

- Biodiversity of insects is threatened worldwide.
- These reductions are mainly attributed to agricultural practice and pesticide use.
- There is sufficient evidence on the damage caused by electromagnetic radiation.
- Electromagnetic radiation may be a complementary driver in this decline.
- The precautionary principle should be applied before any new deployment (e.g. 5G).

GRAPHICAL ABSTRACT



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ABSTRACT

The biodiversity of insects is threatened worldwide. Numerous studies have reported the serious decline in insects that has occurred in recent decades. The same is happening with the important group of pollinators, with an essential utility for pollination of crops. Loss of insect diversity and abundance is expected to provoke cascading effects on food webs and ecosystem services. Many authors point out that reductions in insect abundance must be attributed mainly to agricultural practices and pesticide use. On the other hand, evidence for the effects of non-thermal microwave radiation on insects has been known for at least 50 years. The review carried out in this study shows that electromagnetic radiation should be considered seriously as a complementary driver for the dramatic decline in insects, acting in synergy with agricultural intensification, pesticides, invasive species and climate change. The extent that anthropogenic electromagnetic radiation represents a significant threat to insect pollinators is unresolved and plausible. For these reasons, and taking into account the benefits they provide to nature and humankind, the precautionary principle should be applied before any new deployment (such 5G) is considered.

Contents

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1. Insects and their importance in ecosystem services

There are numerous studies that show the fundamental importance of insects as key species in ecosystems (see for example: Noriega et al., 2018). Some of the most important ecosystem services they provide are climate regulation, crop pollination, pest control, decomposition and seed dispersal (Kremen and Chaplin-Kramer, 2007; Schowalter, 2013). Insects are at the structural and functional base of many of the world's ecosystems (Sánchez-Bayo and Wyckhuys, 2019), and numerous birds, lizards, frogs and bats feeds on insects (Nocera et al., 2012). The group of insect pollinators plays an important role in crop pollination, and insects provide an important contribution to crops as well as to wild plants (Powney et al., 2019).

2. The current decline of insects and causative drivers of this decline

Numerous studies have reported the serious decline in insects that has occurred in recent decades (Vogel, 2017). A study carried out in protected nature areas throughout Germany found a 76–82% decline in total flying insects between 1989 and 2016. The authors consider that agricultural intensification, with increased use of pesticide and fertilisers, may have aggravated the reduction in insect abundance over the last decades, whereas landscape modifications and climate change are unlikely explanatory factors (Hallmann et al., 2017).

A study of insects crashing into car windscreens in rural Denmark, based on data collected between 1997 and 2017, concluded that the number of insects had decreased by 80% in those 20 years, and the authors point out that reductions in insect abundance must mainly be attributed to agricultural practices and pesticide use (Møller, 2019). In a survey conducted in Kent (UK) in 2019, which examined the presence of crushed insects in the front grille above the licence plates of cars, a 50% reduction compared to 2004 was reported (Tinsley-Marshall et al., 2019).

Some authors also point out climate change as a cause of insect decline (Baranov et al., 2020). In a tropical rainforest in Puerto Rico, one study found a 30- to 60-fold decline (a 97–98% decline) in total insects captured in sticky traps between 1976 and 2012. This decline may be attributed to climate change, since between 1976 and 2012, mean maximum temperatures have risen by 2.0 °C, and tropical arthropods are particularly vulnerable to climate warming (Lister and Garcia, 2018). However, in colder climes and the mountains of temperate zones, this factor affects only a minority of species (Sánchez-Bayo and Wyckhuys, 2019).

After reviewing 73 historical reports of insect declines from across the globe, a recent study revealed that the biodiversity of insects is threatened worldwide (Sánchez-Bayo and Wyckhuys, 2019). The rates of decline may lead to the extinction of 40% of the world's insect species, both specialists and generalists. Based on the results of this review, the most affected groups in terrestrial ecosystems are *Lepidoptera*, *Hymenoptera* and *Coleoptera*, whereas in terms of aquatic taxa, *Odonata*, *Plecoptera*, *Trichoptera* and *Ephemeroptera* are most affected. The authors conclude that the main plausible drivers are, in order of importance: i) habitat loss and conversion to intensive agriculture and urbanisation; ii) pollution, mainly by synthetic pesticides and fertilisers; iii) pathogens and introduced species; iv) climate change (Sánchez-Bayo and Wyckhuys, 2019).

This same is happening with the important group of pollinators. A study has found evidence of declines across a large proportion of pollinator species in Britain between 1980 and 2013 (Powney et al., 2019). Another study strongly suggests a causal connection between local extinctions of functionally linked plant and pollinator species (Biesmeijer et al., 2006). Further, pollinator populations may collapse suddenly once drivers of pollinator decline reach a critical point (Lever et al., 2014). Key threats to pollinators include agricultural intensification (particularly habitat loss and pesticide use), climate change and the spread of alien species (Powney et al., 2019). The decline of pollinators may have important ecological and economic impacts that could significantly affect the maintenance of wild plant diversity, crop production and human welfare (Lázaro et al., 2016).

Loss of insect diversity and abundance is expected to provoke cascading effects on food webs and ecosystem services (Hallmann et al., 2017; Møller, 2019). For example, associated with the decline of insects, parallel decreases in insectivorous lizards, frogs and birds have been documented (Lister and Garcia, 2018). Pesticides have dramatically altered insect community structures and decimated populations, triggering nutritional consequences for aerially foraging insectivorous birds and bats (Nebel et al., 2010; Nocera et al., 2012). Agriculture is the largest contributor to insect and biodiversity loss, destroying biodiversity by converting natural habitats into intensely managed systems and by releasing pollutants, fertilisers and pesticides (Dudley and Alexander, 2017).

3. Scientific evidence for electromagnetic radiation as a factor contributing to insect decline

Insects are especially sensitive to electromagnetic radiation. An increasing number of reports indicate that flies and spiders, among other invertebrates, disappear from areas that receive the highest levels of radiation from mobile telephone antennas, and these observations are consistent with numerous laboratory studies showing the negative effects of electromagnetic radiation (EMR) on reproductive success, development and navigation (Balmori, 2009; Lázaro et al., 2016).

Evidence for the effects of non-thermal microwave radiation on insects has been known for at least 50 years, e.g., the abnormal development of irradiated coleopteran pupae (Carpenter and Livstone, 1971). Radio frequency (RF) signals produced by mobile phones increased the numbers of offspring, elevated hsp70 levels by non-thermal stress and caused other effects on reproduction and development of the fruit fly *Drosophila melanogaster* (Weisbrot et al., 2003). Another study showed that the reproductive capacity of fruit flies decreased by 50–60% after exposure to the RF signal of a mobile phone during the first 2–5 days of adult life (Panagopoulos et al., 2004). The same authors compared the biological activities of the two systems, GSM (900 MHz) and DCS (1800 MHz), and concluded that both types of radiation significantly decrease the reproductive capacity of fruit flies (Panagopoulos et al., 2007). This non-thermal effect diminished with distance (decreasing intensity) and is provoked by induction of cell death (Panagopoulos et al., 2010).

Other authors have also worked with this species and have observed a statistically significant decrease in mean fecundity (Atli and Ünlü, 2006). Further, the mean pupation time was delayed linearly with an increasing period of exposure to an electromagnetic field (EMF), and the mean offspring number was significantly lower than that of the control (Atli and Ünlü, 2007). Pupae from another dipteran, the house fly *Musca domestica*, were exposed to an EMF (50 Hz), and the results showed that the field significantly slowed down metamorphosis (Stanojević et al., 2005).

Insects may be equipped with the same magnetoreception system as birds, and there is evidence that the geomagnetic field reception in the American cockroach is sensitive to a weak RF field (Vácha et al., 2009). Several laboratory studies have been carried out with ants, demonstrating the important effects of artificial EMFs on their orientation by geomagnetic fields (Camlitepe et al., 2005). Other authors demonstrate how changes of low intensity in the normal local magnetic field values affect the behaviour of workers of three magnetosensitive ant species, inducing significant changes in their foraging activities (Pereira et al., 2019). Belgian researchers experimentally demonstrated the effect of 900-MHz electromagnetic waves on ant olfactory and visual learning, revealing an impact on their physiology (Cammaerts et al., 2012). The ants' speed of movement was immediately altered by the presence of electromagnetic waves (Cammaerts and Johansson, 2014). These authors state that electromagnetic radiation affects the behaviour and physiology of social insects, and such results provide convincing evidence of a negative impact of electromagnetic waves on insects, at least on those whose life depends on communication and memory (Cammaerts et al., 2012). Wireless technology has negative impacts on living organisms; ants react quickly to the existence of electromagnetic waves in their environment, and bees may behave abnormally when exposed to EMFs generated by GSM masts (Cammaerts et al., 2013).

To replace chemical insecticides for controlling pests of various species of plants and seeds, in several different studies, radiofrequency exposure was applied to *Callosobruchus chinensis* (Coleoptera), *Maruca vitrata* (Lepidoptera), *Nysius plebeius* and *Nysius hidakai* (Hemiptera). The EMF affected the developmental period, adult longevity, adult weight and the fecundity of subsequent generations in all these species of insects from different orders in the same way (Maharjan et al., 2019a, 2019b, 2020).

Studies have also been conducted on other invertebrates. A study performed in an RF electromagnetic field (RF-EMF) anechoic chamber, irradiating ticks (*Dermacentor reticulatus*) with a 900-MHz RF-EMF at levels below the proposed limit for public exposure to mobile phone base stations, found that exposure induces an immediate tick locomotor response manifested as a jerking movement, and ticks exhibited overall significantly greater movement in the presence of this electromagnetic radiation (Vargová et al., 2017).

In some studies conducted in natural habitats with real phone masts, electromagnetic radiation (EMR) emitted by telecommunication antennas affected the abundance and composition of several guilds of wild pollinator insects (Lázaro et al., 2016). Another study, also carried out in the field, examined the impact of exposure to the fields from mobile phone base stations (GSM 900 MHz) for a 48-h period on the reproductive capacity of four different invertebrate species. Although a significant impact on reproductive capacity was not found, probably because the exposure time was too short, the authors warned that more attention should be paid to the possible impacts of EMF radiation on biodiversity because the exposure to an RF-EMF is ubiquitous and is still increasing rapidly over large areas (Vijver et al., 2014).

As a result of most of the studies carried out, EMF radiation can be a problem for insects and for their orientation (Balmori, 2006, 2009, 2014 and 2015), and both laboratory and field studies on different invertebrate species have shown this.

4. Bee studies on electromagnetic radiation

Bees are highly sensitive to magnetic fields, especially for orientation and navigation, and for this reason, most of such studies have been carried out on bees. Adult honeybees possess a magnetoreception sense, and significant differences in their return rates have indicated that interactions exist between forager losses and exposure to magnetic fields, as well as during fluctuations in the Earth's magnetosphere (Ferrari, 2014).

The first study on the effects of EMFs on bees were carried out under power lines. Honeybee colonies exposed to a 765-kV, 60-Hz transmission line at 7 kV/m showed increased motor activity, abnormal propolisation, impaired hive weight gain, queen loss, abnormal production of queen cells, decreased sealed brood and poor winter survival. When the colonies were exposed to different electric fields with increasing distance from the line, different thresholds for biological effects were obtained (Greenberg et al., 1981). Another more recent study has shown that the extremely low-frequency EMF (50 Hz) emitted from powerlines affects honeybee olfactory learning, flight, foraging activity and feeding and may represent a prominent environmental stressor for honeybees, potentially reducing their ability to pollinate crops (Shepherd et al., 2018). In Italy, deleterious results of both pesticides and EMFs from a 132-kV (50-Hz) high-voltage power line have been found. In the electromagnetic-stress site, the effect of a behavioural over-activation of all analysed biomarkers was observed at the end of the season, and this finding poses potential problems for the winter survival of bees (Lupi et al., 2020).

Lopatina et al. (2019) studied the effect of non-ionising EMR from a Wi-Fi router on sensory olfactory excitability, food motivation and memory in honeybees and observed that a 24-hour exposure to Wi-Fi EMR had a significant inhibitory effect on food excitability and short-term memory. In natural conditions, worker piping announces either the swarming process of the bee colony or is a signal of disturbance, and active mobile phone handsets have a dramatic impact on the behaviour of the bees by inducing the worker piping signal (Favre, 2011). In another study, with GSM (900-MHz) cell phones, a significant decline in colony strength and egg-laying rate by the queen was observed. The behaviour of exposed foragers was negatively influenced by such exposure: there was neither honey nor pollen in the colony at the end of the experiment (Sharma and Kumar, 2010). In another study, queens exposed to telephone radiation in the test colonies produced fewer eggs/day compared to the control (Sainudeen Sahib, 2011). A more recent study provided solid evidence that mobile phone radiation significantly reduces hatching and may alter pupal development (Odemer and Odemer, 2019).

In a study carried out in Germany, with bees exposed to DECT radiation, only a few bees returned to the beehive, and they needed more time; also, honeycomb weight was lower in irradiated beehives (Stever et al., 2005; Harst et al., 2006). The concentrations of carbohydrates, proteins and lipids in the haemolymph increased under the influence of cell phone radiation (Kumar et al., 2013). Another study observed an increase in mortality in two conditions: after exposure to HF (13.56 MHz) and to UHF (868 MHz) (Darney et al., 2016).

Regarding the colony collapse disorder (CCD) observed in honeybee colonies around the world, several authors consider that EMR exposure provides a better explanation than other theories (Sainudeen Sahib, 2011; Cammaerts et al., 2012). Several authors warn that the massive amount of radiation produced by mobile phones and towers disturbs the navigational skills of honeybees, preventing them from returning to their hives (Warnke, 2009; Sainudeen Sahib, 2011). In fact, winter colony losses in the northeast USA correlated with the occurrence of annual geomagnetic storms, and abnormal fluctuations in magnetic fields related to the epidemiology of honeybee losses are consistent with their behaviour and development (Ferrari, 2014).

5. Action mechanisms

There are well-known mechanisms of action of low-frequency pulsed RF, such as interference with calcium channels in cells (Pall, 2013; Panagopoulos and Balmori, 2017) and deleterious effects on sperm and reproductive systems (Panagopoulos et al., 2004;

Panagopoulos, 2012; Adams et al., 2014). In vertebrates, studies have also found a pathologic leakage across the blood-brain barrier (Salford et al., 2003) and interference with brain waves (Mann and Roschkle, 1996; Beasond and Semm, 2002; Kramarenko and Tan, 2003). Microwave radiation has particular effects on nervous, immune and reproductive systems (Balmori, 2009).

In recent years, there has been an important advance in understanding the underlying mechanisms for orientation in birds, insects and other groups. It has also been verified that RF-EMFs alter the biological response characteristics of cryptochrome receptors. These results are consistent with the radical-pair mechanism of magnetosensing. Since cryptochromes are molecules highly sensitive to RF radiation and are found in many organisms, including humans, these results also may have more general implications for the capacity of living organisms to respond to man-made electromagnetic noise by analogy with broadband RF, which has previously been shown to disrupt the orientation of birds (Engels et al., 2014). These possible risks have already been indicated by Balmori (2015).

A recent study has warned that future, more short wavelengths of electromagnetic fields used for the wireless telecommunication systems (5G), will become comparable to the body size of insects, and therefore, the absorption of RF-EMF in this group is expected to increase (Thielens et al., 2018).

6. The precautionary principle and the importance of seriously considering EMR as a factor of insect decline

Despite the strong scientific evidence of the negative impacts of electromagnetic radiation on insects, a recent study funded by the European Union's Horizon 2020 Research and Innovation Programme (EKLIPSE) stated that our current knowledge concerning the impact of anthropogenic RF-EMR on pollinators (and other invertebrates) is inconclusive (Vanbergen et al., 2019). Thus, the extent to which anthropogenic EMR represents a significant threat to insect pollinators is unresolved. For these reasons, and taking into account the benefits they provide to nature and humankind, the precautionary principle of the European Union (Communication from the Commission on the Precautionary Principle, 2000) should be applied.

The potential effects of RF-EMFs on most taxonomic groups, including migratory birds, bats and insects, are largely unknown, and the potential effects on wildlife could become more relevant with the expected adoption of new mobile network technology (5G), raising the possibility of unintended biological consequences (Sutherland et al., 2018). Thus, before any new deployment (such 5G) is considered, its effects should be clearly assessed, at least while conclusions are drawn and these existing uncertainties are overcome, according to the official document 'Late Lessons of Early Warnings' (European Environment Agency, 2013).

A letter by the United States Department of the Interior sent to the National Telecommunications and Information Administration in the Department of Commerce warns about the scarcity of studies carried out on the impacts from non-ionising EMR emitted by communication towers (United States Department of the Interior, 2014). The precise potential effects of increases in EMR on wildlife, which are not yet well recognised by the global conservation community, have been identified as an important emerging issue for global conservation and biological diversity (Sutherland et al., 2018). Thus, as we have explained in this review, EMR should be seriously considered as a complementary driver for the dramatic decline in insects in recent studies, acting in synergy with agricultural intensification, pesticides, invasive species and climate change.

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The author declare that have no conflict of interest.

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November 19, 2021

To: The Honorable Jessica Rosenworcel, Commissioner
Chairwoman
Federal Communications Commission

The Environmental Working Group, a nonprofit public health research and advocacy organization with offices in Washington, D.C, Minneapolis, and Sacramento, Calif., requests that the Federal Communications Commission reopen Docket #13-84, "Reassessment of FCC Radiofrequency Exposure Limits and Policies," and Docket #03-137, "Proposed Changes to the Commission Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields," to allow robust review and consideration of scientific evidence published in the past two years and in response to the court ruling in *Environmental Health Trust et al. v. the FCC*.

Since 2009, the Environmental Working Group has extensively researched the topic of the human and environmental health impacts of radiofrequency radiation emitted from wireless communication devices. EWG also closely follows regulatory approaches and recommendations on radiofrequency radiation made by authoritative health agencies around the world. The World Health Organization states on its website:

> *… during the 20th century, environmental exposure to man-made sources of EMF steadily increased due to electricity demand, ever-advancing wireless technologies and changes in work practices and social behaviour. Everyone is exposed to a complex mix of electric and magnetic fields at many different frequencies, at home and at work, and concern continues to grow over possible health effects from overexposure*.[1]

Extensive research literature points to the potential health risks of radiofrequency radiation, particularly for the developing child. Peer-reviewed studies show that the bodies of children absorb more radiofrequency radiation, compared to adults, putting children at greater health risk as a result to such exposure.[2]

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[1] World Health Organization, web page not dated, "Supporting the development of national policies on electromagnetic fields". https://www.who.int/activities/supporting-the-development-of-national-policies-on-electromagnetic-fields Accessed Nov. 16, 2021.

[2] Fernández C, de Salles AA, Sears ME, Morris RD, Davis DL. Absorption of wireless radiation in the child versus adult brain and eye from cell phone conversation or virtual reality. Environ Res. 2018; 167:694-699. https://doi.org/10.1016/j.envres.2018.05.013; Gandhi OP, Morgan LL, de Salles AA, Han YY, Herberman RB, Davis DL. Exposure limits: the underestimation of absorbed cell phone radiation,

Scientists and public health advocates have raised concerns for decades about the adverse health effects of exposure to electromagnetic radiation. Recent research publications highlight the severity of these impacts, especially among vulnerable populations, and the need for more stringent health-based exposure standards. In 2011, the International Agency for Research on Cancer (IARC), an agency of the World Health Organization, classified radiofrequency electromagnetic fields as "possibly carcinogenic to humans."[3]

For today's generation of children, exposure to radiofrequency radiation from wireless communication devices starts from the fetal development period as a result of wireless devices in the pregnant person's everyday environment. Following birth, today's children will be exposed to radiofrequency radiation throughout their lives – an exposure scenario that is drastically different from the very limited consumer use and exposure to wireless radiation of the 1980s and 1990s, when the basis for current FCC standards was established.

This comment letter highlights two key considerations that point to the need for the FCC to reassess existing radiofrequency exposure limits and policies:

1. A 2021 peer-reviewed publication we authored that uses Environmental Protection Agency methodology to determine protective health-based exposure limits for radiofrequency radiation, based on the U.S. government's landmark 2018 laboratory study; and
2. Recent literature that documents a range of effects of non-ionizing electromagnetic radiation on different body systems that current FCC standards do not take into account.

1. Health-based limits developed with consideration for children's health

A peer-reviewed article published by our organization in 2021 (Uche & Naidenko, 2021)[4] documented how the current FCC exposure limit for radiofrequency radiation is not

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especially in children. Electromagn Biol Med. 2012; 31(1):34-51. https://doi.org/10.3109/15368378.2011.622827

[3] International Agency for Research on Cancer. IARC classifies radiofrequency electromagnetic fields as possibly carcinogenic to humans. Press Release N: 208. 2011. https://www.iarc.who.int/wp-content/uploads/2018/07/pr208_E.pdf Accessed Nov. 16, 2021.

[4] Uche UI, Naidenko OV. Development of health-based exposure limits for radiofrequency radiation from wireless devices using a benchmark dose approach. Environ Health. 2021; 20(1):84. https://doi.org/10.1186/s12940-021-00768-1

sufficient to protect the general population, especially children, against the adverse impacts associated with radiofrequency radiation exposure. The current limit, last revised a quarter-century ago – well before wireless devices became ubiquitous – needs to be updated with the latest science to be fully health protective for all users of wireless communication technologies.

Our study, published in the journal *Environmental Health*, recommends strict, lower health-based exposure standards for both children and adults for radiofrequency radiation emitted from wireless devices. This recommendation draws on data from a landmark 2018 study from the National Toxicology Program, one of the largest long-term laboratory studies on the health effects of radiofrequency radiation exposure.[5]

EWG's study uses a similar EPA methodology developed to assess human health risks arising from toxic chemical exposures to radiofrequency radiation from wireless devices. It recommends a whole-body specific absorption rate (SAR) limit of 0.2 to 0.4 mW/kg for children, which is 200 to 400 times lower than the current federal whole-body exposure limit. For adults, EWG recommends a whole-body specific absorption rate limit of 2 to 4 mW/kg, which is 20 to 40 times lower than the federal limit (Uche & Naidenko, 2021).[4]

EWG's analysis and recommendation for a much stricter limit for radiofrequency radiation exposure is a step toward advancing a re-evaluation of the existing federal limit for radiofrequency radiation exposure while reviewing the latest research on radiofrequency radiation exposure.

2. Wide range of potential impacts of non-ionizing electromagnetic radiation on human health not accounted for in the current FCC standard

The current FCC standard was based on the 1986 recommendations of the National Council on Radiation Protection and Measurements[6] and 1991 recommendations of the

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[5] National Toxicology Program. 595: NTP Technical Report on the Toxicology and Carcinogenesis Studies in Hsd: Sprague Dawley SD Rats Exposed to Whole-Body Radio Frequency Radiation at a Frequency (900 MHz) and Modulations (GSM and CDMA) Used by Cell Phones. National Toxicology Program, US Department of Health and Human Services. 2018.
https://ntp.niehs.nih.gov/ntp/htdocs/lt_rpts/tr595_508.pdf?utm_source=direct&utm_medium=prod&utm_campaign=ntpgolinks&utm_term=tr595

[6] National Council on Radiation Protection and Measurements. Biological effects and exposure criteria for radiofrequency electromagnetic fields: NCRP Report No. 86; 1986. Available from:
https://ncrponline.org/shop/reports/report-no-086-biological-effects-and-exposure-criteria-for-radiofrequency-electromagnetic-fields-1986/

Institute of Electrical and Electronics Engineers,[7] which chose an exposure level based on behavioral changes observed in laboratory animals exposed to radiofrequency radiation for a duration of minutes to hours in studies conducted in the 1970s and 1980s. With extensive current research linking radiofrequency exposure to adverse impacts, even at exposure levels below the current federal limit, the FCC needs to review the latest science and update the allowable exposure limits.

Among the reported biological effects of electric and magnetic fields are harm to fetal growth and development (Ozgur et al., 2013);[8] changes in brain activity (Wallace and Selmaoui, 2019);[9] changes in heart rate variability (Wallace et al., 2020);[10] DNA damage (Smith-Roe et al., 2020);[11] cognitive effects (Azimzadeh and Jelodar);[12] and increased risk of cancer, including gliomas,[3] parotid gland tumors (Sadetzki et al., 2008),[13] thyroid cancers (Luo et al., 2019).[14] These adverse health effects may be associated with different mechanistic pathways, such as changes in the activity of voltage-gated calcium channels (Blackman et al., 1991);[15] changes in the concentrations of reactive oxygen species and redox homeostasis (Ertilav et al., 2018);[16] changes in intracellular enzymes

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[7] Institute of Electrical and Electronics Engineers. (Revision of ANSI C95.1–1982). IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz. IEEE Std C95. 1991. https://doi.org/10.1109/IEEESTD.1992.101091

[8] Ozgur E, Kismali G, Guler G, Akcay A, Ozkurt G, Sel T, et al. Effects of prenatal and postnatal exposure to GSM-like radiofrequency on blood chemistry and oxidative stress in infant rabbits, an experimental study.
Cell Biochem Biophys. 2013;67(2):743–51. https://doi.org/10.1007/s12013- 013- 9564-1

[9] Wallace J, Selmaoui B. Effect of mobile phone radiofrequency signal on the alpha rhythm of human waking EEG: a review. Environ Res. 2019; 175:274–86. https://doi.org/10.1016/j.envres.2019.05.016

[10] Wallace J, Andrianome S, Ghosn R, Blanchard ES, Telliez F, Selmaoui B.Heart rate variability in healthy young adults exposed to global system for mobile communication (GSM) 900-MHz radiofrequency signal from mobile phones. Environ Res. 2020; 191:110097. https://doi.org/10.1016/j.envres.2020.110097

[11] Smith-Roe SL, Wyde ME, Stout MD, Winters JW, Hobbs CA, Shepard KG, et al. Evaluation of the genotoxicity of cell phone radiofrequency radiation in male and female rats and mice following subchronic exposure. Environ Mol Mutagen. 2020; 61(2):276–90. https://doi.org/10.1002/em.22343

[12] Azimzadeh M, Jelodar G. Prenatal and early postnatal exposure to radiofrequency waves (900 MHz) adversely affects passive avoidance learning and memory. Toxicol Ind Health. 2020;36(12):1024–30. https://doi.org/10.1177/0748233720973143

[13] Sadetzki S, Chetrit A, Jarus-Hakak A, Cardis E, Deutch Y, Duvdevani S, et al. Cellular phone use and risk of benign and malignant parotid gland tumors – a nationwide case-control study. Am J Epidemiol. 2008;167(4):457–67. https://doi.org/10.1093/aje/kwm325

[14] Luo J, Deziel NC, Huang H, Chen Y, Ni X, Ma S, et al. Cell phone use and risk of thyroid cancer: a population-based case–control study in Connecticut. Ann Epidemiol. 2019; 29:39–45. https://doi.org/10.1016/j.annepidem.2018.10.004

[15] Blackman C, Benane S, House D. The influence of temperature during electric-and magnetic-field-induced alteration of calcium-ion release from in vitro brain tissue. Bioelectromagnetics. 1991;12(3):173–82. https://doi.org/10.1002/bem.2250120305

[16] Ertilav K, Uslusoy F, Ataizi S, Nazıroğlu M. Long term exposure to cellphone frequencies (900 and 1800 MHz) induces apoptosis, mitochondrial oxidative stress and TRPV1 channel activation in the hippocampus

and gene expression (Fragopoulou et al.,2018);[17] and changes in membrane permeability (Perera et al., 2018).[18]

Table 1. Extensive research points to effects of non-ionizing electromagnetic radiation on individual body systems that are not considered by the current FCC standards for cell phone radiation.

Reported health effects	**Key studies**
Elevated risk of brain cancer, breast cancer, parotid gland tumors, and thyroid cancer	Choi YJ, Moskowitz JM, Myung SK, Lee YR, Hong YC. Cellular Phone Use and Risk of Tumors: Systematic Review and Meta-Analysis. Int J Environ Res Public Health. 2020; 17(21):8079. West JG, Kapoor NS, Liao SY, Chen JW, Bailey L, Nagourney RA. Multifocal Breast Cancer in Young Women with Prolonged Contact between Their Breasts and Their Cellular Phones. Case Rep Med. 2013; 2013:354682 Sadetzki S, Chetrit A, Jarus-Hakak A, Cardis E, Deutch Y, Duvdevani S, et al. Cellular phone use and risk of benign and malignant parotid gland tumors – a nationwide case-control study. American journal of epidemiology 2008; 167(4):457-67. Luo J, Li H, Deziel NC, Huang H, Zhao N, Ma S, et al. Genetic susceptibility may modify the association between cell phone use and thyroid cancer: A population-based case-control study in Connecticut. Environmental Research. 2020; 182:109013.
Eye strain, damage to eye tissues cataracts	Bormusov E, P Andley U, Sharon N, Schächter L, Lahav A, Dovrat A. Non-thermal electromagnetic radiation damage to lens epithelium. Open Ophthalmol J. 2008; 2:102-6

and dorsal root ganglion of rats. Metab Brain Dis. 2018;33(3):753–63. https://doi.org/10.1007/s11011-017-0180-4

[17] Fragopoulou AF, Polyzos A, Papadopoulou MD, Sansone A, Manta AK, Balafas E, et al. Hippocampal lipidome and transcriptome profile alterations triggered by acute exposure of mice to GSM 1800 MHz mobile phone radiation: an exploratory study. Brain Behavior. 2018; 8(6):e01001. https://doi.org/10.1002/brb3.1001

[18] Perera PGT, Nguyen THP, Dekiwadia C, Wandiyanto JV, Sbarski I, Bazaka O, et al. Exposure to high-frequency electromagnetic field triggers rapid uptake of large nanosphere clusters by pheochromocytoma cells. Int J Nanomed. 2018;13:8429. https://doi.org/10.2147/IJN.S183767

Cardiomyopathy, heart rate variability	National Toxicology Program. 2018. Technical Report on the Toxicology and Carcinogenesis Studies in Hsd: Sprague Dawley SD Rats Exposed to Whole-Body Radio Frequency Radiation at a Frequency (900 MHz) and Modulations (GSM and CDMA) Used by Cell Phones. Wallace J, Andrianome S, Ghosn R, Blanchard ES, Telliez F, Selmaoui B. Heart rate variability in healthy young adults exposed to global system for mobile communication (GSM) 900-MHz radiofrequency signal from mobile phones. Environmental Research 2020; 191:110097
Damage to sperm, decreased male fertility	Kesari KK, Agarwal A, Henkel R. Radiations and male fertility. Reprod Biol Endocrinol. 2018; 16(1):118
Changes in brain activity Changes in blood-brain barrier	Volkow ND, Tomasi D, Wang G-J, Vaska P, Fowler JS, Telang F, et al. Effects of cell phone radiofrequency signal exposure on brain glucose metabolism. JAMA 2011; 305(8):808-13 Wallace J, Selmaoui B. Effect of mobile phone radiofrequency signal on the alpha rhythm of human waking EEG: A review. Environmental research. 2019; 175:274-86
Changes in the immune system function	Piszczek P, Wójcik-Piotrowicz K, Gil K, Kaszuba-Zwoińska J. Immunity and electromagnetic fields. Environ Res. 2021; 200:111505.

As documented in Table 1, exposure to non-ionizing electromagnetic fields can harm a variety of organs and body systems, highlighting the urgency of a public-health-focused reassessment of existing exposure limits for radiofrequency radiation. Further, exposure to non-ionizing electromagnetic fields during pregnancy has been associated with an increased risk of miscarriage (Li et al., 2017)[19] and an increased frequency of hyperactivity and inattention during early childhood (Birks et al., 2017).[20]

[19] Li DK, Chen H, Ferber JR, Odouli R, Quesenberry C. Exposure to Magnetic Field Non-Ionizing Radiation
and the Risk of Miscarriage: A Prospective Cohort Study. Sci Rep. 2017; 7(1):17541. https://doi.org/10.1038/s41598-017-16623-8

[20] Birks L, Guxens M, Papadopoulou E, Alexander J, Ballester F, Estarlich M, Gallastegi M, Ha M, Haugen M, Huss A, Kheifets L, Lim H, Olsen J, Santa-Marina L, Sudan M, Vermeulen R, Vrijkotte T, Cardis E, Vrijheid M. Maternal cell phone use during pregnancy and child behavioral problems in five birth cohorts. Environ Int. 2017; 104:122-131. https://doi.org/10.1016/j.envint.2017.03.024

In conclusion, the Environmental Working Group urges the FCC to open its record for a more comprehensive evaluation of radiofrequency radiation and update its standard to ensure the safety of wireless radiation devices for everyone, especially young children.

Submitted on behalf of the Environmental Working Group,

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1. Charge

Mobile or cellular phones, cellular towers and wi-fi base stations are sources of radiofrequency electromagnetic field (RF-EMF or simply RF) exposure to humans. This exposure falls predominantly in the range of 850 to 2500 megahertz (MHz). Epidemiological studies have suggested that exposure to RF is associated with an increased risk of brain tumors (glioma, acoustic neuroma) in humans. After evaluating the body of existing scientific research and literature including very recent studies, I have now developed the conclusions set forth in this report on whether it is feasible that RF exposure can cause specific brain tumors in humans.

2. Qualifications

I received an undergraduate degree in mathematics in 1977 from Nicholls State University and a Master's degree and Ph.D. in biostatistics from the University of North Carolina School of Public Health in 1979 and 1981 respectively. My Ph.D. thesis addressed the optimal way to design a two-year rodent carcinogenicity study to assess the ability of a chemical to cause cancer[1, 2]; the optimal dosing pattern from my thesis is still used by most researchers. My first employment following my doctoral degree was a joint appointment at the National Institute of Environmental Health Sciences (NIEHS) and the National Toxicology Program (NTP) to conduct research on the design and analysis of experiments generally employed in toxicology. After 5 years with NIEHS/NTP, I developed my own research group which eventually became the Laboratory of Quantitative and Computational Biology and then the Laboratory of Computational Biology and Risk Assessment (LCBRA). One highlight during this period was the development of the Poly-3 Test for survival adjustment of data from two-year carcinogenicity studies in rodents [3, 4]; this test is used as the main method of analysis of these studies by the NTP and many others. We also did a complete analysis of the historical controls animals from the NTP studies [5, 6]. The LCBRA focused on the application of computational tools to identify chemicals that are toxic to humans, to develop tools for understanding the mechanisms underlying those toxicities and to quantify the risks to humans associated with these toxicities. The main toxicological focus of the LCBRA was cancer and my laboratory developed many methods for applying multistage models to animal cancer data and implemented the use of these models in several experimental settings [7-19]. In my last few years at the NIEHS/NTP, my research focus expanded to the development of tools for evaluating the response of complex experimental and human systems to chemicals [20-24] and the name of the laboratory shifted to Environmental Systems Biology.

Over my 32 years with the NIEHS/NTP, I was involved in numerous national priority issues that went beyond my individual research activities. After Congress asked NIEHS to work with the Vietnamese government to address the hazards associated with Agent Orange use during the Vietnamese War, I was given the responsibility of working with my counterparts in Vietnam to build a research program in this area [25]. Congress also tasked NIEHS with developing a research program (EMF-RAPID) to address concerns about the risks to humans from exposure to extremely low frequency electric and magnetic fields (ELF-EMF) from power lines and to report back to Congress on what we found. I was in charge of evaluating all research developed under this program and was responsible for the final recommendations to Congress on this issue [26-28].

While at the NIEHS/NTP, I also had administrative positions that relate to my qualifications. From 2000 to 2006 I was the Director of the Environmental Toxicology Program (ETP) at NIEHS. The ETP included all of the toxicology research laboratories within the NIEHS Intramural Research Program. It was my responsibility to ensure the research being done was pertinent to the mission of the NIEHS, addressing high priority concerns about toxic substances and human health and that the NIEHS had adequate resources to complete this research.

During this time I was also Associate Director of the NTP, a position in which I was the scientific and administrative director of the NTP (The Director of the NTP was also the NIEHS Director and gave me complete autonomy in the management and science of the NTP). These two positions were historically always combined at the NIEHS and the NTP so that one person was in charge of all toxicological research at the NIEHS/NTP. The NTP is the world's largest toxicology program, routinely having 15 to 25 active two-year carcinogenicity studies, numerous genetic toxicology studies and many other toxicological studies being conducted at any given time. The NTP two-year carcinogenicity studies and their technical reports are also considered the "gold standard" of cancer studies due to their extreme high quality, their tremendous utility in evaluating human health hazards and the rigor and transparency they bring to the evaluation of the data. All data from NTP two-year cancer studies are publicly available including data on individual animals and images from the pathology review of each animal. The NTP is also home to the Report on Carcinogens, the US Department of Health and Human Services official list of what is known or reasonably anticipated to be carcinogenic to humans. It was my responsibility to decide what items eventually went onto this list while I was Associate Director of the NTP. In 2006, I became an Associate Director of the NIEHS, a senior advisor to the director and the director of the Office of Risk Assessment Research (ORAR). ORAR focused on stimulating new research areas on the evaluation of health risks from the environment and addressed major risk assessment issues on behalf of the NIEHS/NTP. For example, in this capacity, I lead a multiagency effort to understand the health risks to humans from climate change and to develop a research program in this area [29].

I left the NIEHS/NTP in 2010 to become the Director of the National Center for Environmental Health (NCEH) at the Centers for Disease Control and Prevention and simultaneously Director of the Agency for Toxic Substances and Disease Registry (ATSDR). NCEH does research and supports activities aimed at reducing the impact of environmental hazards on public health. One well-respected research effort of the NCEH is the National Biomonitoring Program. This program tests for the presence of hundreds of chemicals in human blood and urine in a national sample of people in the United States. ATSDR advices the Environmental Protection Agency (EPA) and communities on the potential health impacts from toxic waste dump sites (superfund sites). ATSDR is required by law to produce ToxProfiles. These are comprehensive reviews of the scientific literature for specific chemicals generally found at superfund sites. They also provide an assessment of the safety of these chemicals. As part of my activities at ATSDR, I began a modernization of the

ToxProfiles to use systematic review methods in their assessments; this effort was linked to a similar effort that I had helped to implement at the NIEHS/NTP.

Aside from my official duties in my various federal jobs, I also served on numerous national and international science advisory panels. Most notable, for my qualifications for this statement, are my serving as Chair from 2005 to 2010 of the Subcommittee on Toxics and Risk of the President's National Science and Technology Council, member and chair of EPA'S Science Advisory Panel from 1998 to 2003 (focused specifically on advising their pesticides program) and chair of the International Agency for Research on Cancer (IARC) advisory group that updated and improved its rules for reviewing scientific data to ensure that conclusions on the carcinogenicity of human exposures are the best possible (Preamble) [30]. As part of my work on science advisory panels, I have served on EPA's Science Advisory Board, as an advisor to the Australian Health Council on risk assessment methods, as an advisor to the Korean Food and Drug Administration on toxicological methods and served on several World Health Organization (WHO) International Program on Chemical Safety scientific panels dealing with risk assessment. Besides the guidelines for evaluating cancer hazards used by the IARC, I have either chaired or served as a member of scientific panels developing guidance documents for other organizations including the EPA.

I have received numerous awards, most notably the Outstanding Practitioner Award from the International Society for Risk Analysis and the Paper of the Year Award (twice) from the Society of Toxicology Risk Assessment Specialty Section. I am a fellow of the American Statistical Association, the International Statistical Institute, the World Innovation Foundation and the Ramazinni Institute. I have published over 250 peer-reviewed scientific papers, book chapters and technical documents on topics in toxicology and risk assessment.

Finally, I have served on numerous national and international committees tasked with evaluating the risk and/or hazard of specific environmental chemicals, including RF exposure. For example, I have contributed to risk assessments for EPA, the Food and Drug Administration, the Centers for Disease Control and Prevention, the National Institutes of Health, the WHO and IARC.

3. Explanation of Bradford Hill Causality Evaluation

Most of the guidelines [31-33] used for cancer risk assessment trace their origins to a paper by Hill (1965) [34]. The IARC review of RF [35] followed guidelines derived from Hill (1965) and concluded RF exposure was "possibly carcinogenic to humans".

The evaluation of whether RF exposure can cause brain tumors in humans requires the review and synthesis of scientific evidence from studies of human populations (epidemiology), animal cancer studies, and studies investigating the mechanisms through which chemicals cause cancer. Many different approaches[36, 37] are used to synthesize these three areas of science to answer the question "Does this chemical/agent cause cancer in humans?" In any of these three science areas, the quality of the individual studies has to be assessed and summarized to make certain the studies included in the overall assessment are done appropriately. Once the quality of the individual studies has been assessed, a judgment needs to be made concerning the degree to which the studies support a finding of cancer in humans. To do this, the EPA, IARC, the European Chemical Agency (EChA), the US Report on Carcinogens, and many others use guidelines [30, 31, 33, 38] that rely upon aspects of the criteria for causality developed by **Hill (1965)** [34].

Hill listed nine (9) aspects of epidemiological studies and the related science that one should consider in assessing causality. The presence or absence of any of these aspects is neither sufficient nor necessary for drawing inferences of causality. Instead, the nine aspects serve as means to answer the question of whether other explanations are more credible than a causal inference. As noted by Hill:

> *"None of my nine viewpoints can bring indisputable evidence for or against the cause-and-effect hypothesis and none can be required as a sine qua non. What they can do, with greater or less strength, is to help us to make up our minds on the fundamental question — is there any other way of explaining the set of facts before us, is there any other answer equally, or more, likely than cause and effect?"*

The nine aspects cited by Hill include consistency of the observed association, strength of the observed association, biological plausibility, biological gradient, temporal relationship of the observed association, specificity of the observed association, coherence, evidence from human experimentation and analogy. These are briefly described below.

An inference of causality is strengthened when several of the studies show a **consistent positive association** between cancer and the exposure. This addresses the key issue of replication of studies which is critical in most scientific debates. If studies are discordant, differences in study quality, potential confounding, potential bias and statistical power are considered to better understand that discordance.

An inference of causality is strengthened when **the strength of the observed association** in several studies are large and precise. These large, precise associations lessen the possibility that the observed associations are due to chance or bias. A small increase in risk of getting cancer does not preclude a causal inference since issues such as potency and exposure level may reduce the ability of a study to identify larger risks. Meta-analyses provide an objective evaluation of the strength of the observed association across several studies with modest risks to help clarify strength of the observed associations.

An inference of causality is strengthened when there is data supporting **biological plausibility** demonstrated through experimental evidence. Animal carcinogenicity studies, in which tumor incidence is evaluated in experimental animals exposed to RF, play a major role in establishing biological plausibility. There are numerous types of mechanisms that can lead to cancer [39], most of which can be demonstrated through experimental studies in animals, human cells, animal cells, and/or other experimental systems. Occasionally, occupational, accidental or unintended exposures to humans allow researchers to evaluate mechanisms using direct human evidence.

An inference of causality is strengthened when there is a **biological gradient** showing a reasonable pattern of changing risk with changes in exposure (e.g. risk increases with increasing exposure or with longer exposure). In many epidemiological studies, this aspect cannot be examined due to limitations in the study design or due to a lack of clarity in the presentation of the results. When a study does address an exposure-response relationship, failure to find a relationship can be due to a small range of exposures, insufficient sample size or a changing exposure magnitude over time that has not been accounted for.

An inference of causality is strengthened when there is a **temporal relationship** in which the exposure comes before the cancer. This aspect is necessary to show causality; if it is not present, a causal inference is not plausible. Because the latency period for cancers can be long (years), evaluation of studies should consider whether the exposure occurred sufficiently long ago to be associated with cancer development.

An inference of causality is strengthened when the exposure is **specific for a given cancer**. This would mean that the disease endpoint being studied is only due to the cause being assessed or that, even though many different cancers have been studied for an association with a given exposure, only one type of cancer shows a consistent association for the exposure of interest.

An inference of causality is strengthened when other lines of experimental evidence are **coherent** with a causal interpretation of the association seen in the epidemiological evidence. To evaluate coherence, information from animal carcinogenicity studies, and mechanistic investigations would be considered.

An inference of causality is strengthened when there is **experimental evidence in humans** supporting a causal interpretation. Seldom is this type of information available when addressing the toxicity of environmental exposures. However, experiments in which an individual reduces or limits exposures and the risk of cancer is reduced would carry considerable weight in the evaluation (e.g. studies evaluating the cancer risks of people who stop cigarette smoking compared with continuing smoking have demonstrated reduced lung cancer risks). No such data are available for RF exposures.

Finally, an inference of causality is strengthened when there are other agents with **analogous** characteristics showing similar effects in humans and/or animals and/or showing similar biological impacts in mechanistic studies.

The most logical approach to developing an inference of causality is to step through each of the aspects of causality developed by Hill (1965) [34] and apply them to the available data for RF exposures. This is done after a review of the relevant literature from human epidemiology studies, animal cancer studies, and mechanistic studies.

4. Human Epidemiology

The evidence on an association between cellular phone use and the risk of glioma and/or acoustic neuroma in adults is strong.

4.1 Glioma

4.1.1 Studies in Adults

4.1.1.1 Case-Control Studies

Muscat et al. (2000) [40] conducted a case-control study of cancers of the brain in five academic medical centers in the US from 1994-1998. Cases consisted of 469 patients with brain cancers (mainly glioma patients) and 422 controls matched from the same medical center as the cases. They basically saw no increased odds ratios for brain tumors overall or any subtype with the exception of neuroepitheliomatous tumors (14 exposed cases) where they saw an odds-ratio of 2.1 (0.9-4.7). Only 35 patients had these tumors and 14 of these used cellular phones. (Note, these are tumors arising in the neuroepithelial cells which serve as somewhat pluripotent stem cells in the brain). This study has a small number of cases, exposures were low and for short duration, they were predominantly analog exposures and many study participants had never used a cellular phone. (Table 1) (other related papers include [41-43]).

Inskip et al. (2001) [44] performed a case-control study of intracranial tumors of the nervous system (brain tumors) and cellular phone use from 1994-1998 from three hospitals in the United States (Boston Brigham and Women's Hospital, Phoenix St. Joseph's Hospital and Pittsburgh Western Pennsylvania Hospital). They had 782 cases (489 with glioma, 197 with meningioma, and 96 with acoustic neuroma) and 799 matching hospital controls. Controls were predominantly hospital admissions without tumors however there were some neoplastic controls (leukemia/lymphoma patients excluded). Regular use was defined as 2 calls per week. Usage of handheld cellular phones increased dramatically during the study (e.g. controls doubled usage from 1994 to 1998 from ~20% to ~40%). The cases were older than the controls. They saw no increases in any ORs for any analysis done in the study (use/no use, frequency of use, years of use, cumulative use, year of first use) or any linkage between predominant side of use and the side on which tumors appeared. The study was basically negative in all aspects. Like the previous study, exposures were low and for short duration, they were predominantly analog exposures and many study participants had never used a cellular phone. (Table 1, Table 2, Table 3, Table 4, Table 5, Table 6)

Auvinen et al. (2002) [45] conducted a case-control study of brain tumors in males and females aged 20-69 in 1996 from the Finish Cancer Registry. There were 398 brain tumors (198 gliomas, 129 meningiomas, and 72 other unspecified types) and 5 age- and sex-matched controls for each case. For gliomas, there were 172 cases (86% response) and 921 controls (93% response). Each subject in the study was linked to a list of all subscribers to mobile phone networks in Finland to determine exposure. The OR for gliomas and any mobile phone subscription was 1.5 (1.0-2.4) with increasing ORs for increasing years of subscription (1.2 (0.5-3.0) for <1 year, 1.6 (0.8-2.9) for 1-2 years and 1.7 (0.9-3.5) for ≥2 years, 1.2 (1.0-1.4) increase in OR per year). The increases seen for analog phones was larger than that seen for digital phones. The major strengths of this study are their linkage to cancer records and mobile phone subscription records. It was limited by its size, inability to look at subscriptions of greater than 2 years and inability to look at the frequency of phone usage. (Table 1, Table 2)

Gousias et al. (2009) [46] conducted a hospital-based case-control study for cerebral gliomas and various exposures. The study included 41 cases (persons referred to the Neurosurgery and Neurology departments of University Hospital of Ioannina and surrounding hospitals) and 82 controls (2 neurosurgery patients per case matched for age, gender and district of residence with cervical myelopathy or disk herniation). They used one measure for cell phone use; minute-years of exposure (undefined). Logistic regression gave an OR of 1.00 (0.99-1.01, p=0.56). All evaluations were adjusted for alcohol consumption, smoking and history of severe cranial trauma. This is a small study with limited statistical power. (Table 1, Table 2)

Spinelli et al. (2010) [47] conducted a hospital-based case-control study in France on malignant primary brain tumors and various exposures. The study included 122 cases (new cases between Jan. 2005 and Dec. 2005 in the public reference hospitals in Marseilles and St. Anne's Hospital in Toulon) and 122 controls (neurosurgery patients matched for age and gender with no cancer diagnosis). They evaluated cell phone use in hour-years (number of hours of subscription per month x number of years of use in categories). They show ORs of 0.86 (0.30-2.44) for less than 4 hour-years of exposure, 1.45 (0.75-2.80) for 4 to 36 hour-years and 1.07 (0.41-2.82) for ≥36 hour-years of exposure. All evaluations were adjusted for sex and age. This is a small study with limited statistical power. (Table 1, Table 3)

The **INTERPHONE Study** (IS) [48] is a interview-based multi-center case-control study on the use of cellular phones and histologically-confirmed cases of glioma, meningioma or acoustic neuroma. The study had 16 study centers in 13 countries with a common protocol (Australia, Canada, Denmark, Finland, France, Germany, Israel, Italy, Japan, New Zealand, Norway, Sweden, and the U.K.). Participants were mostly between 30 and 59 years of age (differing a bit by country), lived in a major metropolitan region, and were recruited from candidates over a 2-4 year timeframe from 2000 to 2004. Population controls were randomly selected from population registries (part of Canada, Denmark, Finland, Germany, Italy, Norway and Sweden), electoral lists (Australia, part of Canada, France, New Zealand), patient lists (U.K.) or random-digit dialing (part of Canada, France, Japan). Controls were either individually matched to cases or frequency matched to cases on year of birth, sex and study region. Glioma and meningioma patients had one matched control and acoustic neuroma patients had 2 controls. All patients or their proxies were interviewed in person using a questionnaire. Some centers also included a few other tumors which will not be discussed here.

Numerous publications have resulted from this study for single countries [49-62], subsets of pooled countries [58, 63-66], and pooled analyses of the entire study [48, 67]. There were also numerous papers addressing methodological issues [68-75]. I will focus on the overall pooled results.

In the **IS (2010)** [48] study, the evaluation of the data is complicated, looking at four different ways to characterize exposure, three different types of referent populations, multiple sensitivity analyses and three different evaluations of tumor location relative to phone use. During the study period, the IS identified 3115 meningioma cases, 4301 glioma cases and 14354 controls. The IS eventually included 2708 glioma cases with 2972 matched controls and 2409 meningioma cases with 2662 matched controls resulting in participation rates of 64% (range 36-92%) among cases of glioma, 78% (56-92%) among meningioma cases and 53% (42-74%) among controls. Meningioma cases were predominantly female, glioma cases were predominantly male, mean age at diagnosis was 51 years for meningioma cases and 49 years for glioma cases and gliomas were diagnosed at a younger age than meningiomas.

The OR for meningiomas for regular users versus others was 0.79 (0.68-0.91) with four countries having individual ORs greater than 1. Breaking time since start of use into 4 categories yielded ORs below 1 for all categories (0.90, 0.77, 0.76, 0.83) and for cumulative number of calls with no hands-free device, divided into 10 categories, the ORs were also all below 1 with no obvious pattern (0.95, 0.62, 0.90, 0.80, 0.60, 0.81, 0.79, 0.92, 0.81, 0.80). Only for cumulative call time with no hands-free device was there a single OR>1 and only in the highest percentile of cumulative use with OR=1.15 (0.81-1.62) (0.90, 0.82, 0.69, 0.69, 0.75, 0.69, 0.71, 0.90, 0.76, 1.15). Digital phone users in the highest exposure category had a significant OR 1.84 (1.17-2.88) as did those who used both digital and analog phones OR=4.43 (1.42-13.9); analog-only phone users had an OR of 0.50 (0.25-0.99). When the data were divided into use 1-4 years before reference date (date of diagnosis), 5-9 years and ≥10 years, ORs in the highest quintile of cumulative use for the most recent groupings were greater that 1.0 (4.80 [1.49-15.4] for 1-4 years, 1.03 [0.65-1.65] for 5-9 years, 0.95 [0.56-1.63] for ≥10 years). The ORs for anatomical location were generally <1 for most analyses.

When analyzing for ipsilateral use or contralateral use independently, all ORs were <1.0. The ratio of ORs for ipsilateral use to contralateral use were always above 1 using any of the exposure metrics suggesting there was some degree of discernment in the results. A case-case analysis based on methods from **Inskip et al. (2001)** [44] showed an OR of 1.07 (1.00-1.16).

The OR for gliomas for regular users versus others was 0.81 (0.70-0.94) with three countries having individual ORs greater than 1. For time since start of use, ORs were below 1 for all categories (0.62, 0.84, 0.81, 0.98) and for cumulative number of calls with no hands-free device, the ORs were also all below 1 with a slightly increasing pattern (0.74, 0.71, 0.76, 0.90, 0.78, 0.83, 0.71, 0.93, 0.96, 0.96). For cumulative call time with no hands-free device two categories had ORs>1 and only in the highest tertile was it significant with OR=1.40 (1.03-1.89) (0.70, 0.71, 1.05, 0.74, 0.81, 0.73, 0.76, 0.82, 0.71, 1.40). Digital phone users in the highest exposure cumulative call time category had an increased OR 1.46 (0.98-2.17) as did those who used analog phones OR=1.95 (1.08-3.54). When the data were divided into use 1-4 years before reference date (date of diagnosis), 5-9 years and ≥10 years, ORs in the highest quintile of cumulative use for the most recent groupings were greater that 1.0 (3.77 [1.25-11.4] for 1-4 years, 1.28 [0.84-1.95] for 5-9 years, 1.34 [0.90-2.01] for ≥10 years). The ORs for anatomical location were generally <1 for most analyses except in the temporal lobe where the highest exposures in all three exposure measures were >1 (1.36 [0.88-2.11] for time since start of use, 1.87 [1.09-3.22] for cumulative call time, and 1.10 [0.65-1.85] for cumulative number of calls). When analyzing for ipsilateral use or contralateral use independently, all ORs were <1.0 except the highest exposures in all three exposure measures (1.21 [0.82-1.80] for time since start of use, 1.96 [1.22-3.16] for cumulative call time, and 1.51 [0.91-2.51] for cumulative number of calls). The ratio of ORs for ipsilateral use to contralateral use were all above 1 using any of the exposure metrics except for one category of time since first use suggesting there was some degree of discernment in the results. These ratios increased in an exposure-dependent fashion for cumulative number of calls. A case-case analysis based on methods from **Inskip et al. (2001)** [44] showed an OR of 1.27 (1.19-1.37) and was 1.55 (1.24-1.99) for the highest decile of cumulative call time.

An extensive sensitivity analysis on 13 separate factors did not substantively change the results for gliomas or meningiomas.

The reason for the low ORs seen in the various analyses could not be established. The authors examined sampling bias as a reason, arguing cases may have been missed and that controls may not have represented the study base, but concluded this was unlikely. Selection bias and participation bias may have contributed to the lower ORs, but they were unlikely to explain it all [48, 74]. When never regular users were excluded from the analysis and the lowest exposure category was used as the reference category (in an attempt to reduce participation bias), most of the ORs for gliomas increased above unity. Most notably, all three ORs for time since start of use became significant (1.7 [1.2-2.4] for 2-4 years, 1.5 [1.1-2.2] for 5-10 years, and 2.2 [1.4-3.3] for >10 years).

Some subjects reported very high cell phone use (>5h/day) and this was more common in glioma cases than controls. Truncating these at 5h/day had no effect on the resulting ORs. Thus, although there was some evidence of overestimation by heavy users [71], it is unlikely to have a large impact on the ORs.

The main strengths of the IS are the large sample size, the use of population-based controls and the extensive analyses performed on the data. One major limitation, as with most case-controls studies, is the use of a questionnaire for obtaining exposure information and the possibility of recall bias. Using a small sample of participants from three countries, the authors compared self-reported mobile-phone use with operator-recorded data and saw very little differential exposure misclassification. A second limitation was the low participation rate. There was some evidence that controls who regularly used mobile phones were more likely to participate than those who never used mobile phones; this could lead to a reduction in the ORs in the various exposure categories. The analyses using the lowest exposure category as the referent partially addressed this issue. (Table 1, Table 2, Table 3, Table 5, Table 6, Table 7)

In an effort to better refine the exposure in the IS, **Cardis et al. (2011)** [63] developed an estimate of the radio frequency (RF) dose as the amount of mobile phone RF energy absorbed at the location of a brain tumor in a selection of cases from the IS. This measure is a function of the frequency band and the types of phones the subjects had used and is multiplied by the duration of use to determine the total specific energy absorbed at the location of the tumor (TCSE, J/kg). After applying these exposure measures to the 5 countries in the IS where they could get the necessary usage information and tumor location data [63], they saw slight increases in both the glioma and meningioma ORs compared to the cumulative duration of mobile-phone use seen in the larger analysis [48]. The most significant finding was in the highest exposure group with a 7-year lag yielding an OR of 1.91 (1.05-3.47).

Grell et al. (2016) [76] used a model for spatial distribution of glioma occurrence developed by **Grell et al (2015)** [77] to reanalyze the tumor location data and laterality using the data from **Cardis et al. (2011)** [63]. The cases consisted of the 792 regular mobile phone users who provided data on preferred side of phone use and the center location of their tumor mass. The statistical test has the null hypothesis that the chances of getting the tumor are independent of side of use (in their parlance, the alphas for the four distances from the phone are all equal to 1 against the ordered alternative) with three different analyses based on slightly different assumptions. The p-value for the hypothesis of no association with mobile phone use was <0.01 for all three models. Dichotomizing (one variable at a time) by sex, age, tumor grade, tumor size, and years of mobile phone use yielded p<0.01 in all cases. The only weakness of this study would be if recall bias is driving the choice of which side of the brain the phone is typically used.

Cardis et al. (2011) [63] also conducted a case-case analysis in which mobile phone use was compared between cases whose probable tumor location was in the most exposed part of the brain region versus cases where the location of the tumor was elsewhere. The most exposed area was defined as falling within the 3 dB exposure volume of the brain regardless of laterality of use [78]. The OR for gliomas in regular users versus not regular users was 1.35 (0.64-2.87). For time since start of use, the ORs were 1.37 (0.59-3.19) for 1-4 years, 0.72 (0.27-1.90) for 5-9 years and 2.80 (1.13-6.94) for ≥10 years. A similar pattern was seen for cumulative call time. Because this uses only cases, case-case analysis is likely to have very limited recall bias but could still have exposure misclassification which is likely to be non-differential and reduce the ORs toward 1.0.

Larajavara et al. (2011) [79] also conducted a case-case analysis using seven European countries from the IS (Denmark, Finland, Germany, Italy, Norway, Sweden, and Southeast

England). In this analysis, distance between the midpoint of the glioma and the mobile phone axis was used to compare cases. Using the direct distance measurement, there was little difference between mean distance for various exposures categories with all p-values exceeding 0.39. Classifying tumors as ≤5 cm from midpoint of the glioma to the mobile phone axis or not yielded ORs that were below 1 for all but one situation and none were statistically significant. They also did a case-specular analysis of these same data. In a case-specular analysis, a mirror image of the location of the glioma is projected across the midpoint of the axial and coronal planes to use as the control. An association of cell phone usage with gliomas would exist if the ORs increased with increasing exposure; this was not seen. Using distance instead of exposure dose could lead to greater exposure misclassification since most exposures occur in the area of the brain closest to the ear and is not evenly distributed along the phone axis [63].

Hardell and colleagues conducted five separate case-control studies in Sweden on the risks of malignant brain tumors and exposure to cellular telephones [80-85]. All of the studies used self-administered questionnaires to ascertain mobile phone use followed by supplementary phone interviews to verify information provided in the questionnaire. All studies obtained matching controls for living cases from the Swedish Population Registry matching on gender and 5-year age group, and matching controls for deceased cases were obtained from the Death Registry of Sweden matched for year of death, gender, 5-year age group and medical region. The first study, **Hardell et al. (1999)** [85], was a small study with 233 patients identified from records in two regions of Sweden from 1994 to 1996. This study was effectively negative, probably due to the short latency periods for cellular phone use (Table 1, Table 6).

The next two studies were conducted back-to-back and used the same basic methodology. **Hardell et al. (2002)** [83] was conducted on males and females, aged 20-80 years, who developed a malignant brain tumor between 1997-2000 in Uppsala-Orebro, Stockholm, Linkoping and Goteborg; this study included 588 cases and 581 controls. Only cases that were alive at the time of the study were included in the evaluation. Ever use of an analog mobile phone showed an elevated OR for ipsilateral use of 1.85 (1.16-2.96) for malignant brain tumors. Digital phones showed a smaller OR for ipsilateral use of 1.59 (1.05-2.41). Multivariate analysis showed an elevated risk for all types of phones with confidence bounds that included 1. **Hardell et al. (2006a)** [81] was conducted in the same manner from 2000 to 2003 in Uppsala-Orebro and Linkoping and included 317 cases and 692 controls. No participants in this study overlapped with the previous study [83] and, as before, only cases alive at the time of the study were included. The use of analog cell phones yielded an OR for malignant brain tumors of 2.6 (1.5-4.3) and increased to 3.5 (2.0-6.4) for >10-year latency and 6.2 (2.5-15) for >15-year latency. The use of digital cell phones yielded an OR of 1.9 (1.3-2.7) and increased to 2.9 (1.6-5.2) for >10-year latency. Other exposure metrics were provided, some of which were also significant. A third case-control study [80] was conducted using those who had died prior the start of the previous two studies. Deceased cases were matched with two controls, one who had died of cancer and one who had died of another cause. The study included 346 cases (75% response rate, 314 cases of glioma) and 619 controls (67% response rate, 74% response rate from cancer controls). The OR for all malignant brain tumors and use of a mobile phone was 1.3 (0.9-1.9) increasing to 2.4 (1.4-4.1) with a latency of >10 years. They saw increasing ORs with increasing cumulative lifetime use (1.2 [0.8-1.8] for 1-1,000h, 2.6 [0.9-8.0] for 1,001-2,000h, and 3.4 [1.5-8.1] for

≥2,000h). The ORs were the same in the low exposure and high exposure groups regardless of whether cancer controls or other controls were used but differed in the middle exposure group with analyses using cancer controls showing no increased OR and using non-cancer controls showing an OR very similar to the analysis using all controls.

These three case-control studies [80, 81, 83] were combined in a pooled analysis in **Hardell et al. (2006)** [86]. The final study included 1,251 cases and 2,438 controls. This constitutes a response rate of 85% for cases and 84% for controls. For mobile phone usage and 1-year latency, they reported an OR for gliomas of 1.3 (1.1-1.6) that stayed at 1.3 (0.99-1.6) for 5-10-year latency and rose to 2.5 (1.8-3.3) for >10-year latency; the numbers were slightly higher if only a mobile phone was used (no cordless phone). They also saw a clear exposure-response relationship for lifetime use in hours where the OR was 1.2 (1.03-1.5) for 1-1000 hours of use, 1.8 (1.2-2.8) for 1001-2000 hours of use and 3.2 (2.0-5.1) for >2000 hours of use. The OR increase per 100 hours of use was 1.023 (1.013-1.034). In a follow-up to this study, **Hardell and Carlberg (2013)** [87] evaluated the survival of glioma patients until death or May 30, 2012 using Cox's proportional hazards model adjusted for age, gender, year of diagnosis, socioeconomic status and study. Exposed patients were those using a phone at least 1 year prior to tumor development, unexposed were all other patients. The hazard ratio (HR) for users of mobile phones was 1.1 (0.9-1.2) and increased with latency (0.9 [0.8-1.1] for 1-5 years; 1.1 [0.9-1.4] for 5-10 years; 1.3 [1.0005-1.6] for >10 years), and tertiles of cumulative use (0.9 [0.7-1.1] for T1; 1.0 [0.8-1.3] for T2; 1.3 [1.05-1.6] for T3). For lower grade astrocytomas (I and II), all HRs were below 1, for grade III astrocytomas, most HRs were below 1 and for grade IV, all HRs were greater than 1, but none were significant.

The fourth case-control study, **Hardell et al. (2013)** [82], covered all of the administrative regions of Sweden and included males and females aged 18-75 years who were diagnosed with a brain tumor between 2007 and 2009 (there were some differences by region). Deceased cases were excluded from the study. The study eventually included 593 cases (87% response rate) and 1368 controls (85% response rate). There were more female controls responding than males although there were more male cases than female cases. The OR for use of a mobile phone for more than 1 year and malignant brain tumors was 1.6 (0.99-2.7) with very little change by latency until a latency of 20-25 years where the OR was 1.9 (1.1-3.5) and >25 years where the OR was 2.9 (1.4-5.8). They conducted a novel analysis where they used meningioma patients as the controls and saw similar patterns but slightly higher ORs. The OR for ipsilateral use was slightly increased from the overall OR with a value of 1.7 (1.01-2.9). Analyses were also conducted separately for use of analog mobile phones with an OR of 1.8 (1.04-3.3), second-generation (2G) digital mobile phones 1.6 (0.996-2.7) and third-generation (3G) phones 1.2 (0.6-2.4). All of these had the highest ORs in the longest latency group. They also broke exposure to wireless phones (combined exposure to mobile phones and cordless phones) in the controls into quartiles and, using these categories, calculated ORs for malignant tumors and use of mobile phones. Regardless of phone type, the highest ORs were seen in the highest quartile of exposure and analog, 2G and the combined analysis of all mobile phones displayed significant trends with increasing ORs across quartiles. They also did a separate analysis for malignant tumors located in temporal and overlapping lobes and saw a similar pattern with latency, but higher ORs. Finally, they did a separate analysis for exclusive use of each type of phone, but numbers were small in most cases and this does not relate well to phone use (e.g. there were no users of only analog phones since every phone user had moved on to digital phones by the time of this study).

Hardell and Carlberg (2015) [88] pooled the data on glioma patients from all of their case-control studies into one large study; they excluded deceased cases from all of the studies in this analysis. Cases and controls are described above. The pooled cases of malignant tumors number 1498 (89% response rate total) with 817 males and 563 females with gliomas. There are 3530 controls (87% total response rate) with 1492 males and 2038 females. The median latency time for use of mobile phones in glioma patients was 9 years (range 2-28 years). All analyses were adjusted for age at diagnosis, gender, socio-economic index, and year of diagnosis. Ever use (>1 year) of analog phones gave an OR of 1.6 (1.2-2.0), ever use of 2G phones gave an OR of 1.3 (1.1-1.6), ever use of 3G phones gave an OR of 2.0 (0.95-4.4), ever use of any 2G or 3G digital phone gave an OR of 1.3 (1.1-1.6) and ever use of any mobile phone gave an OR of 1.3 (1.1-1.6). For any use of mobile phones, all latency groups showed significantly increased ORs except for the >1-5 years group (OR=1.2, 0.98-1.5) and all phone groupings had their highest ORs for the longest latencies. Ipsilateral use of mobile phones gave an OR of 1.8 (1.4-2.2) whereas contralateral use gave an OR of 1.1 (0.8-1.4). Using the method of **Inskip et al. (2001)** [44] gave a relative risk (RR) of 1.5 with $p<0.001$. Dividing hours of exposure into quartiles (as done in [82]) yielded significant trends for use of any mobile phone as well as analog and 2G phones. Age at first use of a mobile phone was significant in all categories with <20 years showing the highest OR=1.8 (1.2-2.8) and the highest ipsilateral OR of 2.3 (1.3-4.2). Using meningiomas as the referent group led to similar results. Multivariate analysis yielded increases per 100 hours of cumulative use for analog mobile phones (1.025, 1.010-1.041) and 2G phones (1.009, 1.005-1.014) but not 3G phones (0.980, 0.944-1.017). Multivariate analysis also yielded increases per year of latency for analog mobile phones (1.056, 1.036-1.076) and 2G phones (1.030, 1.009-1.052) but not 3G phones (1.127, 0.955-1.329).

The greatest strengths of these studies are their use of population-based controls and the high participation rates of cases and controls. One major limitation, as with most case-controls studies, is the use of a questionnaire for obtaining exposure information and the possibility of recall bias. Overall, the studies show little indication of recall bias, especially since the meningioma cases used as the referent population showed little change in the ORs. (Table 1, Table 2, Table 3, Table 5, Table 6)

Baldi et al. (2011) [89] conducted a case-control study (CEREPHY) of brain tumors in the area of Gironde, France. Eligible cases were patients aged 16 and older diagnosed with a brain cancer from May 1, 1999 to April 30, 2001. The study had 221 (70% participation rate) cases and 442 (69% participation) controls matched on age, sex and residence. Gliomas were seen in 105 cases (26 ever used a cellular phone) and the OR for ever versus never use of a cellular telephone was 0.82 (0.53-1.26). The use of a cellular telephone exceeded 10 years for 1 user and 5 years for 12 users. (Table 1)

The CERENAT study by **Coureau et al. (2014)** [90] is a multicenter case-control study conducted in four areas of France. Cases were defined as all subjects aged 16 and over diagnosed between June 2004 and May 2006 and living in one of four French areas (Gironde, Calvados, Manche, Herault) with a benign or malignant brain tumor (with specific ICDO-3 codes). These tumors were verified either through neuropathological, clinical or radiological assessment. For each case, two controls with no history of CNS tumors were randomly selected from electoral rolls and matched on age (±2 years), sex and department of residence. Exposures were determined through non-blinded, face-to-face application of questionnaires; proxies were given a simplified questionnaire. Regular users were defined as people who were phoning at least once per week for 6 months or more and at least one-year prior to diagnosis. An adjustment was made for subjects using hands-free calling or sharing their phones with others. The analyses for gliomas included 253 cases and 504 controls with a participation rate of 66% for gliomas and 45% for controls. The OR for regular users versus others was 1.24 (0.86-1.77) adjusted for level of education and exposure to ionizing radiation. Exposure-response analyses were conducted for time since first use (p=0.17, ≥10 years 1.61, 0.85-3.09), average calling time per month (p<0.001, ≥15 hours 4.21, 2.00-8.87), average number of calls per day (p=0.04, 5-9 calls 2.74, 1.33-5.65, ≥10 calls 1.78, 0.88-3.59), cumulative duration of calls (p=0.02, ≥896 hours 2.89, 1.41-5.93) and cumulative number of calls (p=0.41, ≥18,360 calls 2.10 (1.03-4.31). Analyses excluding proxies saw almost the same results. Among the heaviest users (≥896 hours cumulative duration of calls), the OR for 5-year latency was 5.30 (2.12-13.23), for occupational users the OR was 3.27 (1.45-7.35) and for exclusive use in an urban setting the OR was 8.20 (1.37-49.07). Ipsilateral use (0.70, 0.46-1.07) was higher than contralateral use (0.30, 0.17-0.52), however, these findings were questioned by **Hardell and Carlberg (2015)** [91] because the approach used was different than that used in their analyses and in the Interphone Study. The authors responded [92] and, using the same method as **Hardell and Carlberg (2015)** [88], obtained an OR for ipsilateral use of 4.21 (0.70-25.52) and for contralateral use of 1.61 (0.36-7.14). They also applied the same method used in **Inskip et al. (2001)** [44] and obtained an OR of 2.40 (1.002-5.73). The major weaknesses of this study are the response rates and the use of questionnaire data for exposure. The authors addressed concern for recall bias by carefully assessing exposure in the highest exposed individuals. They found that there may be some small concern for exposure misclassification, but it is likely to be non-differential and is unlikely to have affected the final results. (Table 1, Table 2, Table 3, Table 4, Table 5, Table 6, Table 7)

Yoon et al. (2015) [93] conducted a case-control study in five areas of Korea (Seoul, Gyeonggi-do, Gyeongsang-do, Jeolla-do, Chungcheong-do, Gangwon-do, and Jeju-do). Cases (285 participated, 142 refused, 465 had excessive pain and 5 had no matched control) were identified as glioma patients between the ages of 15 and 69 years of age and controls (285 participated, 354 refused, 7 had excess pain and 405 had no matched case). Cases and controls came from the recruiting hospitals and were given a questionnaire during the initial interview. Cases were also excluded if they died during the course of the study. There were some significant differences between cases and controls (residential region, education, patient or proxy, use of dye, alcohol use, computer use and use of electric blankets). Users were defined as having more than 1 year of cellular phone use. The OR for users was 1.17 (0.63-2.14) for all respondents and 0.94 (1.46-1.89) for self-respondents. The largest group of users had used both analog and digital phones and they had an OR of 1.89 (0.96-3.81). Lifetime years of use, cumulative hours of use, average number of calls received daily, average number of calls sent daily and average duration of calls had ORs that were generally greater than 1.0, included 1.0 in the 95% confidence interval, and did not appear to show dose-response although no test was done. Using the method of **Inskip et al. (2001)** [44] gave a relative risk (RR) of 1.26 (p=0.05) for all respondents and 1.43 (p=0.01) for self-respondents. ORs for ipsilateral versus contralateral use were very mixed and seldom included the OR from the original evaluation as falling between the ORs for the two sides (it appears they used the same method as the **CERENAT study (2014)** [90] but this cannot be verified). Besides the usual possibility of recall bias in these types of studies, this study's weaknesses include poor reporting of the methods, an unusual exclusion of patients due to pain and very high refusal rates for both cases and controls. (Table 1, Table 2, Table 3, Table 6)

4.1.1.2 Cohort Studies

Schuz et al. (2006) [94] extended the evaluation of a retrospective cohort study in Denmark [95]. They identified 723,421 cellular telephone subscribers in Denmark from 1982 to 1995, 420,095 of whom could be identified as individuals and became part of the cohort. The other 303,326 were excluded because the user was listed as a corporation (200,507) or excluded for other reasons (102,819). Approximately 85% of the cohort members were males. Only first cancer diagnoses were used in this analysis and the ending date of follow-up is December 31, 2002. The observed cancers in the cohort were compared to the expected numbers in the Danish population using the Danish Cancer Registry after subtracting the number of cancer case patients and person-years observed in the cohort from those in the registry.

There was a significant decrease in all cancers for males (RR 0.93, 0.92-0.95) and a marginally significant increase in females (1.03, 0.99-1.07). All of the RRs for cancers in males, including brain and CNS tumors (0.96, 0.87-1.05), lacked statistical significance with 14 of the 20 grouped organ sites having RRs below 1. In females, all smoking-related sites, cervix/uteri and kidney tumors showed significantly increased RRs with brain and CNS tumors non-significant (1.03, 0.82-1.26). For males and females combined, gliomas (1.01, 0.89-1.14), meningiomas (0.86, 0.67-1.09) and cranial nerve sheath tumors (0.73, 0.50-1.03) were all non-significant. There was no increase with years on use in both males and females for brain and CNS tumors (p=0.51) or leukemias (p=0.69).

Frei et al. (2011) [96] conducted an update of the Danish cohort study using the same information on cellular phone subscriptions (1982-1995); hence the update is only with regard to tumor rates and contains no information on cellular phone subscriptions post 1995. Only first cancer diagnoses were used in this analysis and the ending date of follow-up is December 31, 2007. To obtain information on socioeconomic factors, they used the CANULI cohort study data [97] which includes all Danes aged 30 or older born after 1925 in Denmark. Because of eligibility requirements for CANULI, the number of subscribers was reduced by 54,350; thus, the follow-up contained 358,403 subscription holders.

There was a significant decrease in all cancers for males with subscriptions (RR 0.96, 0.95-0.98) and a marginally significant increase in females (1.02, 0.98-1.06). There were slight increases in central nervous system tumors for both males (1.02; 0.94-1.10) and females (1.02; 0.86-1.22) with no apparent increase in risk as years of subscription increased. There was a stronger increase for gliomas alone in males (1.08; 0.96-1.22) but not in females (0.88; 0.69-1.40) with the highest RRs in males for only 1-4 years of subscription (1.20; 0.96-1.50) and the lowest for ≥13 years of subscription (0.98; 0.70-1.36); there was no exposure response in females. There is a chance some of the gliomas could have fallen in the "other and unspecified" category and those saw RRs above 1 for both males (1.12; 0.95-1.33) and females (1.19; 0.85-1.67). For men, RRs for mobile phone use and tumors in the frontal lobe (1.13; 0.89-1.45), temporal lobe (1.13; 0.86-1.48), occipital lobe (1.47; 0.87-2.48) and other or unspecified brain regions (1.35; 1.05-1.75) were above 1. (Table 1, Table 2, Table 7)

Schuz et al. (2009) [98] also looked at central nervous system diseases in this same cohort. They looked for hospital contacts for migraine (RR 1.2, 1.1-1.3), vertigo (1.1, 1.1-1.2), alzheimer's (0.7 , 0.6-0.9), vascular dementia (ns), other dementia (0.7, 0.6-0.8), Parkinson (0.8, 0.7-0.9), ALS (ns), MS (ns), epilepsy in men (0.7, 0.7-0.7) and women (ns).

The biggest concern with all these studies [94, 96, 98, 99] are the various sources of misclassification that could be differential and/or non-differential. By their own count, 303,326 phone contracts could not be assigned to specific users and were classified into the non-user category. In addition, a member of the cohort may have been the owner of the account but not the primary user of the cellular phone (e.g. parents or spouses paying for the account). Using information from a separate case-control study [49], it was estimated that 16% of the non-users could have been frequent users; this was used to suggest the potential impact of this bias on the overall RRs will be low; no sensitivity analysis was provided. No phone data past 1995 was used for any of these analyses. According to the World Bank (2020) [100], there were 15.714 subscriptions to mobile phones per 100 people in Denmark in 1995 against a population of 5,233,373 [101]. To compare, 723,421 subscriptions in Denmark from 1982 to 1995 would be 13.82 per 100 people (very close to the World Bank numbers). By 2002, when the Schuz et al. (2006) [94] follow-up ended, there were 83.341 subscriptions per 100 people (5.3x increase) and by 2007 when Frei et al. (2011) [96] follow-up ended, there were 115.322 per 100 people (7.3x increase); in 2018, there are 125.119 subscriptions per 100 people in Denmark. Thus, of the 1853 male and 1455 female non-subscribers who had gliomas, most of them will have had subscriptions of some sort by 2007. Hence, the exposure misclassification is extreme with many cellular phone users in the non-subscription category who are undoubtedly using mobile phones. Finally, in the **Frei et al (2011)** [96] update, the use of the CANULI database required dropping all cell phone users below the age of 30 before 1995 which appears to be the 54,350 subscribers they lost; hence the youngest phone users before 1995 were excluded from the study.

Benson et al. (2013) [102] used data from the Million Women Study (MWS; for details, see [103, 104]) to evaluate the linkage between brain tumors and mobile phone use. Researchers recruited 1.3 million middle-aged women in the UK into the MWS during the period of 1996-2001. Women completed an initial survey on lifestyle factors, sociodemographic factors and medical history and are resurveyed every 3-4 years. Questions on mobile phone use were asked in 1999-2005 and again in 2009. Information about incident cases of brain tumors were obtained through linkage to Hospital Episode Statistics in England and Scottish Morbidity Records. Of the 866,525 women who answered the questionnaire between 1999 and 2005, numerous women were excluded from the analysis (14,387 got a questionnaire without cell phone usage, 11,981 did not answer the cell phone usage question, 48,531 had CNS tumors at baseline and 6 had a genetic predisposition to get neurological tumors); eventually leaving 791,710 women in the study. Average follow-up time was 7 years (follow-up was through December 31, 2009 except for 1 region where the date was December 31, 2008). Cell phone usage was assessed with two questions: 1) About how often do you use a mobile phone? Never/less than once a day/every day; 2) For how long have you used one? Responses to mobile phone usage questions in 2009 were used to assess the repeatability of earlier questions for the 31,110 women who answered both; however, the questions were different and consistency is not easy to assess. Approximately half of those who reported no use of a mobile phone in the first survey reported use in 2009. There were a number of demographic differences between mobile phone users and non users, including age, affluence, exercise, alcohol and smoking. In addition, the phone users saw less incident cancers (6.05%) than did non-users (7.32%) during the follow-up period. In total, there were 571 gliomas in this cohort. Risk ratios (RRs) for phone use were ever/never 0.91 (0.76-1.08), daily use 0.80 (0.56-1.14), <5 years 0.93 (0.71-1.21), 5-9 years 0.92 (0.75-1.13) and 10+ years of use 0.78 (0.55-1.10) (all adjusted for socioeconomic status, region, age (in 3-year groupings), height, BMI, alcohol intake, exercise and hormone therapy). In a letter responding to a letter by **de Vocht (2014)** [105], **Benson et al. (2014)** [106] updated their follow-up to 2011 but did not update cellular phone usage (still relying on the 1999-2005 response) and saw the RR for glioma for ever/never users of 0.86 (0.75-0.99). Note that with 7 years average follow-up, they saw 571 gliomas or 82/year but adding 2010 and 2011 increased the gliomas by over 100 per year. The main limitations of this study are the rapidly changing exposures to mobile phones and the short follow-up period. Both of these factors likely pushed the results toward the null. In essence, this study creates considerable challenges in terms of misclassification of exposure. For example, a case answering the question in 2005 with 1 year of usage would have 6 years of exposure. In contrast, a woman answering in 1999 with no cell phone usage who then gets a phone in 2000 has 10 years of use but is considered a non-user. This problem is exacerbated by the rapid increase in cellular phone usage in the UK during this period. Cellular phone usage in the UK increased dramatically during the actual study period as well as the recruiting period with rates per 100 people of 9.901 (1995), 12.473 (1996), 78.281 (2001), 108.598 (2005) and 121.73 (2009) [107] so some of the cases with no exposure are likely to have been exposed. They attempted to address these issues by excluding women who reported phone use in 1999-2000 since many of these will have changed their status but this discards the longest exposed individuals and removed 73 glioma patients with cellular phone usage (21.8%). In addition, the fact that the use of a cellular phone is associated with a significant reduction in all invasive neoplasms (e.g. ever use 0.97 [0.95-0.99]) could indicate a difference between the groups that is not being addressed in the analysis. (Table 1, Table 2)

Table 1: Results from epidemiology studies for ever versus never or regular versus non-regular use of a cellular telephone and the risk of glioma in adults

Author (year)	Study Type	Years, Country	Age (years), sex	Tumor Type	Sample Size for all endpoints (% resp.)	Exposed (%) Cases	OR (95% CI)	Comparison group
Hardell et al. (1999)	CC	1994-1996 ,Sweden	20-80, Both	All Malignant Astrocytoma, glioblastoma	272 (90%) Gliomas 439 (91%) Controls	53 (19.5) 36 (38.3)	0.98 (0.63-1.50) 1.09 (0.64-1.84)	>1 year, all malignant (mostly gliomas, 4 NUD) >1 year, astrocytoma & glioblastoma (L&R match)
Muscat et al. (2000)	CC	1994-1998, US	18-80, Both	Astrocytic tumor Oligodendroglioma	354 cases 55 cases	41 (11.6) 9 (16.4)	0.8 (0.5-1.2) 0.9 (0.4-2.1)	Has subscription
Inskip et al. (2001)	CC	1994-1998, US	≥18, Both	Glioma	782 (92%) Cases 799 (86%) Controls	201 (41.4) 121 (24.7)	1.0 (0.7-1.4) 0.9 (0.7-1.4)	Any use >5 times use
Auvinen et al. (2002)	CC	1996, Finland	20-69, Both	Glioma	198 (100%) Gliomas 989 (100%) Controls	32 (16.3)	1.5 (1.0-2.4)	Has subscription
Gousias et al. (2009)	CC	2005-2007, Greece	22-82, Both	Glioma	36 (ND) Gliomas 82 (ND) Controls	ND (ND)	1.0 (0.99-1.01)	ND
Spinelli et al. (2009)	CC	2005, France	≥18, Both	Glioma	122 (17.2%) Gliomas 122 (90.2%) Controls	85 (69.7)	ND (ND)	Used a phone
INTERPHONE (2010)	CC	2000-2004, 13 countries	30-59, Both	Glioma	2765 (64%) Gliomas 7658 (53%) Controls	1,666 (61.5)	0.81 (0.70-0.94)	Avg 1 call per week for 6 mo (lag 1 yr)
Baldi et al. (2011)	CC	1999-2001, France	≥16, Both	Glioma	221 (70%) Brain 442 (69%) Controls	26 (24.8)	0.82 (0.53-1.26)	Ever versus never use
Coureau et al. (2014)	CC	2004-2006, France	≥16, Both	Glioma	596 (73%) Cases 1192 (45%) Controls	142 (57.0) Excluding proxies 123 (21.6)	1.24 (0.86-1.77) 1.33 (0.89-1.98)	Avg 1 call per week for 6 mo
Hardell et al. (2015)	CC	1997-2003, 2007-2009, Sweden	20-80, Both	Glioma	1498 (89%) Gliomas 3530 (87%) Controls	945 (68.5) Per year of latency	1.3 (1.1-1.6) 1.032 (1.017-1.046	>1 year
Yoon et al. (2015)	CC	2002-2007, Korea	15-69	Glioma	285 (32%) Giomas 285 (27%) Controls Excluding proxies 219 Gliomas 273 Controls	235 (83.9) 191 (87%)	1.17 (0.63-2.14) 0.94 (0.46-1.89)	>1 year (maybe also non-regular user)
Frei et al. (2011)	Cohort	1990-2007, Denmark	≥30 at time of entry	Glioma	358,403	324 (17.5) Male 32 (2.2) Female	1.08 (0.96-1.22) 0.98 (0.69-1.40)	Subscription >1 year between 1982 and 1995 Phone use only for before 1995
Benson et al. (2013)	Cohort	1999-2009, UK	Middle-aged women	Glioma	791,710 (65%) Follow-up to 2011	334 (58.5) Ever use 36 (6.3) Daily use Exclude first 3 years 261 (63.3) Follow-up to 2011	0.91 (0.76-1.08) 0.80 (0.56-1.14) 0.83 (0.68-1.02)	Ever used (asked 1999-2005) Every day (asked 1999-2005) Ever used (asked 1999-2005)

Benson et al. (2014)		1999-2011, UK			875 glioma cases vs 571 in 2009	Not given	0.86 (0.72-1.02)	Ever used (asked 1999-2005)

Table 2: Results from epidemiology studies for duration (years) of use of a cellular telephone and the risk of glioma in adults

Author (year)	Study Type	Years, Country	Age (years) sex	Tumor Type	Duration	Exposed cases	OR (95% CI)	P trend	Comments
Inskip et al. (2001)	CC	1994-1998, US	≥18, Both	Glioma	<0.5 years 0.5-3 years >3 years ≥5 years	24 31 30 11	0.6 (0.3-1.1) 0.9 (0.5-1.6) 0.9 (0.5-1.5) 0.6 (0.3-1.4)	ND	Any use 2+ calls/w
Auvinen et al. (2002)	CC	1996, Finland	20-69, Both	Glioma	<1 year 1-2 years >2 years	ND	1.2 (0.5-3.0) 1.6 (0.8-2.9) 1.7 (0.9-3.5)	ND	Has subscription Increase in OR per year 1.2 (1.0-1.4)
Gousias et al. (2009)	CC	2005-2007, Greece	32-82, Both	Glioma	Minute years	ND	1.0 (0.99-1.01)	0.56	undefined
INTERPHONE (2010)	CC	2000-2004, 13 countries	30-59, Both	Glioma	1-1.9 years 2-4 years 5-9 years ≥10 years 1-1.9 Years as referent 2-4 years 5-9 years ≥10 years	155 644 614 252 460 468 190	0.62 (0.44-0.89) 0.84 (0.70-1.00) 0.81 (0.70-0.94) 0.98 (0.76-1.26) 1.68 (1.16-2.41) 1.54 (1.06-2.22) 2.18 (1.43-3.31)	ND	Avg 1 call per week for 6 mo (ag 1 yr), no hands-free Excludes hands-free usage
Coureau et al. (2014)	CC	2004-2006, France	≥16, Both	Glioma	1-4 years 5-9 years ≥10 years Excluding proxies 1-4 years 5-9 years ≥10 years	49 66 22 42 58 14	0.88 (0.56-1.39) 1.34 (0.87-2.06) 1.61 (0.85-3.09) 1.04 (0.64-1.69) 1.46 (0.91-2.33) 1.45 (0.68-3.08)	0.17 0.30	Avg 1 call per week for 6 mo
Hardell et al. (2015)	CC	1997-2003, 2007-2009, Sweden	20-80, Both	Glioma	1-5 years >5-10 years 10-15 years 15-20 years 20-25 years >25 years	362 301 211 92 50 24	1.2 (0.98-1.5) 1.5 (1.2-1.8) 1.4 (1.1-1.9) 1.6 (1.1-2.2) 2.1 (1.3-3.2) 3.0 (1.7-5.2)	ND	>1 year
Yoon et al. (2015)	CC	2002-2007, Korea	15-69	Glioma	1-5 years 5-8 years >8 years Excluding proxies 1-5 years 5-8 years >8 years	97 70 70 37 76 76	1.26 (0.59-2.64) 1.27 (0.65-2.50) 1.04 (0.52-2.06) 0.94 (0.42-2.11) 1.01 (0.45-2.24) 0.90 (0.40-2.02)	ND	>1 year (maybe also non-regular user)

Frei et al. (2011)	Cohort	1990-2007, Denmark	≥30 at time of entry	Glioma	Male 1-4 years 5-9 years ≥10 years 10-12 years ≥13 years Females 1-4 years 5-9 years ≥10 years	Male 85 122 117 80 37 Females 8 14 10	Males 1.20 (0.96-1.50) 1.05 (0.87-1.26) 1.04 (0.85-1.26) 1.06 (0.85-1.34) 0.98 (0.70-1.36) Females 0.87 (0.43-1.75) 1.02 (0.60-1.72) 1.04 (0.56-1.95)	ND	Subscription >1 year between 1982 and 1995 Phone use only before 1995
Benson et al. (2013) Benson et al. (2014)	Cohort	1999-2009, UK 1999-2011, UK	Middle-aged women	Glioma	<5 years 5-9 years ≥10 years Excluding first 3 years <5 years 5-9 years ≥10 years Follow-up to 2011 <5 years 5-9 years ≥10 years	89 185 40 66 148 29 Not given	0.93 (0.71-1.21) 0.92 (0.75-1.13) 0.78 (0.55-1.10) 0.77 (0.57-1.06) 0.86 (0.68-1.09) 0.75 (0.49-1.13) 0.96 (0.75-1.23) 0.86 (0.72-1.02) 0.77 (0.62-0.96)	ND	Ever used (asked 1999-2005) Ever used (asked 1999-2005)

[illegible] Results from epidemiology studies for duration (cumulative hours) of use of a cellular telephone and the risk of glioma in adults

[illegible]	CC	[illegible]	[illegible]	Glioma	[illegible]	[illegible]	[illegible]	ND	[illegible]
[illegible]	CC	[illegible]	[illegible]	Glioma	[illegible]	[illegible]	[illegible]	ND	[illegible]
INTERPHONE (2010)	CC	[illegible]	[illegible]	Glioma	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	CC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	CC	[illegible]	[illegible]	Glioma	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	CC	[illegible]	[illegible]	Glioma	[illegible]	[illegible]	[illegible]	ND	[illegible]

[illegible] Results from epidemiology studies for average daily or monthly use of a cellular telephone and the risk of glioma in adults

Author (year)	Study Type	Years, Country	Age (years), sex	Tumor Type	Measure	Exposed Cases	OR (95% CI)	P Trend	Comparison group
Inskip et al. (2001)	CC	1994-1998, US	≥18, Both	Glioma	Average daily <3 minutes 3 to 15 minutes ≥15 minutes ≥60 minutes	 53 64 51 24	 0.9 (0.5-1.6) 1.0 (0.6-1.6) 0.5 (0.3-1.0) 0.7 (0.3-1.7)	 ND	 Any use 2+ calls/w
Coureau et al (2014)	CC	2004-2006, France	≥16, Both	Glioma	Average monthly <2 hours 2-4 hours 5-14 hours ≥15 hours Excluding proxies <2 hours 2-4 hours 5-14 hours ≥15 hours	 40 19 36 29 36 16 33 25	 0.91 (0.57-1.46) 0.97 (0.50-1.86) 1.70 (0.97-2.99) 4.21 (2.00-8.87) 1.01 (0.61-1.65) 0.59 (0.29-1.21) 1.78 (0.99-3.22) 4.04 (1.84-8.86)	 <0.001 <0.001	Avg 1 call per week for 6 mo

Table 9: Results from epidemiology studies for other use measures of a cellular telephone and the risk of glioma in adults

Author/year	Study Type	Years, Country	Age range, sex	Tumor type	Measure	Exposed Cases	OR (95% CI)	P trend	Comments
Inskip et al. (2001)	CC	1994-1998, US	≥18, Both	Glioma	Year use began			NR	Any use
					1983-1986	61	0.8 (0.4-1.5)		5 years
					1983-1994	62	1.0 (0.6-1.6)		
					<1996	52	0.9 (0.4-1.1)		
					<1990	22	0.9 (0.3-1.9)		
INTERPHONE (2010)	CC	2000-2004, 13 countries	30-59, Both	Glioma	Cumulative use by time since starting use			NR	Avg. 5 yrs before reference date (log hrs?) no hands free
					1-4 years before reference date				
					<5 hours	137	0.68 (0.54-0.91)		
					5-114.9 hours	449	0.82 (0.67-0.95)		
					115-359.9 hours	121	0.74 (0.57-1.03)		
					360-1639.9 hours	82	0.72 (0.50-1.03)		
					≥1640 hours	24	3.77 (1.25-11.4)		
					2-4 years before reference date				
					<5 hours	12	0.86 (0.31-2.28)		
					5-114.9 hours	180	0.86 (0.66-1.13)		
					115-359.9 hours	156	0.71 (0.55-0.93)		
					360-1639.9 hours	178	0.73 (0.54-0.93)		
					≥1640 hours	91	1.26 (0.83-1.97)		
					≥10 years before reference date				
					<5 hours	4	1.15 (0.16-2.25)		
					5-114.9 hours	22	0.63 (0.27-1.25)		
					115-359.9 hours	41	0.84 (0.4-1.74)		
					360-1639.9 hours	98	0.91 (0.43-1.41)		
					≥1640 hours	92	1.34 (0.90-2.03)		
Coureau et al. (2014)	CC	2004-2006, France	≥16, Both	Glioma	Cumulative no. of calls			0.10	Avg. 5 yrs before reference date
					<360	21	1.16 (0.55-2.43)		
					1440-3410	21	1.06 (0.50-2.33)		
					3220-7349	28	1.41 (0.75-2.74)		
					7350-18359	12	1.33 (0.60-3.10)		
					≥18360	21	2.10 (1.03-4.31)		
					Excluding professional use [illegible]				
					<475	15	0.82 (0.42-1.49)		0.14
					1475-3942	21	1.26 (0.40-2.25)		
					[illegible]	35	1.71 (1.47-3.04)		
					10270-18359	11	1.19 (0.57-2.50)		
					≥18360	25	3.11 (1.05-4.33)		
					Outdoor use [illegible]	15	3.22 (1.45-7.33)		
					Rural use only	11	6.20 (1.72-15.37)		
Hardell et al. (2005)	CC	1997-2000, 2000-2003, Sweden	20-80, Both	Glioma	Age				Any use
					<20 years old	65	1.8 (1.2-2.8)		
					20-49 years old	435	1.5 (1.3-1.6)		
					≥50 years old	271	1.3 (1.1-1.6)		

Table 6: Results from epidemiology studies for laterality of cellular telephone use and the risk of glioma in adults

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	CC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
[illegible]	CC	[illegible]	[illegible]	Glioma	[illegible] Left Right	 [illegible] [illegible]		[illegible]	[illegible]
[illegible]	CC	[illegible]	[illegible]	Glioma	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	CC	[illegible]	[illegible]	Glioma	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	CC	[illegible]	[illegible]	Glioma	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	CC	[illegible]	[illegible]	Glioma	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table [illegible] Results from epidemiology studies for cellular telephone use and the location of glioma in adults

Author (year)	Study Type	Years, Country	Age (y) and Sex	Tumor type	Location of Tumor [illegible]	Exposed Controls	OR (95% CI)	Comparison group
INTERPHONE (2010)	CC	2000-2004, 13 countries	30-59, Both	Glioma	Temporal lobe	305	0.86 (0.66-1.13)	Avg 1 call per week for 6 mo (regularly)
					≥10 years since start	93	1.36 (0.88-2.10)	
					≥1640 hours cumulative	78	1.87 (1.09-3.22)	
					≥270 calls (hundreds)	61	1.30 ([illegible]-1.67)	
					Parietal lobe	321	0.77 (0.58-0.99)	
					≥10 years since start	125	0.78 (0.47-1.30)	
					≥1640 hours cumulative	105	1.21 (0.81-1.81)	
					≥270 calls (hundreds)	86	1.06 (0.67-1.70)	
					Other locations	268	0.79 (0.51-1.21)	
					≥10 years since start	47	0.61 (0.36-1.05)	
					≥1640 hours cumulative	18	0.71 (0.35-2.43)	
					≥270 calls (hundreds)	19	0.46 (0.22-1.00)	
Coureau et al. (2014)	CC	2004-2006, France	≥16, Both	Glioma	Temporal lobe	61	3.94 (0.81-19.08)	Avg 1 call per week for 6 mo
					Frontal lobe	76	1.97 (0.67-5.84)	
					Other locations	113	1.11 (0.30-12.62)	
Hardell et al. (2013)	CC	1997-2003, 2007-2009, Sweden	20-80, Both	Glioma	Temporal lobe	347	1.8 ([illegible])	
Frei et al. (2011)	Cohort	1990-2007, Denmark	[illegible]	Glioma	Cerebellum	5	0.80 (0.47-1.36)	Subscription ≥1 year between 1982 and 1995
					Frontal lobe	79	1.03 (0.89-1.41)	Phone use ends before 1995
					Temporal lobe	65	1.05 (0.86-1.28)	
					Parietal lobe	33	0.75 (0.50-1.13)	
					[illegible]	18	1.42 (0.83-2.44)	
					Other or unknown location	72	1.05 (0.81-1.37)	

4.1.2 Studies in Children

Elliott et al. (2010) [108] conducted a case-control study of cancers in children aged 0-4 in Great Britain looking at a linkage to mobile phone base stations. Cases were all registered children with cancer in 1999-2001 (1926 cases) and four controls for each case were chosen from the national birth registry matched by sex and date of birth. Birth addresses (or approximate addresses) were needed for each case and each control leaving a total of 1397 cases and 5588 controls. Three exposure metrics were used, distance from the nearest mobile phone base station, total output from all base stations within 700 meters, and a modeled power density (dBm) from all base stations within 1400 meters of the birth address (modeling was based upon surveys and then validated against later additional survey data). Of the 1397 cases, there were 251 brain cancers (1004 controls). None of the mean exposures for any of the three metrics were different between cases and controls. ORs were very close to 1 for all exposure metrics when exposure was broken into tertiles and the referent group was the first tertile. Similar results were seen in an analysis using the continuous exposure measure directly. The same patterns were true for all cancers and leukemias. (Table 8)

The CEFALO study (**Aydin et al. (2012)** [109]) is an international case-control study conducted in Denmark, Norway, Sweden and Switzerland of children and adolescents aged 7-19 years at time of diagnosis of a brain cancer. Cases had brain tumors with a specific ICD-10 classification and were identified by a combination of factors. Controls were matched on year and month of birth or just year of birth (Norway) with two cases per control. The study included 352 cases (83.2% response) and 646 controls (71.1% response); 213 of the cases had gliomas. Exposure was obtained by personal interviews with mobile phone use 6 months prior to diagnosis excluded from the analyses. Cases were asked for permission to access usage data from mobile phone operators. In Denmark and Sweden, data covered the entire period of usage whereas in Switzerland, data was only kept for 6 months so data were only available for after diagnosis; data from providers in Norway was not obtained. The OR for regular use (one call per week for at least 6 months) versus not was 1.36 (0.92-2.02). All ORs for time since first use were above 1 (1.35 (0.89-2.04) for <3.3 years, 1.47 (0.87-2.49) for 3.3-5.0 years, 1.26 (0.70-2.28) for > 5 years). Similar patterns were seen for cumulative duration of subscriptions (≤2.7 years, 1.34 [0.89-2.01]; 2.8-4 years, 1.45 [0.83-2.54]; >4 years, 1.58 [0.86-2.91]) , cumulative duration of calls (≤35 hours, 1.33 [0.89-2.01]; 36-144 hours, 1.44 [0.85-2.44]; >144 hours, 1.55 [0.86-2.82]) and cumulative number of calls (≤936 calls, 1.34 [0.89-2.02]; 937-2638 calls, 1.47 [0.86-2.51]; >2638 calls, 1.42 [0.79-2.53]). Stratifying the analysis for only gliomas yielded an OR of 1.14 (0.66-1.97) but only included 192 cases (it appears they excluded the 21 ependymomas even though these are gliomas). When they analyzed brain tumors using the operator-recorded data (35% of cases, 34% of controls), they saw a significant trend for time since first subscription (p=0.001) with the highest exposure group (>2.8 years) having a statistically significant OR of 2.15 (1.07-4.29). The same analysis using self-reported use had a trend test with p=0.22 and an OR in the highest exposure class of 1.47 (0.81-2.67). Other exposure metrics saw generally higher ORs using the operator-recorded use data than self-reported use; this is likely due to some degree of differential exposure misclassification since a study showed cases overestimated their numbers of calls (9%) and duration of calls (52%) much less than controls (34% and 163% respectively) [110]. The OR for ipsilateral use (1.74, 0.91-3.33) was not larger than that for contralateral use (2.07, 0.95-4.52), although the definition used for ipsilateral and contralateral was unique to this study [111]. For ipsilateral and contralateral use, exposure-response relationships were seen for all exposure measures and the highest exposure groups had the biggest ORs, many statistically significant. The major strengths of this study include the participation rates and the exposure information. The major weaknesses include a failure to analyze all gliomas and to do the ipsilateral analysis and operator-generated usage on the gliomas alone. There were other criticisms of this paper [112]. (Table 8)

Li et al. (2012) [113] conducted a population-based case-control study of incident cases of all cancers in Taiwan in children and adolescents <15 years of age between 2003 and 2007. Thirty controls were randomly selected for each case and matched on year of birth. The annual power density (APD; wattwatt-year/km^2) for each township was calculated from the 71,185 mobile phone base stations in Taiwan. Exposure was calculated as the average APD five years prior to diagnosis for cases and prior to July 1 for the controls in the year their matched case was admitted. For brain tumors there were 394 cases and 11,820 controls. OR for above median versus below median exposure was 1.09 (0.88-1.36) for the crude estimate and 1.14 (0.83-1.55) for the adjusted estimate (calendar year, age, gender, high-voltage transmission line, and urbanization of township). When the exposures were divided into tertiles, there was an indication of a trend (crude: 1.01 [0.84-1.42] T2, 1.09 [0.77-1.32] T3; adjusted: 1.03 [0.73-1.45] T2, 1.14 [0.70-1.85] T3), but no test for trend was used. The major limitation of this study is that the exposure metric does not pertain to the individual's exposure, but exposure to anyone in the township. Nearness to a tower, use of a cellular telephone, and other sources of RF that might have been related to disease incidence were not assessed. Thus, this study is closer to using an ecological exposure measurement than an individual personal exposure measurement. (Table 8)

Feltbower et al. (2014) [114] conducted a pilot case-control study of children and young adults ages 0-24 in two UK cancer treatment centers. Eligible cases were 0-24 years of age presenting with a diagnosis of intracranial tumor during an unspecified period. At one center, cases were matched by age and sex with a target of 2 controls per case and randomly selected from the general practice. At the second center, 3 friend controls were envisioned but the researchers were unable to attain any controls. Eventually, they were able to interview 49 cases (52% response) and 78 controls (32% response). The study was designed to be compatible with the CEFALO study [109]. The OR for brain cancer and having spoken on a mobile phone more than 20 times was 0.9 (0.2-3.3). The main weaknesses of this study are its size, response rate, and failure to get controls from the second center. (Table 8)

Table [illegible]: Results from epidemiology studies RF and brain tumors in children and adolescents

Author (year)	Study Type	Years, Country	Age group/years	Tumor Type	Sample Size (cases/controls)	Exposed (n) Cases	Group	OR (95% CI)	P-trend	Comparison group
Elliott et al. (2010)	CC	1999-2001, Great Britain	[illegible]	Brain and CNS tumors	[illegible] Brain and CNS		Base station distance			Reference lowest exposure group
						[illegible]	Medium	[illegible]		
						[illegible]	High	[illegible]		Most adjusted analysis
						[illegible]	[illegible] change	[illegible]		
							Total power			
						[illegible]	Medium	[illegible]		
						[illegible]	High	[illegible]		
						[illegible]	[illegible] change	[illegible]		
							Modeled Power			
						[illegible]	Medium	[illegible]		
						[illegible]	High	[illegible]		
						[illegible]	[illegible] change	[illegible]		
Aydin et al. (2011)	CC	[illegible], Denmark, Norway, Sweden, Switzerland	[illegible]	Brain and CNS tumors	[illegible] cases / [illegible] controls	[illegible]	Regular use	1.36 [0.92-2.02]		[illegible]
							Time since first use			
						[illegible]	[illegible]	[illegible]	[illegible]	
						[illegible]	[illegible]	[illegible]		
						[illegible]	[illegible]	[illegible]		
							Duration of [illegible] use			
						[illegible]	[illegible] years	[illegible]	[illegible]	
						[illegible]	[illegible] years	[illegible]		
						[illegible]	[illegible] years	[illegible]		
							Cumulative [illegible]			
						[illegible]	[illegible]	[illegible]	[illegible]	
						[illegible]	[illegible]	[illegible]		
						[illegible]	[illegible]	[illegible]		
							[illegible]			
						[illegible]	[illegible] years	[illegible]	[illegible]	
						[illegible]	[illegible] years	[illegible]		
						[illegible]	[illegible] years	[illegible]		
							Cumulative hours			
						[illegible]	[illegible]	[illegible]	[illegible]	
						[illegible]	[illegible]	[illegible]		
						[illegible]	[illegible]	[illegible]		
							[illegible]			
						[illegible]	[illegible] hours	[illegible]	[illegible]	
						[illegible]	[illegible] hours	[illegible]		
						9	[illegible] hours	[illegible]		
							Tumor location			
						[illegible]	Temporal, frontal [illegible]	[illegible]		
						[illegible]	Other	[illegible]		
							Morphology			
						[illegible]	Glioma	[illegible]		
						[illegible]	Other	[illegible]		
Li et al. (2012)	CC	2003-2007, Taiwan	[illegible] years	Brain tumors	[illegible] cases / [illegible] controls		[illegible]			
						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
						[illegible]	[illegible]	[illegible]	[illegible]	
							[illegible]			Most adjusted analysis
						[illegible]	[illegible]	[illegible]	[illegible]	
[illegible] (2014)	CC	[illegible]	[illegible]	Brain tumors	[illegible] cases / [illegible] controls		[illegible]			[illegible]
						[illegible]	[illegible]	[illegible]		

4.1.3 Discussion

The strongest evidence for an effect of RF on the risks of glioma come from the case-control studies. Case-control studies are designed to compare the exposure characteristics of cases (people who have or have had a glioma) against a collection of controls (people without a history of gliomas). In evaluating the results from case-control studies, researchers must consider two possible sources of bias; selection bias and recall bias. Selection or participation bias occurs when the people who are selected to be a part of the study (both cases and controls) are not willing to participate and that participation is related to both the status of the person (case versus control) and to the exposure (cellular phones) being investigated. For example, if participants that do not use a cellular phone are less willing to participate than participants who do use a cellular phone and that controls are less likely to participate than cases, this can reduce the odds ratio[1] (OR) and hide a potential risk.

Case-control studies rely on measures of exposure that are generally obtained through a questionnaire administered to both the cases and the controls about their past exposures. Because they are recalling past exposures, there is a possibility that this recall may be linked in some way to their status as a case or a control. This is recall bias. For example, if cases are more likely to say they have used a cellular phone than controls or they are more likely to overestimate their cellular phone usage, this could increase the ORs and lead to an overestimation of the risk from cellular phone use. The recall must be different for the cases than the controls for this to cause a bias; errors in recalling past exposures that are similar for both cases and controls would not be recall bias.

Cohort studies generally do not have these two problems since they are asked about their exposure prior to getting the disease of interest. Cohort studies are usually aimed at identifying causes for disease in a large population of people who are followed over time. As the diseases appear in the population, an analysis is done to evaluate the risk ratio[2] (RR) in order to find exposures that are associated with the disease. Exposure is generally determined using a questionnaire administered during the course of the study where participants are asked about their exposures. Disease status (e.g. presence or absence of a glioma) is usually determined through periodic evaluations of cancer registries and publication of the results; thus the study has a baseline date (the date a participant enters into the study) and a follow-up date (the last date of update of the cancer registry or the date the participant got the tumor or the date the participant left the study). In evaluating the results from cohort studies, researchers must consider a different source of bias; exposure

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[1] The odds ratio (OR) is calculated as the proportion of exposed cases with disease to exposed controls divided by the proportion of non-exposed cases to non-exposed controls. For rare diseases, this value approximates the population risk ratio (PRR) which is the probability of having the disease in exposed individuals divided by the probability of having the disease in non-exposed individuals. If the PRR is 1, then there is no difference in the probability of having the disease regardless of your exposure. Values of PRR greater than 1 imply the risk is higher in the exposed population. Because the OR is an estimate of the PRR for rare diseases, it is usually accompanied by a 95% confidence interval that describes the probable range of the estimate. If the OR is greater than 1, then the exposure is associated with the disease. If the lower 95% confidence bound for the OR is greater than 1, this is typically used to say the association is statistically significant.

[2] The rate ratio (RR) is estimated as the incidence in the exposed population divided by the incidence in the unexposed population. Incidence is calculated as the number of events in a fixed period of time divided by the person years at risk. Unlike the OR, the RR does not require the assumption of a rare disease to serve as a good estimate of the population risk ratio (PRR). Like the OR, RR>1 implies an association between the disease and the exposure.

misclassification. Exposure misclassification occurs when the exposure for participants is incorrectly applied. For example, if a participant is asked on Tuesday about their cellular phone use and they do not use a cellular phone, they would be classified as a non-user. If on Wednesday, they go to the store and purchase a phone, they are now a user, but if they do not get asked again about their use prior to the follow-up date, they would be misclassified in any evaluations. Non-differential exposure misclassification occurs when the probability of an error in determining whether an individual is exposed or not is the same for both those with the disease and for those without the disease. Non-differential exposure misclassification generally results in RRs that are closer to 1 than the true underlying risk would imply and can hide risks that are really there. Differential exposure misclassification occurs when there is a difference in the exposure misclassification between those with the disease and those without. Depending on the direction of the misclassification relative to disease status, this can either hide risks or inflate risks. For example, if those with the disease are more likely to be misclassified as non-exposed, the estimated RRs will be smaller than they should be and this would result in a reduced estimate of the risk.

Finally, one other problem to be carefully considered is confounding. Confounding occurs when exposure is correlated with another factor that is also associated with the disease of interest. For example, if age is associated with the incidence of gliomas and is also correlated with cellular phone usage, failure to recognize this potential confounding could lead to an association between cell phone usage and the incidence of gliomas that is spurious. To avoid this, researchers, when evaluating their data, will "adjust" the analysis for other potential confounders. Thus, in evaluating the findings from these studies, it is important to evaluate what adjustments were made for potential confounders in the analysis. This problem can affect both case-control studies and cohort studies.

In evaluating the epidemiological evidence, there are three areas that need to be carefully explored: consistency of the association, the existence of an exposure-response relationship (definitions to follow), and the strength of the association.

4.1.3.1 Consistency of the Association

I will focus on the main studies listed in Table 1. All of these studies did a reasonable job of addressing confounders in their analyses and so this problem will not be discussed further. First, we should consider timing of the study. According to the **World Bank** [115], 0.001% of people globally had subscriptions to mobile phones in 1980. By 1990, that was 0.2% and by 2000 it was 12%. In the US, by 1990, 2% of people had subscriptions and by 2000, 39% had cellular phones. Thus, for studies in the 1990s, we are looking at a rare exposure and trying to associate it with a rare disease (gliomas) and probably with very little time from the beginning of exposure to disease onset. Thus, it is unlikely that studies like **Hardell et al. (1999)** [85], **Muscat et al. (2000)** [40], **Inskip et al. (2001)** [44], and **Auvinen et al. (2002)** [45] would show much of an association. And that is basically the case, with these studies producing ORs of approximately 1.0 except for **Auvinen et al. (2002)** [45] with an OR of 1.5 (1.0-2.4). Thus, the later studies are more likely to show an effect if one exists than are the earlier studies and these should be given greater weight.

The size of a study will also matter since studies with greater numbers of cases and controls (especially exposed cases) will generally have smaller confidence bounds and have a greater chance of seeing an effect if one exists. Thus, the studies by **Gousias et al. (2009)** [46] and **Baldi et al. (2011)** [89] will carry less weight in an overall evaluation.

There are also studies where the referent group was "never used a mobile phone" versus studies where the referent group was "not a regular user of mobile phones" defined by different measures. Less weight should be given to studies with comparisons to "never used" simply because the "ever used" group could include people who used a phone only a few times.

Given these caveats, there are 4 case-control studies that should carry the greatest weight; **Interphone (2010)** [48], **Coureau et al. (2014)** [90], **Hardell et al. (2015)** [88] and **Yoon et al. (2015)** [93]. Three of these studies show ORs >1 for regular use of a cellular phone with only one showing a significantly increased OR (**Hardell et al. (2015)** [88], 1.3 (1.1-1.6)).

The largest study, **Interphone (2010)**, has an OR<1 and more cases and controls than the other three studies combined. The ORs also did not increase with increasing duration of the use of a mobile phone (Table 1). This study used cases that were both living and, by proxy information, those who had died before interview. However, in the Interphone study there was some degree of participation bias [48, 116] that could have resulted in a reduction of the ORs by as much as 10% according to some analyses [74, 116]. For example, just looking at the cases and controls from Canada in the Interphone study, the OR for regular use of a cellular phone went from 1.0 (0.7-1.5) to 1.1 (1.0-1.2) when this bias was theoretically corrected [116]. Applying this same bias correction to the Interphone study yields an OR of 0.9, still below 1. Another correction one could use to account for participation bias, and to some degree recall bias, is to use the lowest category of usage as the reference category rather than the non-regular user category. When this was done for the Interphone study, using the lowest duration of use as the reference group, all longer durations were significantly greater that 1.0 (Table 2). Analyses of recall bias in the Interphone study showed very little impact of recall bias on the evaluation of regular usage [74, 116].

The studies demonstrating the greatest ORs for regular use are the studies that went into the pooled analysis by **Hardell et al. (2015)** [88]. Their pooled study showed an overall OR of 1.3 (1.1-1.6) for regular use. In addition, all of the 5-year groupings of duration of use were greater than 1 and all usage longer than 5-years was significantly greater than 1 (Table 2). Only living cases were included. Their response rate was high enough that participation bias is unlikely to have lowered the OR values. It is possible that participation bias could have occurred from the use of only live cases, but in a separate analysis from a subset of the pooled studies, they saw no important differences between their analyses using live cases when compared to analyses using only deceased cases. On the other hand, recall bias could have increased the ORs. In one of the original case-control studies [117] used in their pooled analysis, they evaluated this issue and saw little indication of recall bias. In addition, in their pooled analysis, they used meningioma cases as the reference group since they were likely to have the same recall bias as the glioma cases if recall bias was a problem. The OR from the population-based reference group was 1.3 (1.1-1.6) and dropped slightly to 1.2 (0.97-1.5) with the meningioma reference group. It is unlikely recall bias explains these results.

Spinelli et al. (2010) [47] is also a very small study, but they provided no information on ever versus never use of mobile phones.

Coureau et al. (2014) [90] is about 12 times smaller than the Interphone study and about 7 times smaller than **Hardell et al. (2015)** [88]. Their evaluation showed an overall OR for regular users of 1.24 (0.86-1.77) which rose slightly to 1.33 (0.89-1.98) if proxies are removed. Duration of use was weakly associated with duration of cellular phone use but had the highest OR (1.61 [0.85-3.09]) in the longest duration group (≥10 years) (Table 2). This study used cases that were both living and, by proxy information, those who had died before interview. This study had a lower participation rate than the other two studies and a large difference in participation between cases (66%) and controls (45%). They did not have a questionnaire for non-participants so there is no information on whether participation bias is a problem in this study. Exposure from mobile phones was done by interview using a standardized questionnaire which limits mistakes, but does nothing to control for potential recall bias. The fact that ORs for analyses with proxies versus those without proxies gave equivalent results helps to reduce the possibility of recall bias, but the number of proxy respondents was small.

Yoon et al. (2015) [93] has about twice as many exposed cases as **Coureau et al. (2014)** [90]. The OR for regular use was 1.17 (0.63-2.14) dropping to 0.94 (0.46-1.89) if proxy responders are removed. The OR for duration of use was >1 for all categories but showed no obvious pattern and dropped slightly when proxies were removed. The participation rates in this study were very low (32% cases, 27% controls) mostly due to cases refusing to participate or not participating due to excess pain. Participation bias and recall bias are certainly possible from this study.

One way in which to evaluate the consistency of these findings across the various studies is by means of a meta-analysis. A meta-analysis is a technique of synthesizing research results by using various statistical methods to retrieve, select, and combine results from previous separate but related studies. There have been numerous meta-analyses on the relationship between cell phone use and gliomas [118-125]. The three most recent studies are worth a quick review. **Roosli et al. (2019)** [118] explored the risks of glioma using the two cohort studies [96, 102] and 10 case-control studies [40, 44, 45, 47, 48, 85, 88-90, 93] based upon an inclusion criteria of 1) a clearly defined source population, 2a) provide a comparison of ever versus never use of a mobile phone (they also included regular use) and/or 2b) allow for an evaluation of long-term use (≥10 years of use before glioma diagnosis) and 3) where there are multiple publications on the same data or subsets of the same data, they included the most recent comprehensive analysis. Where there were multiple publications of subgroups of studies (e.g. Interphone), they did sensitivity analyses to examine the impact of using the subgroups rather than the pooled publications. Meta-estimates of glioma risks (mRRs) were calculated using a random-effects model using the DerSimonian and Laird method using Stata (version 11.2, Stata Corp, College Station, Texas). Unless noted otherwise, all of the meta-analyses used the same method of a random-effects model and the DerSimonian and Laird method).

The main analysis from **Roosli et al. (2019)** [118] is shown in their Figure 1 and give the mRRs for the analyses of studies showing ORs for ≥10 years exposure. For the case-control studies, they get an mRR of 1.30 (0.90-1.87). For the Cohort studies, they show an mRR of 0.92 (0.72, 1.16) and for all studies combined they get 1.11 (0.85-1.46). Entering their numbers into Stata (v 16.2 for MAC), I am able to reproduce their mRRs, however, they had to first calculate an mRR for ≥10 years in the study by Hardell et al. (2015) [88] by combining results from multiple 5-year categories. They list this combination as giving an mRR for ≥10 years for that study of 1.69 (1.40-2.03) whereas when I do the same analysis, I get 1.81 (1.35-2.43). The only way I was able to achieve the same results as **Roosli et al. (2019)** [118] for the mRR was to use a fixed-effects model rather than a random-effects model (this appears to be a mistake in the paper). They also did a meta-analysis of ever versus never use for all 10 case-control studies (1.03 [0.86-1.22]) and the cohort studies (0.97 [0.82-1.15]) with a combined mRR of 1.00 (0.89-1.13). They also conducted a cumulative meta-analysis of the studies with ≥10 years of use splitting the Hardell group studies into those from 1997-2003 and 2007-2009 yielding a slightly higher mRR (1.24 [0.93-1.66]) for all studies combined. They also did several other analyses of ever versus never use with no appreciable changes in the results. One problem with these meta-analyses is that they give very little weight to the largest studies. For example, in their analysis of the 12 ever versus never studies, **The Interphone (2010)** [48] study with 1666 exposed cases got a relative weight of 13%, **Hardell et al. (2015)** [88] with 945 exposed cases got a relative weight of 11.6% and the remaining studies with a total of 1586 exposed cases got a relative weight of >75%. In addition, all of these analyses showed highly significant heterogeneity. Roosli et al. (2019) [118] did not consider laterality or tumor location in the brain.

Wang et al. (2018) [119] did a meta-analysis like that done by **Roosli et al. (2019)** [118] for ever versus never use, but did not include the **Spinelli et al. (2010)** [47] study (no reason given) and instead of using all malignant brain tumors from **Muscat et al. (2000)** [40], they included separate ORs for astrocytic tumors (0.80 [0.50-1.20]) and oligodendrogliomas and mixed gliomas (0.90 [0.40-2.10]). They also included wireless telephones from **Hardell et al. (2015)** [88] in their analyses. Their analysis resulted in an mRR of 1.03 (0.92-1.16). They also did meta-analyses on the data for 0-5 years (0.92 [0.77-1.09]), 5-10 years (1.07 [0.88-1.30]) and ≥10 years (1.33 [1.05-1.67]). Their ≥10 years category was done differently than **Roosli et al. (2019)** [118] in that they did not include **Yoon et al. (2015)** [93] and the 4 exposure categories for **Hardell et al. (2015)** [88] were entered directly into the analysis rather than being pooled first. All of these analyses showed significant heterogeneity which they said was reduced by removing either the Interphone study or the study by **Hardell et al. (2015)** [88]. For ipsilateral tumors and ever versus never use, they saw an mRR of 1.26 (0.87-1.84) in comparison to contralateral use that showed an mRR of 1.10 (0.85-1.42). Finally, evaluating gliomas located in the temporal lobe, again for ever versus never use, they saw an mRR of 1.61 (0.78-3.33) [Note that in the text of the manuscript rather than their table, they list this mRR as 0.93 (0.69-1.24); I was able to verify the mRR of 1.61 but could not find a reasoning behind the number in the text]. The relative weights for the individual studies also fail to match the sample sizes in these evaluations.

Yang et al. (2017) [120] also performed a meta-analysis on some of the studies included in this review. Their analysis excluded both the **Hardell et al. (2015)** [88] pooled analysis and the **Interphone (2010)** [48] pooled analysis. Instead, they included the **Hardell et al. (2011)** [126] study that included the pooled analysis of the 1997-2003 studies with the inclusion of deceased cases and individual Interphone studies from separate countries [49, 52, 54, 55, 59, 61] or a pooled analysis from 5 countries [64]. For ever versus never use, they saw an mRR of 0.98 (0.88-1.10) and for ≥10 years duration of use, the mRR was 1.44 (1.08-1.91); both evaluations showed substantial heterogeneity. For ipsilateral use and ever/never exposures, the mRR was 0.97 (0.88-1.06) whereas for contralateral use it was 0.75 (0.65-0.87) with marginal heterogeneity. For ≥10 years use, the ipsilateral mRR was 1.46 (1.12-1.92) and contralateral use was 1.12 (0.81-1.55) with no heterogeneity. The studies on laterality did not include the study by **Hardell et al. (2011)** [126] for low-grade (1.11 [0.87-1.42] ever/never, 2.22 [1.69-2.92] ≥10 years) and high grade (0.82 [0.68-0.99] ever/never; 1.16 [0.85-1.59] ≥10 years) gliomas.

The remaining meta-analyses are older and use fewer and fewer of the individual studies. One meta-analysis worth mentioning is the one done by **Hardell et al. (2013)** [127] directly comparing the results of **Hardell et al. (2011)** [128] with the results from the pooled **Interphone (2010)** [48] study. For a latency of ≥10 years, the saw the following mRRs: all users 1.48 (0.65-3.35); ipsilateral 1.84 (0.80-4.25); contralateral 1.23 (0.40-3.73); temporal lobe 1.71 (1.04-2.81). For a cumulative use ≥1640 hours, they saw the following mRRs: all users 1.74 (1.07-2.83); ipsilateral 2.29 (1.56-3.37); contralateral 1.52 (0.90-2.57); temporal lobe 2.06 (1.34-3.17). An important point of this report is that the **Interphone (2010)** [48] study included adults 30-59 years of age and **Hardell et al. (2011)** [128] extracted the same group from their 1997-2003 pooled analysis [86] and adjusted the exposure groupings to match the Interphone groupings. They did not present these numbers in their meta-analysis, but that can be done. The results of the same random-effects modeling as done by **Hardell et al. (2011)** [128] yields the following results: ≥10 years 1.30 (0.72-2.33); ≥1640 hours 1.48 (1.13-1.92); ≥1640 hours ipsilateral 2.03 (1.37-3.00); ≥1640 hours contralateral 1.32 (0.76-2.28).

It is clear from these numerous meta analyses, that the choice of which studies to use, how to enter the multiple studies by Hardell et al. and whether to use the pooled analysis from the Interphone study or some of the single analyses can have an impact on the final values. To provide a better view of the results, Figure 1 is a forest plot of all of the ORs from individual publications that evaluated regular use versus minimal or never use or ever use versus never use (if both were given in a study, regular use is shown). The column labeled "Study" provides the reference to the publication and the years in which cases and controls were collected for case control studies and the years when phone use information was collected for cohort studies and the year in which follow-up ended. Some studies are pooled evaluations of multiple other studies, so the other studies are indented. For example, the **Interphone (2010)** [48] study (Study F) is the pooled analysis of studies from 13 countries. **Lahkola et al. (2007)** [64] (Study F3) is a pooled analysis of the data from 5 of those countries and **Christenson et al (2005)** [49] (Study F3a) is the publication for data from one of those 5 countries. The column labeled "RR" is the risk ratio (OR, RR or mRR) from the study, "Lower" and "Upper" are the lower and upper bound on a 95% confidence interval around the RR. The graphic on the right simply plots the RR as a square or diamond with the "whiskers" (blue line running through the box) showing the width of the 95% confidence interval. The vertical line passing through 1 represents no effect. If the box and both whiskers are to the right of this line (greater than 1) and not touching it, this finding is statistically significant with a positive effect; if they fall completely to the left of the vertical line (below 1), then the risk is significantly reduced. The blue boxes that are filled in are major studies, the blue boxes that are white in the middle are the sub-studies and the red diamonds are all meta-analyses.

The graphic in Figure 1 is very useful for examining these types of data in a single view. Looking just at the filled in blue blocks (Studies A,B,C,D,E,F,G,H,I,J,K,L), it is clear some studies (D, I) fall clearly above the vertical line and demonstrate statistically significant increased risk. One study (F) shows a significant reduction in risk. The remaining studies show increases (H, J, K) or decreases (A, B, E, G, L) or no risk (C). The question to be addressed is what is the overall tendency of these data? The meta-analyses address this issue. The first meta-analysis (Meta Analysis A,B,C,D,E,F,G,H,I,J,K,L) combines the information from all of the major studies to produce an mRR of 1.01 (0.92-1.11) for ever versus never exposure suggesting that all of the positives and negatives balance out to give no overall effect. This meta-analysis also shows these studies are very different (Homogeneity Test: p=0.01) which suggests the combination is not accounting for all of the variability in the RRs. However, as mentioned earlier, the newer, larger studies represent longer exposures, so I have also done meta-analyses on four large, recent case-control studies (F,H,I,J) and the two cohort studies (K,L) which should carry the greatest weight in any decision. Combining the four case-control studies (Meta Analysis F,H,I,J) results in a mRR of 1.09 (0.8-1.49), a slight increase in risk from the use of a mobile phone, but still heterogenous across studies. The combined cohort studies yield a mRR of 0.97 (0.74-1.27) suggesting no risk, and no heterogeneity (p=0.84). Combining the 4 case-control studies and the 2 cohort studies (Meta Analysis F,H,I,J,K,L) yields an mRR of 1.03 (0.86-1.24) again suggesting no risk but with significant heterogeneity (p=0.00).

As mentioned earlier, the Interphone study did an alternate set of analyses where the referent group was different depending upon the exposure metric being used (Appendix 2 Table, **Interphone (2010)**). It is possible to use meta-analysis to combine these results to get a pseudo regular/not mRR for each exposure metric[3]. The rows labelled F6, F7 and F8 are the mRR values for these meta-analyses: F6 is an estimate of ≥2years since start of regular use compared to 1-2 years of regular use [mRR 1.75 (1.40-2.18)], F7 is ≥5 hours of cumulative hands-free use compared to <5 hours [mRR 1.16 (1.00-1.35)], and F8 compares ≥1500 cumulative calls to <1500 cumulative calls [mRR 1.12 (0.96-1.30)]. To evaluate the sensitivity of the meta-analyses to the use of this alternative set of reference groups, I applied the least significant evaluation (F8) to the meta-analyses as a replacement for the Interphone study value (F). For the full analysis (Meta Analysis A,B,C,D,E,F8,G,H,I,J,K,L), the mRR becomes almost statistically significant; mRR 1.06 (0.98-1.15). Using just the larger and recent case-control studies (Meta Analysis F8,H,I,J), the mRR is significant [mRR 1.19 (1.07-1.33)] as is the combination of these case-control studies with the cohort studies [mRR 1.12 (1.01-1.24)]. None of these meta-analyses substituting F8 for F show significant heterogeneity. Thus, the meta-analysis is highly sensitive to the use of the reference group for the Interphone study.

Figure 2 is a forest plot of all of the ORs from individual publications that reported on duration of use ≥8 years or more. There are 6 studies; 5 of these studies show groupings of 1-4 years, 5-9 years and ≥10 years and one study with groupings of 1-5 years, 5-8 years and ≥8 years. For the study by **Hardell et al. (2015)** [88], groupings of 10-14, 15-19, 20-24 and ≥25 years were combined by meta-analysis to get a single mRR for ≥10 years. For **Frei et al. (2011)** [96], individual male and female RRs were combined by meta-analysis to get a single mRR for males and females combined. There are 4 groups of meta-analyses each with three separate meta-analyses for 1-4 years, 5-9 years and ≥10 years (combined with 1-<5 years, 5-8 years and ≥8 years respectively for **Yoon et al. (2015)** [93]). The four groups are case-control studies, case-control studies and cohort studies, then the same two groups substituting the original analysis in the Interphone study with their alternative analysis using 1-1.9 years as the referent group. A few things are noticeable in the Forest plot; with the exception of **Yoon et al. (2015)** (D), all of the case-control studies (A, B and C) show increasing ORs with increasing duration of use. The cohort studies (E and F) generally have decreasing RRs with increasing duration. In the meta-analyses, regardless of how the data are combined, there are increasing mRRs with increasing duration. The case-control studies generally show larger mRRs than the case-control and cohort studies combined and using the alternative referent group from the Interphone study yielded the largest mRRs with the highest 2 categories of duration being statistically significant for case-control studies using the alternate referent group.

The studies in adults are consistent.

Aydin et al. (2012) is the only study in children that looked at regular use of a mobile telephone and saw an OR of 1.36 (0.92-2.02). For years since first use, they saw ORs of 1.35 (0.89-2.04), 1.47 (0.87-2.49) and 1.26 (0.70-2.28) for lag times of ≤3.3 years, 3.3-5 years and >5 years respectively. When they used operator-recorded first use and lag times of ≤1.8 years, 1.8-2.8 years and >2.8 years, they saw a significant increasing risk (p=0.001) and ORs of 0.78 (0.43-1.40), 1.71 (0.85-3.44) and 2.15 (1.07-4.29) respectively. When they divided the tumors into gliomas or other tumors, they saw an OR for gliomas of 1.14 (0.66-1.97) and for other of 1.65 (0.93-2.93). They saw no

[3] To build this combination, a meta-analysis is done on all of the risk ratios for a specific exposure metric (e.g. 1-5 years, 5-10 years and ≥10 years latency). To check if this yields reasonable mRRs, meta-analyses were used to combined the various categories under the three exposure metrics in the cases where the referent group is non-regular users. There analysis yielded OR=0.81 (0.70-0.94) whereas doing a meta-analysis to get an equivalent estimate yielded mRR=0.84 (0.72-0.99) for latency years, mRR=0.82 (0.72-0.94) for cumulative hours and mRR=0.82 (0.75-0.90) for cumulative number of call.

relationship with the temporal lobe (1.00 (0.58-1.72). **Feltblower et al. (2014)** saw an OR of 0.9 (0.2-3.3) for young adults who used a mobile phone more than 20 times.

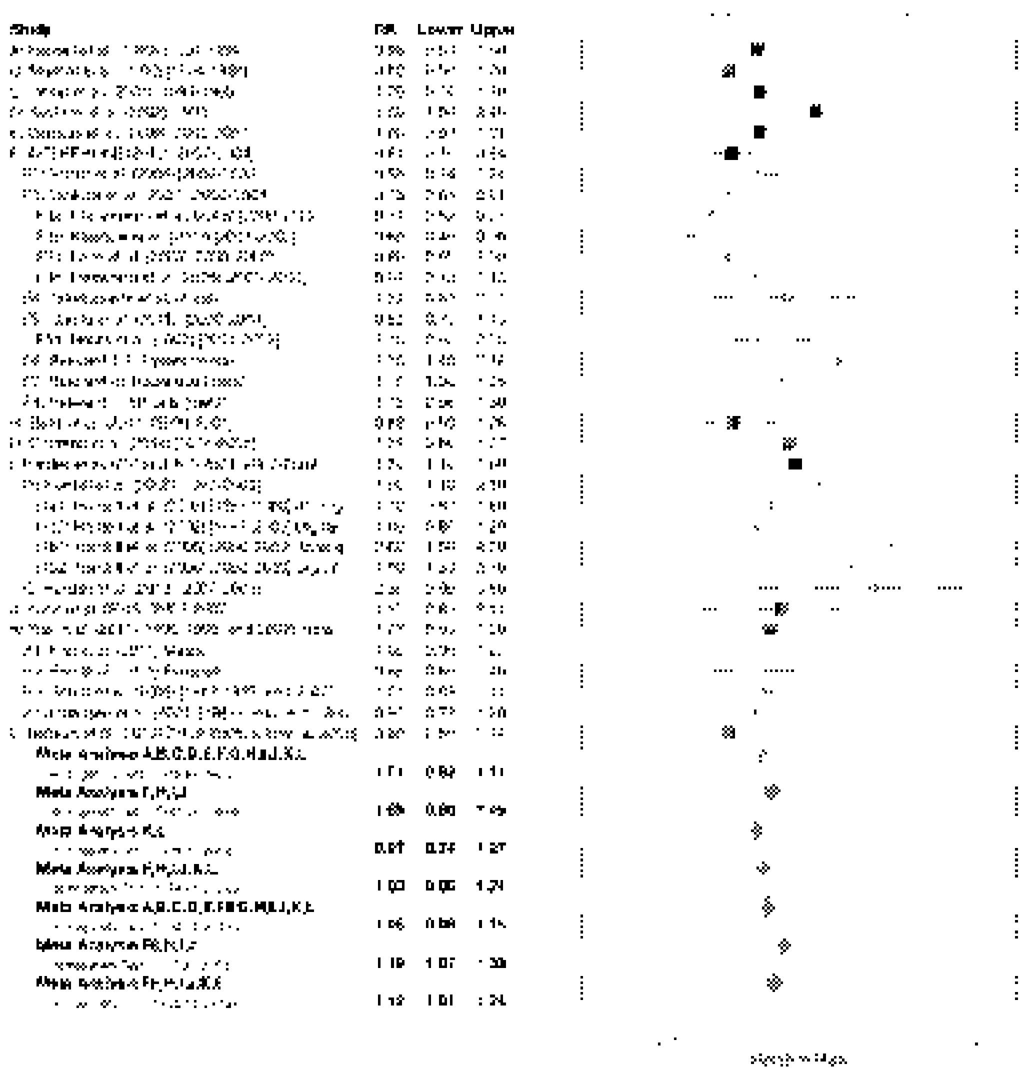
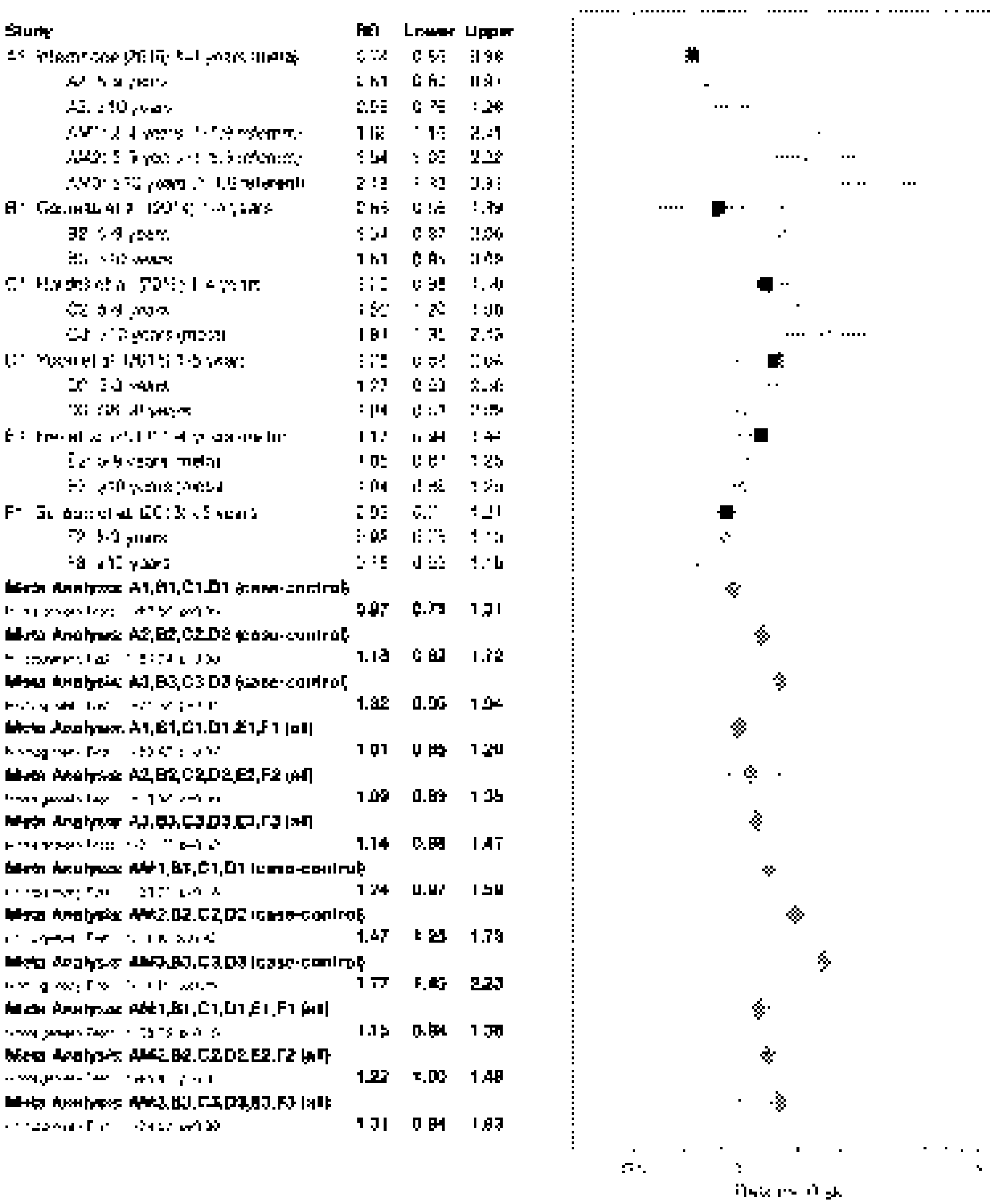


Figure 1: Forest plot and meta analyses of regular use or ever use of cellular telephones and the risk of glioma [studies with a solid blue square either single studies that stand alone or pooled studies that encompass numerous single studies; open squares are individual studies or smaller pooled studies; red diamonds are meta-analyses]*

* - The column labeled "Study" provides the reference to the publication and the years in which cases and controls were collected for case control studies and the years when phone use information were collected for cohort studies and the year in which follow-up ended. Some studies are pooled evaluations of multiple other studies, so the other studies are indented. For example, the Interphone study (Study F) is the pooled analysis of studies from 13 countries. Lahkola et al (2007) (Study F3) is a pooled analysis of the data from 5 of those countries and Christensen et al (2005) (Study F3a) is the publication for data from one of these 5 countries. The column labeled "RR" is the risk ratio (OR, RR or mRR) from the study, "Lower" and "Upper" are the lower and upper bound on a 95% confidence interval around the RR. The graphic on the right simply plots the RR as a square or diamond with the "whiskers" (blue line running through the box) showing the width of the 95% confidence interval. The vertical line passing through 1 represents no effect. If the box and both whiskers are to the right of this line (greater than 1) and not touching it, this finding is statistically significant with a positive effect. If they fall completely to the left of the vertical line (below 1), then the risk is significantly reduced. The blue boxes that are filled in are major studies, the blue boxes that are white in the middle are the sub-studies and the red diamonds are all meta-analyses. "Homogeneity Test" provides the I^2 statistic and the p-value for the Q-test.



[illegible]: Forest plot and meta-analyses of duration of use of cellular telephones and the risk of glioma [studies with a solid blue square are either single studies that stand alone or pooled studies that encompass numerous single studies; open squares area second analysis from that same paper; red diamonds are meta-analyses, the columns and the figure are as in Figure 1].

[illegible]

The best measure for exposure-response relationships is the cumulative hours of use of a cellular telephone since it includes both the frequency of use and the duration of use. While duration of use is also a form of exposure-response, it is more likely that, similar to ionizing radiation, total accumulated exposure is related to the risk of glioma if a relationship exists. Table 8 provides the results for all of the epidemiology studies with estimates of the cumulative use of cellular phones.

Inskip et al. (2001) shows no consistent exposure-response and has all of the ORs below 1. **Spinelli et al. (2005)** show an increase in the OR for use of 48-432 cumulative hours, but this drops for ≥432 hours. In addition, their measure of cumulative hours is different from the remaining studies in that they calculated frequency of use based upon the number of hours allowed in the subscription rather than the actual usage as recounted by the user. This could lead to misclassification of exposure and may have affected the ORs. The **Interphone study (2010)** basically shows flat exposure-response for the entire study until the largest exposure category, that is significantly elevated in risk with an OR of 1.40 (1.03-1.89). Using greater than 0 but less than 5 hours as the referent group, they see higher ORs with a slight increasing pattern and again the highest exposure group significantly elevated. **Coureau et al. (2014)** saw a clearly increasing exposure-response pattern with ORs below 1 in the low exposure categories and becoming marginally significant in the second highest exposure group [1.78 (0.98-3.24)] and significant in the highest exposure category [2.89 (1.41-5.93)]. Excluding proxies did not change this pattern. **Hardell et al. (2015)** saw a clear pattern of increasing risk with increasing exposure with all of their categories statistically significant. They also did a regression resulting in an OR of 1.013 (1.009-1.017) per hundred cumulative hours of use with a p<0.0001. Finally, **Yoon et al. (2015)** saw a similar up-down pattern as **Spinelli et al. (2009)**, but with lower ORs and none of them significant.

It is not possible from the published results to find categories of exposure that match across the various studies in order to do a simple meta-analysis by category. However, it is possible to do a meta-regression where the exposure categories are turned into a single exposure and the meta-regression tests to see if the slope of the data from the various studies is increasing with exposure. In order to do this analysis, I set the exposure for each category equal to the center of the interval defined for the category (e.g., if the category is 512-1486 hours, the midpoint exposure is (512+1486)/2=999 hours). For Inskip et al. (2001), the last category is ≥100 hours and had 54 cases and ≥500 hours had 27, so I chose 500 for the highest exposure. For the remaining studies, it is not clear how to choose the exposure of the highest category. To follow the same pattern seen with **Inskip et al. (2001)**, I chose 5x the lower limit of the last category as the regression point for that category. **Hardell et al. (2015)** did a regression through their data and saw an OR of 1.013 (1.009-1.017) per 100 hours; doing a meta-regression using only the **Hardell et al. (2015)** data with the highest category dose set at 5x1486=7430 hours yields an mRR of 1.011 (1.005-1.018), similar to the result seen by **Hardell et al. (2015)**. A second dosing approach for the last category was to take the difference between the middle of the second largest category and the lower bound of that category and add it to the upper end of the second highest category to get the exposure for the highest category (e.g. if 512-1486 hours is the second highest category and the last category is ≥1486 hours, I set the center of the highest category as (512+1486)/2-512+1486=1973 hours). The exposures for all of the categories of the studies entering into the main meta-regression are shown in Table 9. The study results from **Spinelli et al. (2009)** are excluded from the meta-regression because of the difference in their exposure metric.

Table 10 provides the results of the meta-regression for the 5 case-control studies with duration of exposure where all of the ORs are a comparison against non-regular users. There is a significant association between exposure and risk with an mRR of 1.007 (1.002-1.012, p=0.004). Dropping the **Interphone (2010)** study from the meta-regression results in a highly significant trend (1.011 [1.005-1.017]; p<0.001), almost doubling of the risk, and reduced heterogeneity between the studies. In contrast, dropping the study by **Hardell et al. (2015)** reduces the risk by almost half

(1.004 [0.998-1.010; p=0.184) but the heterogeneity remains. Dropping any of the other studies has little impact on the findings. The alternate dosing strategy for the highest dose yielded the same pattern but mRRs that are roughly 3 times higher than those presented in Table 10 (not shown). (Table 10)

To examine the sensitivity of the analysis to the use of a different referent population in the Interphone study, their analysis using greater than 0 and <5 hours of cumulative exposure as the referent group was plugged into the same analysis. Table 11 provides the results of the meta-regression for the 5 case-control studies with duration of exposure using the alternative referent group. There is an increase in the mRR to 1.010 (1.006-1.014) per 100 hours of use. This fit demonstrated less heterogeneity with I^2=33.95. None of these results change substantially if any one study is dropped from the meta-regression. The alternative high dose yielded the same pattern but higher ORs per 100 hours (not shown). (Table 11)

There were other measures of exposure used in the various studies that are worth mentioning. **Inskip et al. (2001)** used average daily exposure and saw no exposure-response relationship (Table 4). **Coureau et al. (2014)** used average monthly exposure and saw a fairly clear exposure-response relationship (Table 4). **Inskip et al. (2001)** also considered the year that cellular telephone use began and again saw no exposure-response (Table 5). The **Interphone Study (2010)** considered cumulative use by years of duration of use (1-4 years, 5-9 years and ≥10 years). In each duration category, they saw the same pattern of flat exposure-response except for the highest cumulative exposure group that was increased in all categories. The shortest duration had the highest OR in the highest cumulative use category, but also had only 25 exposed cases with that much usage (to get greater than 1640 hours of usage in 4 years would require >1 hour of usage every day) (Table 5). **Coureau et al. (2014)** considered cumulative number of calls and saw a non-significant increasing risk with increasing exposure (Table 5). **Hardell et al. (2015)** used age and saw no pattern (Table 5).

Elliott et al. (2010) compared distance to power station, total power and modeled power to evaluate the contributions of mobile phone towers on the rates of brain and central nervous system tumors in young adults and basically saw no relationship. **Li et al. (2012)** did something similar but calculated exposure for an entire township instead of individuals. They saw slightly increased ORs for different types of divisions of the data and an increase in the risk of brain tumors of 1.09 (0.95-1.25) per standard deviation of their exposure density measure.

Aydin et al. (2013) looked at total cumulative years of use of a mobile phone by self-reporting and operator recorded cumulative years of use and saw marginal increases in risk with increasing exposure (p=0.14 and p=0.15 respectively, (Table 8)). When they also looked at cumulative hours of use for the self-reported and operator-recorded data, they saw no relationship although all ORs were greater than 1.

Table 9: Meta-Regression Exposure Values for Tables 11 and 12

Author (year)	Exposures (times 100 hrs)
Inskip et al. (2001)	0.065, 0.57, 5.00
Interphone (2010)	0.025, 0.09, 0.22, 0.46, 0.88, 1.575, 2.80, 5.475, 11.875, 82
Coureau et al. (2014)	0.215, 0.775, 2.255, 6.27, 44.8
Hardell et al. (2015)	0.615, 3.17, 9.99, 74.3
Yoon et al. (2015)	1.50, 6.00, 45

Table 10: Meta-Regression Analysis with Sensitivity Analysis of ORs for Five Case-Control Studies using Cumulative Hours of Use as the Exposure Metric and the Original Referent Groups

Meta Regression Studies[a,b]	Coefficient	P>|Z|	95% Confidence Interval		I^2	pQ
All	1.007	0.004	1.002	1.012	68.18	<0.001
drop Inskip et al. (2001)	1.007	0.004	1.002	1.012	71.34	<0.001
drop Interphone (2010)	1.011	<0.001	1.005	1.017	54.36	0.006
drop Coureau et al. (2014)	1.006	0.02	1.001	1.011	71.65	<0.001
drop Hardell et al. (2015)	1.004	0.184	0.998	1.010	61.27	0.001
drop Yoon et al. (2015)	1.008	0.001	1.003	1.013	69.85	<0.001
a – studies included in the analysis are Inskip et al. (2001), Interphone (2010), Coureau et al. (2014), Hardell et al. (2015), Yoon et al. (2015); b - Interphone Study uses <1 year duration of use as the referent group						

Table 11: Meta-Regression Analysis[a] with Sensitivity Analysis of ORs for Five Case-Control Studies using Cumulative Hours of Use as the Exposure Metric and the Alternative Referent Group for the Interphone Study

Meta Regression Studies[a,b]	Coefficient	P>|Z|	95% Confidence Interval		I^2	pQ
All	1.010	<0.001	1.006	1.014	33.95	0.054
drop Inskip et al. (2001)	1.010	<0.001	1.006	1.014	38.66	0.037
drop Interphone (2010)	1.011	<0.001	1.005	1.017	54.36	0.006
drop Coureau et al. (2014)	1.009	<0.001	1.005	1.013	35.34	0.065
drop Hardell et al. (2015)	1.008	0.003	1.003	1.013	0.49	0.451
drop Yoon et al. (2015)	1.011	<0.001	1.007	1.014	27.65	0.118

a – studies included in the analysis are Inskip et al. (2001), Interphone (2010), Coureau et al. (2014), Hardell et al. (2015), Yoon et al. (2015); b - Interphone Study uses greater than 0 and <5 hours cumulative use as the referent group

4.1.3.3 Strength of the Association

The strength of the association is tied to the magnitude of the response and the statistical significance of that response. For all of these studies, the actual magnitude of the RRs seen in the studies are small, in many cases falling below 1. It is clear from Figure 2, that the longer the duration, the larger the mRR and the more statistical significance to the risk. It is also clear from Figure 2 that the actual analysis used from the **Interphone study (2010)** can make a difference in the magnitude of the response. This is a strong set of findings.

In addition, laterality matters for addressing the strength of the association. Laterality seems to become more pronounced with a longer duration of exposure or greater cumulative hours of use. For ≥10 years of usage, the **Interphone study (2010)** has an ipsilateral RR of 1.21 (0.82-1.80) and a contralateral RR of 0.70 (0.42-1.15) whereas **Hardell et al. (2015)** saw an ipsilateral mRR of 2.24 (1.61-3.11) (pooling all categories above 10) and contralateral of 1.52 (0.99-2.34). Combining these by meta-analysis yields an mRR of 1.66 (0.91-3.04) for ipsilateral and 1.04 (0.49-2.23) for contralateral with significant heterogeneity (not shown). For cumulative duration of use in the highest category, the **Interphone study (2010)** has ipsilateral 1.96 (1.22-3.15) and contralateral 1.25 (0.64-2.43), **Coureau et al. (2014)** has ipsilateral 4.21 (0.70-25.42) and contralateral 1.61 (0.56-4.62), and **Yoon et al. (2015)** has ipsilateral 1.77 (0.32-1.84) and contralateral 0.63 (0.24-1.65). Combining these by meta-analysis yields an mRR of 1.99 (1.33-3.00) for ipsilateral and 1.11 (0.68-1.80) for contralateral with no heterogeneity (not shown). These results are surprisingly consistent and suggest a strong effect on laterality.

Finally, since the temporal lobe gets some of the highest fields when using a mobile phone, many researchers have looked at whether this location seems to associate with the use of mobile phones.

The Interphone study evaluated this for ≥10 years duration [1.36 (0.88-2.11)] and for ≥1640 hours cumulative use [1.87 (1.09-3.22)]. **Hardell et al. (2015)** did not address this issue for longer latency, but in one of their earlier studies, **Hardell et al. (2013)**, they found the following : 10-15 years latency 1.6 (0.7-4.1), 15-20 years 2.0 (0.8-5.2), 20-25 years 2.7 (1.02-7.3) and ≥25 years (4.8 (1.7-14). A meta-analysis of these numbers from **Hardell et al. (2013)** yields mRR 2.41 (1.49-3.89) (no heterogeneity) which, when combined with **Interphone (2010)** yields an mRR of 1.79 (1.02-3.14) (some heterogeneity, pQ=0.08). Regretfully, no other study looked at this issue for the highest exposure categories. However, 4 studies addressed this for the evaluation of ever versus never exposure and saw ORs of 0.86 (0.66-1.13) (Interphone), 3.94 (0.81-19.08) (Coureau), 4.30 (1.99-9.27) (Hardell) and 1.13 (0.86-1.48) (Frei.). The combined mRR for these 4 is 1.56 (0.88-2.77) with significant heterogeneity (not shown).

4.1.4 Ecological Epidemiology Studies of Malignant Brain Tumors and Gliomas

Ecological epidemiology studies attempt to look at trends of disease in a population and relate this to a particular exposure that changes over time or space in the population. The main difference between an ecological epidemiology study and the studies discussed up to this point (case-control and cohort studies) is that the unit of observation is a population, not an individual. Thus, ecological studies do not ask the individuals about their exposures but instead infer that exposure based upon other information. All of the ecological studies regarding cellular telephone use are based upon the idea that cellular telephone use has been increasing over time and this would imply that glioma rates in a population will be increasing in time as well. To be able to do this type of analysis, one would need to know the statistics on the use of cell phones in this population; something that is seldom known and must be inferred from statistics on ownership of a cellular phone or from the control populations in the case-control studies or from the usage seen in the cohort studies.

Usage data from the cohort studies, if obtained in a timely manner, would be a good estimate of usage in the general population. Regretfully, the two cohort studies in adults obtained these data early on in the use of cellular telephones (1982-1995 in Denmark and 1999-2005 in the UK) and their usage has increased dramatically since that time. Thus, it is hard to extrapolate from the usage in these populations to usage today. In the case-control studies, one can make assumptions of how well the cases and controls represent the general population, but these assumptions generally cannot be tested and may be wrong.

It is also required to have accurate information on cancers in a population. This type of information is usually derived from routinely collected national or regional statistics from cancer registries. Cancer registries can be notoriously inaccurate in the actual diagnosis of the cancer, gaps in coverage of a region or time and other problems. Because of all of these problems, ecological epidemiology studies are often affected by confounding or ecological fallacy (this occurs when inferences about what is happening at the individual level are derived from correlations seen in groups or populations). For these reasons, ecological studies are considered very weak in identifying or excluding risk factors that might be important in a population.

The ecological studies relevant to this review can be broken down into three categories: ecological studies on brain tumors in general, ecological studies on specific types of malignant brain tumors, and ecological studies on acoustic neuromas. In this section, I will review ecological studies on brain tumors and gliomas.

Deltour et al. (2009) [129] investigated temporal trends in glioma incidence rates in Denmark, Finland, Norway and Sweden using data from the national cancer registries. These data are intended to cover the populations incidence for 100% of the Nordic population and there is no discussion about limitations of the data for gliomas. They restricted their analysis to the years 1974-2003. They did a change-point analysis and saw no statistically significant change in incidence rates from 1998-2003, when they claimed changes caused by cell phones would be visible. They concluded any increase in gliomas caused by cell phones, if it exists, is not observable in this population. This is an extension of an earlier paper [130].

Inskip et al. (2010) [131] examined temporal trends in brain cancer incidence rates in the United States using data from the Surveillance, Epidemiology, and End Results (SEER) Program. For this analysis, they used SEER data from 9 cancer-registries which cover about 10% of the US population, restricted their analysis to Caucasians, and covered the years 1992-2006. They only saw increases in the 20-29 year age group in females. They also looked at specific locations in the brain and saw increases in both males and females in frontal lobe tumors. They concluded these findings do not support the view that use of cellular telephones increase cancer risks.

de Vocht et al. (2011) [132] examined temporal trends in brain cancer incidence rates in England using data from the UK Office of National Statistics. These data should cover 100% of the UK population, but there are gaps maybe as high as 35%. They restricted their analysis to the years 1998-2007. They saw no increases in any age group. They also looked at specific locations in the brain and saw increases in both males and females in temporal lobe tumors and in men only, frontal lobe tumors. They concluded these findings do not indicate a pressing need to implement a precautionary principle to reduce RF exposures.

Ding and Wang (2011) [133] investigated temporal trends in brain and nervous tissue cancer incidence rates in Shanghai using data from the Shanghai Cancer Registry. These data should cover 100% of the Shanghai population; gaps were not discussed. They restricted their analysis to the years 1983-2007. They saw a doubling of brain cancer incidence in this period with no statistically significant changes in the increasing rate at any specific time. They concluded the study did not support an increase in brain and nervous system tumors due to RF exposures because the trend began before the widespread use of cellular phones.

Aydin et al. (2011) [109] compared hypothetical incidence trends generated from the ORs seen in their study of childhood brain tumors to incidence data on brain tumors in children and adolescents aged 5-19 years between 1990 and 2008 from the Swedish Cancer Registry. They concluded the patterns did not match and that this indicates that short-term mobile phone use does not cause an increase in brain cancers in children. **Soderqvist et al. (2011)** [112] had concerns regarding the interpretation of these findings and suggested there could still be an effect. **Aydin et al. (2012)** [134] responded, basically reiterating their original arguments.

Deltour et al. (2012) [135] investigated temporal trends in glioma incidence rates in Denmark, Finland, Norway and Sweden using data from the national cancer registries. These data are intended to cover the populations incidence for 100% of the Nordic population and there is no discussion about limitations of the data for gliomas. In this period, incidence rates have increased slightly in men and women, mostly in older populations. Using simulation studies, various relative risks and various induction periods, they simulated the results of a cohort study on the entire population of men aged 40-59 years over this period (with complete follow-up). They then looked to see if they had a significant RR change in that population and equated that to being able to see a change in the incidence rates in the data from the cancer registries. The probability of seeing the change ranged from 2.9 % to 100% depending on the underlying simulation parameters. They concluded that many increased or decreased risks reported in case-control studies are implausible, implying that biases and errors in the self-reported use of mobile phone have likely distorted the findings. This conclusion is at best speculative because the simulations do not actually match the incidence data they are looking at or the analyses they did with the data.

Little et al. (2012) [136] examined temporal trends in brain cancer incidence rates in the United States using data from the Surveillance, Epidemiology, and End Results (SEER) Program. For this analysis, they used SEER data from 12 cancer-registries (coverage of the US population is unknown). They restricted their analysis to non-Hispanic white people and the years 1992-2008. Using the findings from **Interphone (2010)** and **Hardell et al. (2011)**, they predicted what the tumor incidence rates in 2008 should have been by using 1992-1996 as a baseline rate and US subscription data to drive the temporal change. They concluded that the results from **Hardell et al. (2011)** are not consistent with the US SEER data but that the results from the Interphone (2010) study are.

Barchana et al. (2012) [137] examined temporal trends in brain cancer incidence in Israel using data from the Israel National Cancer Registry. These data should cover 100% of the Israeli population and is 95% complete for brain tumors. They restricted their analysis to the years 1989-2009. They focused on high-grade versus low-grade gliomas in males and females. They also examined changes in laterality. They found a decrease in low-grade gliomas over this period and an increase in high-grade gliomas. They also saw an increase in laterality towards more left-sided tumors. They concluded the decrease in low-grade gliomas correlated with the introduction of mobile phone technology in Israel.

Hsu et al. (2013) [138] examined temporal trends in malignant brain cancer incidence rates and death rates in Taiwan using data from the Taiwan National Cancer Registry. There was no discussion of the quality of this cancer registry. They restricted their analysis to the years 2000-2009. Their entire evaluation consisted of a side-by-side comparison in a histogram of deaths, incidence and cell phone usage. No statistical evaluations were performed. They concluded there was no detectable correlation between morbidity/mortality of malignant brain tumors and cell phone use in Taiwan.

Kim et al. (2015) [139] investigated temporal trends in primary brain cancer incidence rates in New Zealand using data from the New Zealand Cancer Registry. These data should cover 100% of the NZ population and there is some discussion about changes in histological classification that could produce a false-negative finding. They restricted their analysis to the years 1995-2010. In general, they saw a decrease in brain tumors over this period with a larger decrease in women than in men. They saw a significant increase in all brain tumors in females aged 30-49, with increases in glioma of the parietal and temporal lobe. This finding was not consistent over other age groups or with the rates in men. They saw increases in the 70+ years group in most categories, but attributed that to better diagnosis, but with no justification. They concluded there has been no increase in primary brain tumors over this period.

Sato et al. (2016) [140] investigated temporal trends in malignant neoplasms of the central nervous system incidence rates in Japan using nationwide estimates of cancer incidence developed by the regional cancer registries. These estimates are intended to cover the populations incidence for 100% of the Japanese population and there is some discussion about limitations of the estimates. They restricted their analysis to the years 1993-2010. They focused on men and women in their 20s and 30s and used data from a survey of cellular phone use to determine if these increases could be due to cellular phone use using the highest response category from the **Interphone (2010)** study as the expected change in risk ratio. In general, they saw an increase in brain tumors over this period with a larger increase in men than in women. They were able to show that the observed increases were greater than what would be predicted for only heavy users and the **Interphone (2010)** OR of 1.4. They then went on to show that using ORs of 6 for men and 12 for women in their 20s and 4 for men and 7 for women in their 30s came close to matching the data. They then concluded that increases in cancers by sex, age and period are inconsistent with sex, age and period usage of mobile phones and thus cannot be explained by the mobile phones.

Chapman et al. (2016) [141] examined temporal trends in brain cancer incidence rates in Australia using data from the Australian Institute of Health and Welfare. These data should cover 100% of the Australian population, but there is no discussion of the quality of the data. They restricted their analysis to the years 1982-2012. They suggested incidence has risen slightly in males and remained steady in females. They then used cellular phone usage data from Australia and created hypothetical curves for a RR of 1.5 for users and a 10-year lag and a second hypothetical curve with a RR of 2.5 for heavy users (defined as >896 hours of cumulative use and assumed for 19% of all users) and a 10-year lag. They concluded the hypothetical curves were significantly different from the observed curves. They cited **Dobes et al. (2011)** [142] as showing no rise in brain tumors in Australia, however, this study concluded there was a significant rise in glioblastoma in Australia from 2000-2008 at an annual rate of 2.5%.

de Vocht (2016) [143] examined temporal trends in brain cancer incidence counts (not standardized rates) in England using data from the UK Office of National Statistics. These data should cover 100% of the UK population, but there are gaps maybe as high as 35% and a 5-year lag in getting complete data. He restricted the analysis to the years 1985-2014. He obtained cellular phone subscription data from the ITU. He built a Bayesian counterfactual model of glioma, glioblastoma, parietal lobe tumors and temporal lobe tumors with covariates annual cancer incidence, population size, median age, cigarette smoking, urbanization rate and a factor to account for data quality in a specific period. The counterfactual model was compared to a model including cell phone subscription rates with several cut points to allow for lag times. He concluded that for glioma, glioblastoma and malignant tumors of the parietal lobe, cell phone usage did not differ from the counterfactual model. For malignant tumors of the temporal lobe, he found cell phone usage could be a causative factor for these tumors. There was a major error in the data used for this analysis and a correction was published [144]. The author claimed it had no impact on the findings although it changed the directions of the effects seen. **de Vocht (2019)** [145] repeated this analysis for glioblastoma in specific brain regions and for meningiomas and acoustic neuromas. Excess of the counterfactual were seen for glioblastomas in the frontal and temporal lobe, but were predominantly in the highest age groups. No excesses were seen for acoustic neuromas or meningiomas. He concluded cell phones are unlikely to be causative for these tumors.

Hardell and Carlberg (2017) [146] demonstrated that the rates of brain tumors of unknown type obtained from the Swedish Inpatient Register were increasing in the years from 1998-2015. In contrast, brain tumor diagnoses confirmed by cytology/histology increased in the Swedish Cancer Registry. Brain tumors diagnosed by MRI and CT are not always reported to the Swedish Cancer Registry. This suggests an under-reporting of brain cancers in the cancer registry and they suggest caution in using cancer registry data to understand any linkage between cellular phone usage and brain cancers. This was also suggested in an earlier evaluation by this group [147].

Phillips et al. (2018) [148] examined temporal trends in brain cancer incidence in England using data from the UK Office of National Statistics. These data should cover 100% of the UK population, but there are gaps maybe as high as 2% and a multi-year lag in getting complete data. They restricted their analysis to the years 1995-2015. They looked at a number of different forms of brain tumors and locations. They saw an increase in glioblastomas for 2011-2015 relative to 1995-1999 by age groups, with the largest increases in the higher age groups. The greatest increases were tumors in the frontal and temporal lobes. They suggest that widespread environmental or lifestyle factors may be responsible, but did not draw any conclusions regarding cellular phones.

Keinan-Boker et al. (2018) [149] examined temporal trends in brain cancer incidence in Israel using data from the Israel National Cancer Registry. These data should cover 100% of the Israeli population and is 95% complete for brain tumors. They restricted their analysis to the years 1990-2015. They focused on benign versus malignant tumors by age and sex. In general, they saw a mixed set of effects that changed over these categories. In conclusion, they found the results to be not consistent with the penetrance of cellular phones in Israel over this period.

Karipidis et al. (2018) [150] examined temporal trends in brain and central nervous system tumor incidence rates in Australia using data from the Australian Institute of Health and Welfare. These data should cover 100% of the Australian population, but there is no discussion of the quality of the data. They restricted their analysis to the years 1982-2013 and cases aged 20-59 years. There is no discussion of standardizing the rates. Percent of the population with mobile phone subscriptions was obtained from the Australian Communications and Media Authority. They used a very simple model to predict incidence rates from subscription data using regular users and heavy users (19%) and various lag times. They concluded that there was no evidence that mobile phone use correlated with any brain tumor histological type or subtype.

Nillson et al. (2019) [151] examined temporal trends in glioma incidence rates in Sweden using data from the Swedish Cancer Registry. These data should cover 100% of the Swedish population. They restricted their analysis to the years 1980-2012 because problems with the registry starting in 2013. They saw no increases in age-standardized incidence rates over time and a significant decrease in low-grade gliomas. They concluded these findings do not indicate any effect of RF exposures on gliomas incidence.

Natukka et al. (2019) [152] examined temporal trends in glioma incidence rates in Finland using data from the Finnish Cancer Registry. These data should cover 100% of the Finnish population. They restricted their analysis to the years 1990-2016 with cases reclassified from 1990 to 2006 to match modern classifications. The data for 2007-2016 could not be classified by sex or age grouping. They discussed several major limitations of their analyses including misclassification, limitations to the analysis and small sample sizes. They saw no increases in age-standardized incidence rates for gliomas over 1990-2006 but could not do this analysis beyond then. There were no major changes in tumor locations over time.

These studies use a variety of different cancer registries and a variety of different methods to evaluate the relationship between temporal changes in brain cancer incidence and the use of mobile phones. Most studies find the relationship between increasing mobile phone use and incidence of brain tumors are inconsistent. However, all of these studies suffer from a variety of problems that are common with ecological studies. In most studies, the surrogate for individual exposure is derived from subscription data and not from actual cellular phone use data. Even in cases where exposure is used (such as high cumulative use), the exposure is simply expressed as a simple percentage of the population. The choice of tumor to examine can have a major impact on the trend as can the statistical model used to examine the data (this is clearly exemplified by the studies using the same UK data and seeing very different results). In many cases, the tumor incidence rates are increasing, but there was insufficient statistical power to identify if the increase matches the increase in cellular phone usage and these were uniformly interpreted as showing no relationship. Finally, the cancer registries themselves have limitations and flaws that may also lead to ecological fallacies regarding their linkage to cellular phone usage.

4.1.5 Conclusions for Gliomas

The evidence on an association between cellular phone use and the risk of glioma in adults is quite strong. While there is considerable difference from study to study on ever versus never usage of cellular phones, 5 of the 6 meta-analyses in Figure 1 are positive and two are significantly positive. Once you consider latency, the meta-analyses in Figure 2 clearly demonstrate an increasing risk with increasing latency. The exposure response meta-regressions in Table 10 and Table 11 clearly indicate that risk is increasing with cumulative hours of exposure, especially in the highest exposure groups. There is a strong tendency toward gliomas appearing on the same side of the head as the phone is generally used and the temporal lobe is strongly suggested as a target. These findings do not appear to be due to chance. The cohort studies appear to show less of a risk than the case-control studies, but one study is likely to be severely impacted by differential exposure misclassification (Frei et al., 2007) and the other (Benson et al., 2012) is likely to have a milder differential exposure misclassification. The case-control studies are possibly impacted by recall bias although that issue has been examined in a number of different evaluations. Selection bias could have been an issue for the Interphone study, but their alternative analysis using different referent groups reduces that concern. Confounding is not an issue here. In conclusion, an association has been established between the use of cellular telephones and the risk of gliomas and chance, bias and confounding are unlikely to have driven this finding. The ecological studies are of insufficient strength and quality to fully negate the findings from the observational studies.

The data in children is insufficient to draw any conclusions.

[illegible] Acoustic Neuromas

[illegible] Studies in Adults

[illegible]

Hardell et al. (1999) [85] did an analysis of acoustic neuromas in their study and saw an OR of 0.78 (0.14-4.20) based on 13 cases. No other information is provided. ([illegible])

Inskip et al. (2001) [44] saw no increases for acoustic neuromas in their study described on page [illegible]. ([illegible])

Muscat et al. (2002) [153] conducted a case-control study of acoustic neuromas from two hospitals in New York city as part of their larger study on brain tumors described on [illegible]. Cases were 18 years of age or older with histologically confirmed acoustic neuromas from 1997 to 1999. There were 90 cases (response rate appears to be 100%) and 86 hospital-based controls matched on age (5-years), sex, race and hospital. Interviewer-based structured questionnaires were used. Regular use was determined by simply asking the patient if they were a regular user. No OR was provided on regular users, but ORs were calculated for years of use, hours/month of use, and total hours. No obvious pattern existed for any of these categories. Ipsilateral use was evaluated using the **Inskip et al. (2001)** [44] method with an OR of 0.9, p=0.07. The main weakness in this study is the potential for recall bias, small sample size, and the short latency. ([illegible])

Warren et al. (2003) [154] conducted a case-control study of intratemporal facial nerve tumors (age not given) in a tertiary care medical center from July 1, 1995 to July 1, 2000 in the United States. As matched controls, and to serve as an alternative case group, they chose 51 acoustic neuroma patients from the same facility. They also had rhinosinusitis controls, dysphonia or gastroesophageal reflux controls and two non-tumor control groups. Matching was based on age (+/- 6 years), sex and race. Cellular telephone usage was assessed via a detailed questionnaire. The study had 51 cases of acoustic neuroma matched with 141 rhinosinusitis, dysphonia or gastroesophageal reflux controls (participation rates were not provided). Ever use of a handheld cellular phone had an OR of 1.2 (0.6-2.2) and use of a handheld cellular phone for more than 1 call per week had an OR of 1.0 (0.4-2.2). They assessed use of tote phones and car phones as well. This is a very small study with limited details. ([illegible])

Baldi et al. (2011) [89] saw no increases for acoustic neuromas in their study. ([illegible])

The Interphone Study Group (2011) [67] also did a case-control study on acoustic neuromas using the same protocol as their brain cancer study [48] shown on [illegible]. As for brain tumors, there were a number of publications from individual countries and/or sub-groups of countries for acoustic neuromas [50, 53, 54, 57, 58, 60, 66, 155, 156]. The odds ratio (OR) of acoustic neuroma with ever having been a regular mobile phone user was 0.85 (95% confidence interval 0.69–1.04). The OR for ≥10 years after first regular mobile phone use was 0.76 (0.52–1.11). There was no trend of increasing ORs with increasing cumulative call time or cumulative number of calls, with the lowest OR (0.48 (0.30–0.78)) observed in the 9th decile of cumulative call time. In the 10th decile (≥1640 h) of cumulative call time, the OR was 1.32 (0.88–1.97); there were, however, implausible values of reported use in those with ≥1640 h of accumulated mobile phone use. With censoring at 5 years before the reference date the OR for ≥10 years after first regular mobile phone use was 0.83 (0.58–1.19) and for ≥1640 h of cumulative call time it was 2.79 (1.51–5.16), but again with no trend in the lower nine deciles and with the lowest OR in the 9th decile. In general, ORs were not greater in subjects who reported usual phone use on the same side of the head as their tumor than in those who reported it on the opposite side, but it was greater in those in the 10th decile of cumulative hours of use. [partially copied from abstract] (Table 12, Table 13, Table 14, Table 16, Table 17)

Han et al. (2012) [157] conducted a case-control study on patients with acoustic neuromas who underwent surgery from 1997 to 2007 at the University of Pittsburgh medical center. The cases were sent questionnaires in 2009-2010 and then interviewed over the phone. Controls were from the outpatient clinic for degenerative spinal disorders at the same medical center, but during the years of 2009-2010. There were eventually 343 (59% response) cases and 343 (response rate not given) controls matched on sex and age (+/- five years). If age-matching was done based on the time of diagnosis for the case or at the time of the questionnaire administration, there should be no problem, but if age-matching was done as diagnosis for the patient matched to current age of the control, this would be a problem for the analysis of cell phone usage. Their main interest was in the relationship between dental x-rays and AN, but they asked about cell-phone usage as a side issue in order to adjust their main analyses on x-rays for cell phone usage. It is not clear exactly how exposure to cellular phones was assessed. If it was done right, regular usage was assessed at the time of the AN patient's diagnosis and the matching control was assessed the same way. The same would need to be true for the duration of use. Any other way in which exposure was assessed would render the interpretation of this study difficult. The questionnaire was not available to address these questions and the write-up does not explicitly make this clear. Assuming the case matching was done correctly and exposure was done correctly, they saw no increased OR [0.95 (0.58-1.58)] for regular use (defined as 1 call per week for 6 months or more) or for use ≤10 years [0.79 (0.45-1.37)] and saw an increased OR for ≥10 years of use [1.29 (0.69-1.63)]. Regular use of a cellular phone was a significant confounder (p=0.006) in their analysis of X-rays and AN. (Table 12, Table 13)

As for malignant brain tumors, **Hardell and colleagues** have published a number of studies on acoustic neuromas and cell phone usage [82, 158-160]. **Hardell et al. (2013)** [82] used data collected at the same time as their pooled case-control study on malignant brain tumors [88], described on page 16, to do a pooled case-control study on acoustic neuromas and cellular phone usage. ORs tended to increase with years of latency with the highest ORs in the longest latency group (>20 years), ORs tended to increase with cumulative use with the largest OR in the highest exposure quartile (>1486 hours cumulative use), ipsilateral ORs were larger than contralateral ORs and changes in tumor volume seemed to be associated with cumulative use. (Table 12, Table 13, Table 14, Table 16, Table 17)

Corona et al. (2012) [161] identified cases of unilateral AN in people ≥18 years of age residing in the municipalities of Salvador and Feira de Santana in Brazil from 2000 to 2010. For each case, they selected 3 controls from the same outpatient clinics as the cases and had visited the doctor "immediately after each case visit". They identified 85 AN patients and 181 controls of which 44 (51.8%) of the cases participated and 104 (57.4%) of the controls participated. There was no description of whether cases and controls were matched on any factor other than clinic. Exposure and demographic information was obtained by interview-administered questionnaire for both cases and controls. For regular use of a mobile phone (defined as one call per week for 6 months), the OR was 1.38 (0.61-3.14). For <6 years of phone use, the OR was 1.14 (0.42-3.08) and for ≥6 years it was 1.81 (0.73-4.47). They also looked at minutes of use per day (≤10, 11-30, >30) and saw increased ORs (1.49 [0.59-3.77], 1.77 [0.62-5.06], 1.15 [0.33-4.08]). Ipsilateral use showed an OR of 1.40 (0.65-3.04) and contralateral use showed an OR of 0.57 (0.23-1.43). (Table 12, Table 13, Table 15, Table 17)

Pettersson et al. (2014) [156] identified incident cases of acoustic neuroma (n = 542) between 20 and 69 years of age at diagnosis from September 2002 to August 2007 in Sweden. Controls (n=1095) were randomly selected from the Swedish population register, matched on age, sex and health-care region. Of these, 451 (83%) cases and 710 (65%) controls participated. The controls were assigned a reference date that corresponded to the date of diagnosis of their matched case. Self-reported exposure information was collected through postal questionnaires, sent to cases and their matched controls simultaneously, starting in October 2007. The referent group was regular users defined as having made or received on average at least one call per week over the last 6 months. Analyses were conducted on all cases and controls and then on cases and their matched controls for which the case was histologically confirmed (47% of cases). The OR for regular use is 1.18 (0.88-1.59). For duration of use, they saw an elevated OR for 5-9 years [1.40 (0.98-2.00)], but not for < 5 years [1.04 (0.72-1.52)] or ≥10 years [1.11 (0.76-1.61)]. Cumulative hours of use saw an exposure-response pattern with the highest OR [1.46 (0.98-2.17)] in the highest exposure group. Cumulative calls saw a similar pattern. When ORs are evaluated for any analog phone usage, the ORs generally increased and the pattern for time since first regular use began is decreasing with years. For digital phones, the pattern is the same as for all phones, with slightly larger ORs. The ORs for histologically-confirmed cases only generally has smaller ORs. ORs for ipsilateral use were generally lower than for contralateral use and near or below 1.0. Over half of the cases who were regular users noted they changed their preferred side of mobile use, mostly due to hearing loss. They attempted to evaluate this issue, but their definition of ipsilateral (having held the mobile phone on the tumor side or on both sides during any period before the reference date) would make it virtually impossible to see an increase in ipsilateral use [NOTE: most studies ask which is the usual hand for holding the mobile phone]. Contralateral was also defined using both sides (or opposite side). This problem is best seen when they looked at laterality over time; at the time of filling in the questionnaire, ipsilateral was 0.31 (0.18-0.53) and contralateral was 2.09 (1.45-3.00) whereas at five years before the reference date, ipsilateral was 0.97 (0.66-1.42) and contralateral was 1.33 (0.89-2.27). They evaluated the potential for recall bias for start year and found no systematic errors that were different between cases and controls [162]. (Table 12, Table 13, Table 14, Table 16, Table 17)

4.2.1.2 Case-Case Studies

Sato et al. (2011) [163] conducted a case-case study of mobile phone use and acoustic neuromas in Japan. Inclusion criteria were all verified cases occurring between January, 2000 and December, 2006 in 22 hospitals recruited to be in the study (32.4% of those asked). Phone usage and other information were obtained by written questionnaire sent to the patient. A total of 1589 cases met the inclusion criteria of which 787 (49.5%) eventually were included in the analysis. Reference dates were set at 1 year and 5 years before diagnosis. The case-case analysis is based upon three assumptions: (1) there was no risk from mobile phones to the contralateral side; (2) risk to the ipsilateral side was the same for left- and right-sided users; and (3) for non-users, incidence of left- and right-sided tumors was the same. Hence, contralateral cases served as controls. Weighted average number of calls per day, weighted average duration of one call and weighted average daily call duration at 5 years prior to diagnosis were all significantly increased (0.043, 0.017, and 0.004 respectively). In addition, patients with an age at diagnosis of <40 years (41 patients) had a significantly increased OR (1.72 [1.08-3.10]). Heavy users (>20 minutes per day) had increased ORs regardless of whether that heavy use was for 1 (2.7 [1.2-7.9]) or 5 (3.1 [1.5-7.4]) years or both (5.0 [1.4-24.8]) or only 5 years (1.9 [0.9-5.8]) before diagnosis, but not for only the period 1 year before diagnosis (0.9 [0.6-2.6]). Tumor sizes tended to be smaller with ipsilateral use compared to contralateral use. The main weaknesses of this study are the potential for recall bias due to the mail-in questionnaire and the low response rate. (Table 17)

4.2.1.3 Cohort Studies

Schuz et al. (2011) [99] used the same cohort as **Frei et al. (2011)** [96] to evaluate the incidence of acoustical neuromas in humans associated with mobile telephone use (description of the cohort on page 19). The cohort was updated to include follow-up to 2006. The results pertain only to people who used phones for greater than 11 years (because of the 1995 cut-off for knowledge of who had a cellular phone subscription) and the referent group is all non-users and people who got phones after 1995. They saw no association (men 0.88, 0.52-1.48, no observed tumors in female users). They also saw no impact of long-term mobile phone use on the size of the tumors. This study has the same limitations of other evaluations with this cohort. There are earlier publications on this cohort [94, 95]. (Table 12)

Benson et al. (2013) [102] also studied acoustic neuromas in their cohort study described on page 19. Relative risks (RRs) for phone use were ever/never 1.44 (0.91-2.28), daily use 1.44 (0.91-2.28)), <5 years 1.0 (0.54-1.82), 5-9 years 1.80 (1.08-3.03) and 10+ years of use 2.46 (1.07-5.64) (all adjusted for socioeconomic status, region, age (in 3-year groupings), height, BMI, alcohol intake, exercise and hormone therapy). In a letter responding to a letter by **de Vocht (2014)** [105], **Benson et al. (2014)** [106] updated their follow-up to 2011 but did not update cellular phone usage (still relying on the 1999-2005 response) and saw OR for acoustic neuroma for ever/never users of 1.19 (0.81-1.75). Note that with 7 years average follow-up, they saw 96 acoustic neuromas or 13.7/year but adding 2010 and 2011 increased the acoustic neuromas by 15 per year. The same limitations mentioned on page 19 also apply here. (Table 12, Table 13)

Table 12: Results from epidemiology studies for ever versus never or regular versus non-regular use of a cellular telephone and the risk of acoustic neuroma in adults

Author (year)	Study Type	Years, Country	Age (years), sex	Tumor Type	Sample Size for all endpoints (% resp.)	Exposed (%) Cases	OR (95% CI)	Comparison group
Hardell et al. (1999)	CC	1994-1996 ,Sweden	20-80, Both	Acoustic Neuroma	13 (ND) Cases ND (ND) Controls	ND (ND)	0.78 (0.14-4.20)	>1 year
Inskip et al. (2001)	CC	1994-1998, US	≥18, Both	Acoustic neuroma	782 (92%) Cases 799 (86%) Controls 96 Acoustic Neuromas	40 (41.7%) 30 (31.2%)	0.8 (0.5-1.4) 1.0 (0.5-1.9)	Any use >5 times use
Warren et al. (2003)	Case-Control	1995-2000	ND	Acoustic Neuroma	51 (ND) Cases 141 (ND) Controls	21 (41.2%) 11 (21.6%) 6 (11.8%) 7 (13.7%) 5 (9.8%)	1.2 (0.6-2.2) 1.0 (0.4-202) 1.0 (0.4-2.7) 1.2 (0.5-3.8) 2.1 (0.6-7.0)	Ever use >1 call per week "tote" phone Automobile phone Automobile phone >1 call/week
INTERPHONE (2010)	CC	2000-2004, 13 countries	30-59, Both	Acoustic neuroma	1105 (82%) Cases 2145 (53%) Controls	643 (58.2%) 304 (27.5%)	0.85 (0.69-1.04) 0.95 (0.77-1.17)	Avg 1 call per week for 6 mo (lag 1 yr) Avg 1 call per week for 6 mo (lag 5 yr)
Han et al. (2012)	CC	1997-2007, US	Age not given, Both	Acoustic Neuroma	343 (59%) Cases 343 (ND) Controls	203 (59.2%)	0.95 (0.58-1.58)	Avg 1 call per week for 6 mo
Corona et al. (2012)	CC	2006-2010, Brazil	18, Both	Acoustic Neuroma	44 (51.8%) 104 (57.4%)	34 (77.3%)	1.38 (0.61-3.14)	Avg 1 call per week for 6 mo
Pettersson et al. (2014)	Case-Control	Sweden	20-69, Both	Acoustic Neuroma	451 (83%) 710 (65%)	302 (67.0%) 143 (70.8%)	1.18 (0.88-1.59) 0.99 (0.65-1.52)	All, Once per week ≥6 months Histopathologically confirmed, Once per week ≥6 months
Hardell et al. (2013)	CC	1997-2003, 2007-2009, Sweden	20-80, Both	Acoustic neuroma	316 (93%) Cases 3530 (87%) Controls	200 (63.3%)	1.6 (1.2-2.2)	>1 year
Schuz et al. (2011)	Cohort	1998-2006, Denmark	≥30 at time of entry	Acoustic neuroma	2,883,665 404 cases	15 (0.38) Male 0 (0) Female	0.87 (0.52-1.46)	Subscription > 11 years prior Phone use only for before 1995
Benson et al. (2013) Benson et al. (2014)	Cohort	1999-2009, UK 1996-2011, (UK)	Middle-aged women	Acoustic neuroma	791,710 (65%) 2009 – 96 cases 2011 – 126 cases	67 (69.8) Ever use 8 (8.3) Daily use Exclude first 3 years 31 (32.3)	1.44 (0.91-2.28) 1.37 (0.61-3.07) 1.96 (0.96-4.02) 1.19 (0.81-1.75)	Ever used (asked 1999-2005) Every day (asked 1999-2005) Ever used (asked 1999-2005) Ever used (asked 1999-2005)

Table [illegible]: Results from epidemiology studies for time (years) since first use of a cellular telephone and the risk of Acoustic Neuroma in adults

Author (year)	Study Type	Years, Country	Age (years), Gender	Tumor Type	Duration	Exposed Cases	OR (95% CI)	P Trend	Comments
Inskip et al. (2001)	CC	1994-1998, US	≥18, Both	Acoustic Neuroma	<0.5 years	4	[illegible]	ND	Any use
					0.5-[illegible] years	[illegible]	[illegible]		[illegible]
					≥3 years	10	[illegible]		
					≥5 years	5	1.9 (0.6-5.9)		
Muscat et al. (2002)	CC	1997-1999, New York City	≥18, Both	Acoustic Neuroma	1-2 years	7	[illegible]	[illegible]	[illegible]
					3-6 years	11	1.7 ([illegible])		
INTERPHONE (2010)	CC	2000-2004, 13 countries	30-59, Both	Acoustic Neuroma	1-1.9 years	[illegible]	0.75 ([illegible])	ND	[illegible]
					2-4 years	[illegible]	0.87 ([illegible])		[illegible]
					5-9 years	[illegible]	[illegible]		
					≥10 years	[illegible]	[illegible]		
					[illegible]				
					5-9 years	[illegible]	[illegible]		[illegible]
					≥10 years	[illegible]	[illegible]		
Han et al. (2012)	CC	[illegible], US	[illegible]	Acoustic Neuroma	<10 years	[illegible]	[illegible]		[illegible]
					≥10 years	[illegible]	[illegible]		
Corona et al. (2012)	CC	[illegible], Brazil	[illegible], Both	Acoustic Neuroma	<[illegible] years	12	[illegible]	ND	[illegible]
					≥[illegible] years	[illegible]	[illegible]		
Pettersson et al. (2014)	Case Control	Sweden	20-69, Both	Acoustic Neuroma	<5 years	[illegible]	[illegible]		[illegible]
					5-9 years	119	[illegible]		[illegible]
					≥10 years	[illegible]	[illegible]		
					[illegible] confirmed				
					<5 years	[illegible]	[illegible]		
					5-9 years	[illegible]	[illegible]		
					≥10 years	[illegible]	[illegible]		
Hardell et al. (2013)	CC	1997-2003, 2007-2009, Sweden	20-80, Both	Acoustic Neuroma	[illegible] years	[illegible]	[illegible]	ND	[illegible]
					[illegible] years	[illegible]	[illegible]		
					10-15 years	[illegible]	[illegible]		
					15-20 years	[illegible]	[illegible]		
					>20 years	12	[illegible]		
					[illegible]		[illegible]		
Benson et al. (2013)	Cohort	1999-2009, UK	[illegible] women	Acoustic Neuroma	<5 years	19	[illegible]	[illegible]	[illegible]
					5-9 years	[illegible]	[illegible]		
					≥10 years	[illegible]	[illegible]		
					[illegible]				
					<5 years	4	[illegible]		
					5-9 years	[illegible]	[illegible]		
					≥10 years	[illegible]	[illegible]		
Benson et al. (2014)		[illegible], UK			<5 years	No data	[illegible]	[illegible]	[illegible]
					5-9 years		[illegible]		
					≥10 years		[illegible]		

Table 15: Results from epidemiology studies for duration (cumulative hours) of use of a cellular telephone and the risk of acoustic neuroma in adults

Author (year)	Study Type	Years, Country	Age (years), Sex	Tumor type	Cumulative use	Exposed Cases	OR (95% CI)	P trend	Comparison group
Inskip et al. (2001)	CC	1994-1998, US	≥18, Both	Acoustic neuroma	<13 hours 13-140 hours >140 hours >500 hours	7 6 9 3	0.7 (0.2-2.3) 1.2 (0.5-3.1) 1.4 (0.4-3.5) 0.4 (0.1-3.3)	NR	Any use 2 or more
Muscat et al. (2002)	CC	1997-1999, New York City	≥18, Both	Acoustic neuroma	1-60 hours ≥60 hours	5 5	0.5 (0.2-1.4) 0.7 (0.2-2.6)	[illegible]	[illegible]
INTERPHONE (2011)	CC	2000-2004, 13 countries	30-59, Both	Acoustic neuroma	1 year lag <5 hours 5-12.9 hours 13-30.9 hours 31-60.9 hours 61-114.9 hours 115-199.9 hours 200-359.9 hours 360-734.9 hours 735-1639.9 hours ≥1640 hours 5 year lag <5 hours 5-12.9 hours 13-30.9 hours 31-60.9 hours 61-114.9 hours 115-199.9 hours 200-359.9 hours 360-734.9 hours 735-1639.9 hours ≥1640 hours	 76 32 50 56 34 28 30 28 49 77 41 30 40 36 31 22 29 26 22 36	 0.77 (0.52-1.15) 0.61 (0.38-0.99) 1.04 (0.71-1.52) 0.95 (0.63-1.42) 0.76 (0.46-1.43) 0.95 (0.61-1.43) 0.87 (0.56-1.34) 0.77 (0.48-1.08) 0.86 (0.52-1.36) 1.32 (0.88-1.97) 1.07 (0.66-1.69) 1.36 (0.80-2.19) 1.32 (0.80-2.17) 1.06 (0.73-1.47) 0.63 (0.35-1.13) 0.71 (0.39-1.25) 0.85 (0.48-1.45) 0.74 (0.43-1.25) 0.63 (0.34-1.05) 2.79 (1.51-5.16)		[illegible]
Pettersson et al. (2014)	Case Control	Sweden	20-69, Both	Acoustic Neuroma	≤38 39-189 190-679 ≥680 Mobile/cordless phone combined ≤88 88-359 360-1279 ≥1280	26 27 26 35 30 39 32 37	1.09 (0.73-1.63) 1.12 (0.74-1.67) 1.15 (0.75-1.75) 1.46 (0.98-2.17) 0.97 (0.50-1.70) 0.91 (0.51-1.04) 1.18 (0.57-1.89) 1.14 (0.65-2.07)		[illegible]
Hardell et al. (2013)	CC	1997-2003, 2007-2009, Sweden	20-80, Both	Acoustic Neuroma	Per 100 cumulative hours of use Quartiles 1-122 hours 123-511 hours 512-1486 hours >1486 hours	NA 21 37 13 30	1.003 (1.001-1.004) 1.6 (1.0-2.5) 1.5 (0.9-2.5) 2.4 (1.3-4.3) 3.6 (2.0-6.4)	 <0.001	<1 year

Table 15: Results from epidemiology studies for average daily or monthly use of a cellular telephone and the risk of acoustic neuroma in adults

Author (year)	Study Type	Years, Country	[illegible]	Tumor Type	Measure	Exposed Cases	OR (95% CI)	P Trend	Comments/Adjustments
Inskip et al. (2001)	CC	1994-1998, US	[illegible]	Acoustic neuroma	Average daily <3 minutes 3 to 15 minutes [illegible] minutes [illegible] minutes	 7 [illegible] 5 1	 [illegible] [illegible] [illegible] [illegible]	NR	Any use [illegible]
Muscat et al. (2002)	CC	1997-1999, New York City	[illegible]	Acoustic neuroma	Average monthly [illegible] hours [illegible] hours	 11 7	 [illegible] [illegible]	[illegible]	Referent was subjects who were not regular user
[illegible]	[illegible]	[illegible]	[illegible]	Acoustic Neuroma	[illegible] [illegible] [illegible] [illegible]	 14 11 [illegible]	 [illegible] [illegible] [illegible]	NR	[illegible]

Table 16: Results from epidemiology studies for other use measures of a cellular telephone and the risk of acoustic neuroma in adults

Author (year)	Study Type	Years/Country	Age/population	Tumor Type	Measure	Exposed Cases	OR (95% CI)	P Trend	Comments
Inskip et al (2001)	CC	1994-1998, US	≥18, Both	Acoustic neuroma	[illegible]			NR	Any use [illegible]
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
INTERPHONE (2010)	CC	2000-2004, 13 countries	30-59, Both	Acoustic neuroma	Cumulative call time [illegible]			NR	[illegible]
					[illegible]				
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]				
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]				
					[illegible]	[illegible]			
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
Pettersson et al (2014)	Case-Control	Sweden	20-69, Both	Acoustic Neuroma	Cumulative hours				[illegible]
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		
					[illegible]	[illegible]	[illegible]		

Table 17: Results from epidemiology studies for laterality of cellular telephone use and the risk of acoustic neuroma in adults

[illegible]	Study Type	[illegible]	[illegible]	Tumor Type	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Inskip et al. (2001)	CC	[illegible]	[illegible]	Acoustic neuroma	[illegible]	[illegible]		[illegible]	[illegible]
Muscat et al. (2002)	CC	[illegible], New York City	[illegible]	Acoustic neuroma	[illegible]	[illegible]		[illegible]	[illegible]
INTERPHONE (2005)	CC	[illegible]	[illegible]	Acoustic neuroma	[illegible]	[illegible]	[illegible]		[illegible]
[illegible] (2012)	CC	[illegible]	[illegible]	Acoustic neuroma	[illegible]	[illegible]	[illegible]		[illegible]
Pettersson et al. (2014)	Case Control	Sweden	[illegible]	Acoustic neuroma	[illegible]	[illegible]	[illegible]		[illegible]
Sato et al. (2011)	Case-Case	[illegible], Japan	[illegible]	Acoustic neuroma	[illegible]	[illegible]		[illegible]	[illegible]
Hardell et al. (2013)	CC	[illegible], Sweden	[illegible]	Acoustic neuroma	Regular users	[illegible]	[illegible]		[illegible]

4.2.2 Studies in Children

I could not identify any studies on acoustic neuromas in children and exposure to RF or cellular telephones.

4.2.3 Discussion

As for gliomas, I will focus on three areas of interest from the epidemiology studies of acoustic neuromas (AN); consistency of the association, the existence of an exposure-response relationship, and the strength of the association.

4.2.3.1 Consistency of the Association

The studies to be considered are listed in Table 12 and **Muscat et al. (2002)** in Table 13. All of these studies did a reasonable job of addressing confounders in their analyses and so this problem will not be discussed further. First, we should consider timing of the study. As mentioned earlier, for studies in the 1990s, we are looking at a rare exposure and trying to associate it with a rare disease (AN) and probably with very little time from the beginning of exposure to disease onset. Thus, it is unlikely that **Hardell et al. (1999)** [85], **Inskip et al. (2001)** [44], **Muscat et al. (2002)** [153], **Warren et al. (2003)** [154], and **Baldi et al. (2011)** [89] would show much of an association. And that is basically the case, with these studies producing ORs of approximately 1.0. The later studies are more likely to show an effect if one exists than these early studies and these should be given greater weight.

The size of a study will also matter since studies with greater numbers of cases and controls (especially exposed cases) will generally have smaller confidence bounds and have a greater chance of seeing an effect if one exists. Thus, the studies by **Hardell et al. (1999)** [85], **Inskip et al. (2001)** [44], **Muscat et al. (2002)** [153], **Warren et al. (2003)** [154], **Baldi et al. (2011)** [89], **Corona et al. (2012)** [161], **Benson et al. (2013)** [102] and **Schuz et al. (2011)** [94] will carry less weight in an overall evaluation.

There are also studies where the referent group was “never used a mobile phone” versus studies where the referent group was “not a regular user of mobile phones” defined by different measures. Less weight should be given to studies with comparisons to “never used” simply because the “ever used” group could include people who used a phone only a few times.

Given these caveats, there are five case-control studies that should carry the greatest weight: **Interphone (2010)** [67], **Hardell et al. (2013)** [160], **Han et al. (2012)** [157], **Corona et al. (2012)** [161], and **Pettersson et al. (2014)** [162]. Three of these 4 studies have ORs greater that 1.0 for regular usage of a cellular phone with 1 (**Hardell et al. (2013)** [160]) being significantly >1 [1.6 (1.2-2.2)].

The largest study, **Interphone (2010)** [67] has an OR for regular use of 0.85 (0.69-1.04). The difference in the response rate for cases (82%) versus controls (53%) could lead to problems with selection bias as was suggested for the brain tumor data from the Interphone study [74]. This study demonstrated no increases in OR with duration of use, even with a 5-year latency. (Table 12, Table 13)

The next largest study, and **Pettersson et al. (2014)** [162], had approximately half the number of exposed cases as **Interphone (2010)** [67] and showed an OR for regular use of

1.18 (0.88-1.59). They saw an increased OR for 5-9 years duration of use [1.39 (0.97-1.97)] which dropped for ≥10 years durations [1.09 (0.75-1.59)]. They had a non-responder questionnaire which was answered by 93 controls and 7 cases. Of the 93 control non-responders, 62 (67%) were regular mobile phone users compared to 442 (69%) out of 643 responding controls. There were only 7 non-responder cases who replied to the questionnaire and 4 were regular phone users. Thus, even though there are a larger number of non-responders in controls, there is no obvious suggestion of selection bias. (Table 12, Table 13)

Hardell et al. (2013) [160] was the next largest study with roughly 1/3 of the number of exposed cases as **Interphone (2010)** [67]. They saw an OR for regular use of 1.6 (1.2-2.2) and an increasing risk with increasing duration of use. In addition, all of the 5-year groupings of duration of use were greater than 1 and all usage longer than 5-years was significantly greater than 1 (Table 13). Only living cases were included. Their response rate was high enough that participation bias is unlikely to have lowered the OR values. Recall bias could have increased the ORs. In one of the original case-control studies [117] used in their pooled analysis, they evaluated this issue and saw little indication of recall bias with regard to malignant brain tumors (no information on AN). (Table 12, Table 13)

Han et al. (2012) [157] also was about 1/3 of the number of exposed cases as **Interphone (2010)** [67]. They saw an OR for regular use of 0.95 (0.58-1.58) and an increasing risk with increasing duration. It is impossible to judge the potential for selection bias since they gave no indication of the response rates for controls. In addition, it is also impossible to judge the quality of the exposure metrics since there was insufficient detail to understand how they related controls to cases in obtaining this information. (Table 12, Table 13)

Corona et al. (2012) [161] had 34 exposed cases or about 20x smaller than **Interphone (2010)** [67]. They saw increased ORs (non-significant) for all categories of usage. The response rates for cases and controls were moderate but not remarkably different suggesting no problem with selection bias although there was no follow-up with non-respondents. It is not possible to judge recall bias in this small study. (Table 12, Table 13)

Sato et al. (2014) [163] is the next largest study; but being a case-case study, it is more relevant to the issue of laterality and will be discussed later.

Schuz et al. (2011) [99], with only 15 exposed cases, is a cohort study with limitations due to potential differential exposure misclassification (discussed earlier). They saw an OR for subscriptions from 11 years prior to reference date of 0.86 (0.52-1.46). (Table 12)

Benson et al. (2013) [102], with only 8 cases that are daily users, saw an OR of 1.37 (0.61-3.07). They had 67 ever users in the cases and these had an OR of 1.44 (0.91-2.28). Using never use as the reference category, they looked at duration of use and saw clearly increasing ORs with increasing duration. This study may also have problems with exposure misclassification (discussed earlier). (Table 12, Table 13)

Roosli et al. (2019) [118] also did a meta-analysis of AN and cellular phones. They give mRRs for the analyses of studies showing ORs for ≥10 years exposure. For the case-control studies, they get an mRR of 1.29 (0.74-2.23). For the Cohort studies, they show an mRR of 0.98 (0.65, 1.48) and for all studies combined they get 1.19 (0.80-1.79). Entering their numbers into Stata (v 16.2 for MAC), I can reproduce their findings. They also did a meta-analysis of ever versus never use for all 9 case-control studies (1.05 [0.84-1.32]) and the cohort studies (0.93 [0.57-1.50]) with a combined mRR of 1.02 (0.84-1.24). They show a number for regular use from **Muscat et al. (2002)** [153] which is not in the paper and appears to be the unadjusted crude OR. They give no reason for using **Shuz et al. (2006)** [94] instead of **Schuz et al. (2011)** [99] for this analysis although they used **Frei et al. (2011)** [96] for their analysis of gliomas. I am also unable to match the number they use for **Benson et al. (2013)** [102] which they list as 1.19 (0.81-1.75) but the paper lists as 1.37 (0.61-3.07). They also conducted a cumulative meta-analysis of the studies with ≥10 years of use. They also did several other analyses of ever versus never use with no appreciable changes in the results. One problem with these meta-analyses is that they give very little weight to the largest studies. They did not consider laterality or tumor location in the brain.

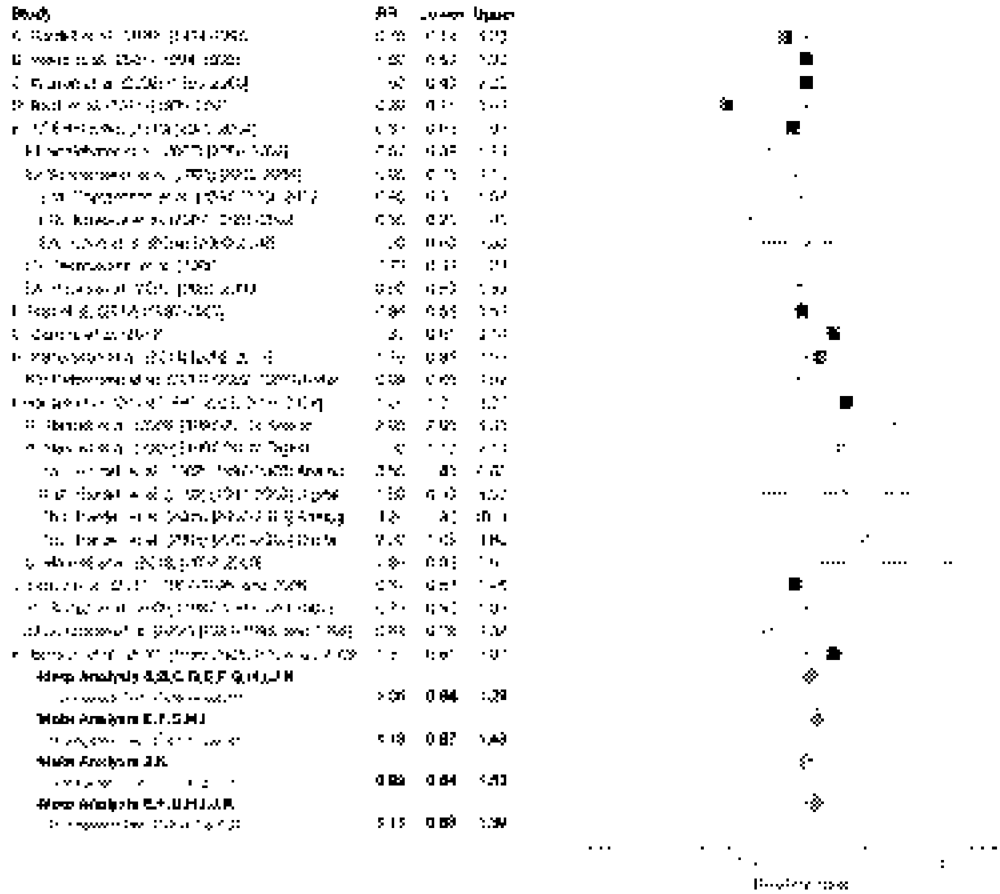
The remaining meta-analyses are older and use fewer and fewer of the individual studies.

To provide a better evaluation of the results, Figure 3 is a forest plot of all of the ORs from individual publications that evaluated regular use versus minimal or never use or ever use versus never use (if both were given in a study, regular use is shown). The column labeled "Study" provides the reference to the publication and the years in which cases and controls were collected for case control studies and the years when phone use information was collected for cohort studies and the year in which follow-up ended. Some studies are pooled evaluations of multiple other studies, so the other studies are indented. The column labeled "RR" is the risk ratio (OR, RR or mRR) from the study, "Lower" and "Upper" are the lower and upper bound on a 95% confidence interval around the RR. The graphic on the right simply plots the RR as a square or diamond with the "whiskers" (blue line running through the box) showing the width of the 95% confidence interval. The vertical line passing through 1 represents no effect. If the box and both whiskers are to the right of this line (greater than 1) and not touching it, this finding is statistically significant with a positive effect; if they fall completely to the left of the vertical line (below 1), then the risk is significantly reduced. The blue boxes that are filled in are major studies, the blue boxes that are white in the middle are the sub-studies and the red diamonds are all meta-analyses.

The graphic in Figure 3 is very useful for examining these types of data in a single view. Looking just at the filled in blue blocks (Studies A,B,C,D,E,F,G,H,I,J,K), 5 studies have their ORs below 1, two are equal to 1 and four are above 1. One study (I) shows a significant increase in risk. The first meta-analysis (Meta Analysis A,B,C,D,E,F,G,H,I,J,K) combines the information from all of the studies to produce an mRR of 1.06 (0.88-1.29) suggesting that all of the positives and negatives balance out to a small, non-significant increased risk. However, as mentioned earlier, the newer, larger studies represent longer exposures, so I have also done meta-analyses on the five case-control studies that collected cases after 2002 (E,F,G,H,I) and the two cohort studies (J,K). Combining the five case-control studies (Meta Analysis E,F,G,H,I) results in a mRR of 1.13 (0.87-1.48), a slight increase in risk from the use of a mobile phone, but heterogenous across studies. The combined cohort studies yield a mRR of 0.99 (0.64-1.53) suggesting no risk, and no heterogeneity (p=0.35). Combining the 5 case-control studies and the 2 cohort studies (Meta Analysis E,F,G,H,I,J,K) yields an mRR of 1.11 (0.88-1.39) again suggesting marginal risk but with significant heterogeneity (p=0.04).

Figure 4 is a forest plot of all of the ORs from individual publications that reported on duration of use ≥5 years or more. There are 8 studies; 5 of these studies show groupings of 1-4 years, 5-9 years and ≥10 years, one study with groupings of <6 years, and ≥6 years, one study with ≥5 years and one study with <10 years and >10 years. For the study by **Hardell et** al. (2013) [160], groupings of 10-14, 15-19 and ≥20 years were combined by meta-analysis to get a single mRR for ≥10 years. There are 2 groups of meta-analyses each with three separate meta-analyses for 1-4 years, 5-9 years and ≥10 years (combined with only ≥10 years for **Han et al. (2012)** [157] and <6 years for **Corona et al. (2012)** [161]). The first group of 3 meta-analyses combines the case-control studies and the second group of 3 meta-analyses adds in the cohort studies. In order to accommodate the study by **Inskip et al. (2001) [44]** with only a ≥5 year grouping and the study by **Corona et al. (2012)** [161] with ≥6 years, all studies with 5-9 and ≥10 years were combined in the last 2 meta-analyses to yield mRRs for ≥5-6 years for the case-control studies and all of the studies. The mRRs for <5 years are all near 1. The mRRs for 5-10 years are all elevated and close to statistical significance. The mRRs for ≥10 years are elevated, but less than for 5-10 years. Finally, both of the mRRs for ≥5 years are significantly elevated.

The studies in adults of an association between cellular phone use and acoustic neuroma are consistent enough to conclude an association exists.



[illegible]: Forest plot and meta-analyses of regular use or ever use of cellular telephones and the risk of acoustic neuroma [studies with a solid blue square either single studies that stand alone or pooled studies that encompass numerous single studies; open squares are individual studies or smaller pooled studies; red diamonds are meta analyses][a]

[a] - The column labeled “Study” provides the reference to the publication and the years in which cases and controls were collected for case control studies and the years when phone use information were collected for cohort studies and the year in which follow-up ended. Some studies are pooled evaluations of multiple other studies, so the other studies are indented. The column labeled “RR” is the risk ratio (OR, RR or mRR) from the study, “Lower” and “Upper” are the lower and upper bound on a 95% confidence interval around the RR. The graphic on the right simply plots the RR as a square or diamond with the “whiskers” (blue line running through the box) showing the width of the 95% confidence interval. The vertical line passing through 1 represents no effect. If the box and both whiskers are to the right of this line (greater than 1) and not touching it, this finding is statistically significant with a positive effect; if they fall completely to the left of the vertical line (below 1), then the risk is significantly reduced. The blue boxes that are filled in are major studies, the blue boxes that are white in the middle are the sub-studies and the red diamonds are all meta-analyses. “Homogeneity Test” provides the I^2 statistic and the p-value for the Q-test.

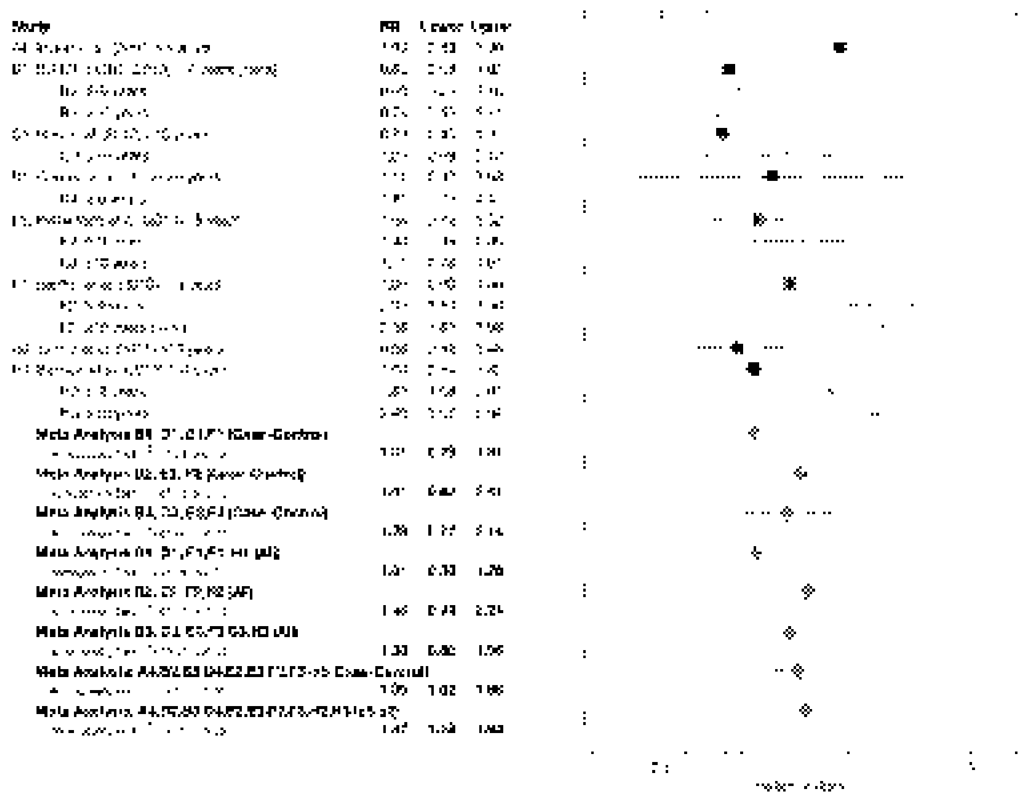


Figure 4: Forest plot and meta-analyses of duration of use of cellular telephones and the risk of acoustic neuroma [studies with a solid blue square are stand alone; red diamonds are meta-analyses, the columns and the figure are as in Figure 1]

[illegible]

As for gliomas, the best measure for exposure-response relationships is the cumulative hours of use of a cellular telephone since it includes both the frequency of use and the duration of use. While duration of use is also a form of exposure-response, it is more likely that, similar to ionizing radiation, RF is likely to have an association between total accumulated exposure and the risk of AN if a relationship exists. Table [illegible] provides the results for all of the epidemiology studies with estimates of the cumulative use of cellular phones.

Inskip et al. (2001) [44] shows consistent exposure-response and has two of the three ORs above 1. **Muscat et** al. **(2002)** [153] shows no increased risk. **Interphone (2010)** [67] basically shows flat exposure-response for the entire study until the largest exposure category, that is elevated in risk with an OR of 1.32 (0.88-1.97). The same pattern holds with a 5-years lag although the highest exposure group is now statistically significant with an OR of 2.79 (1.51-5.16). **Pettersson et al. (2014)** [162] saw a clearly increasing exposure-response pattern with ORs above 1 in all exposure categories and becoming almost significant in the highest exposure category [1.46 (0.98-2.17)]. **Hardell et al. (2013)** [160] saw a pattern of increasing risk with increasing exposure with 3 of their 4 categories statistically significant. They also did a regression resulting an OR of 1.009 (1.001-1.017) per hundred cumulative hours

It is not possible from the published results to find categories of exposure that match across the various studies in order to do a simple meta-analysis by category. However, it is possible to do a meta-regression where the exposure categories are turned into a single exposure and the meta-regression tests to see if the slope of the data from the various studies is increasing with exposure. As for glioma (Section 1.3.2, page 41), I set the exposure for each category equal to the center of the interval defined for the category and or the last category, which is generally expressed as ≥ some number of hours, I used the difference between the middle of the second largest category and the lower bound of that category and added it to the upper end of the second highest category to get the exposure for the highest category. The exposures for all of the categories of the studies entering into the meta-regression are shown in Table 18. As a check, a meta-regression was performed of just the **Hardell et al. (2013)** [160] study; the mRR is 1.015 (1.000-1.030) per 100 hours with p=0.05 compared to 1.009 (1.001-1.016) per 100 hours seen by **Hardell et al. (2013)** [160] using the original data.

Table 19 provides the results of the meta-regression for the 5 case-control studies with duration of exposure where all of the ORs are a comparison against non-regular users. There is a significant association between exposure and risk with a mRR of 1.007 (1.001-1.013, p=0.017). This is almost identical to what was seen by Hardell et al. (2015) [1.009 (1.001-1.016)]. The test of heterogeneity is significant (pQ<0.001) and an I^2 of 57.31. Removing **Interphone (2010)** [67] doubles the mRR to 1.014 (1.066-1.024) and reduces heterogeneity. Removing **Pettersson et al. (2014)** [162] results in no change in the mRR and slightly wider confidence intervals that barely include 1. Removing **Hardell et al. (2013)** [160] cuts the mRR in half and leads to a non-significant risk (1.003 [0.998-1.009; p=0.250) and reduces heterogeneity. The alternative high dose yielded the same pattern but higher mRRs per 100 hours, larger confidences bounds, less statistical significance and less heterogeneity (not shown). (Table 19)

<u>There were other measures</u> of exposure used in the various studies that are worth mentioning. **Inskip et al. (2001)** [44] used average minutes/day and saw no exposure-response relationship (Table 15). **Corona et al. (2012)** [161] also used average minutes/day and saw an increasing exposure response in the first 2 groupings and a lower OR in the highest grouping, all increased but with lower confidence bounds below 1 (Table 15). **Muscat et al. (2002)** [153] used hours/month and saw no pattern (Table 15). **Inskip et al. (2001)** [44] also considered the year that cellular telephone use began and again saw no exposure-response (Table 16). **Interphone (2010)** [67] considered cumulative use by years of duration of use (1-4 years, 5-9 years and ≥10 years). In 1-4 years and 5-9 years duration categories, they saw flat exposure-response. The highest cumulative use, ≥1640 hours, in the highest duration of use category, ≥10 years, was significantly increase (1.93 [1.10-3.38]) (Table 16). **Pettersson et al. (2014)** [162] considered cumulative number of calls and saw a flat exposure-response with all ORs above 1.0 (Table 16).

[illegible]: Meta-Regression Exposure Values for Table 19

Author (year)	Exposures (times 100 hrs)
Inskip et al. (2001)	0.065, 0.57, 1.435
Muscat et al. (2002)	0.30, 3 (0.90[a])
Interphone (2010)	0.025, 0.09, 0.22, 0.46, 0.88, 1.575, 2.80, 5.475, 11.875, 82 (20.925[a])
Pettersson et al. (2014)	0.19, 2.08, 4.345, 34 (9.245[a])
Hardell et al. (2013)	0.615, 3.17, 9.99, 74.3 (19.73[a])

[a] alternative exposure for highest exposure group

[illegible]: Meta Regression Analysis with Sensitivity Analysis of ORs for Five Case Control Studies using Cumulative Hours of Use as the Exposure Metric and the Original Referent Groups

Meta Regression Studies[a]	Per 100 hours Use	P>|Z|	95% Confidence Interval		I^2	pQ
All	1.007	0.017	1.001	1.013	57.31	<0.001
drop Inskip et al. (2001)	1.007	0.021	1.001	1.013	62.4	<0.001
drop Muscat et al. (2002)	1.007	0.019	1.001	1.013	60.91	<0.001
drop Interphone (2010)	1.014	0.001	1.006	1.022	42.36	0.053
drop Petterson et al (2014)	1.007	0.053	1.000	1.014	64.21	<0.001
drop Hardell et al. (2013)	1.003	0.25	0.998	1.009	29.45	0.111

[illegible]

The strength of the association is tied to the magnitude of the response and the statistical significance of that response. For all of these studies, the actual magnitude of the RRs seen in the studies are small, in many cases falling below 1. It is clear from [illegible], that the longer the duration, the larger the mRR and the more statistical significance to the risk.

Laterality matters for addressing the strength of the association. For regular users versus non-regular users, **Interphone (2010)** [67] and **Pettersson et al. (2014)** [162] saw ipsilateral ORs smaller than the contralateral ORs [Note that **Pettersson et al. (2014)** [162] define ipsilateral differently, including people who used both hands in the ipsilateral category]. In contrast, **Corona et al. (2012)** [161] and **Hardell et al. (2013)** [160] saw ipsilateral ORs greater than the contralateral ORs. Laterality seems to become more pronounced with a longer duration of exposure or greater cumulative hours of use in **Interphone (2010)** [67] but not in **Pettersson et al. (2014)** [162].

In the case-case study by **Sato et al. (2014)** [163], they calculated ORs for the grouping left-handed users with left side ANs (l/l) and right-handed users with right-side ANs (r/r) against all miss-matched tumors (l/r and r/l). For a 1-year lag they saw an OR of 1.08 (0.93-1.28) and for a 5-year lag they saw an OR of 1.14 (0.96-1.40). When they examined this for duration of use, they saw generally increasing ORs that were >1, but not statistically significant. For weighted average minutes per day of use, they saw significant ORs for 1-year lag (2.74 [1.18-7.85]) and 5-year lag (3.08 [1.47-7.41]) and significantly increasing ORs for the 5-year lag group (p=0.004). For the average duration of a call, they saw the same basic pattern.

4.2.4 Ecological Epidemiology Studies of Acoustic Neuroma

Benson et al. (2013) [102] examined temporal trends in acoustic neuroma incidence rates in England using data from the UK Office of National Statistics. They restricted their analysis to the years 1998-2008. They provided no analysis of these data, only a plot of incidence over time.

Several studies are also mentioned in Section 1.4.

4.2.5 Conclusions for Acoustic Neuromas

The evidence on an association between cellular phone use and the risk of acoustic neuromas in adults is strong. While there is considerable difference from study to study on ever versus never usage of cellular phones, 3 of the 4 meta-analyses in [illegible] are above 1 although none-significantly. The meta-analyses in Table 14 demonstrate an increased risk in the highest 2 latency groups for the case-control studies that gets slightly higher when the cohort studies are added. For latency ≥5 years, the mRRs are significantly elevated for the case-control studies and the combined case-control and cohort studies. The exposure response meta-regressions in [illegible] indicates that risk is increasing with cumulative hours of exposure, especially in the highest exposure groups. This finding, however, is sensitive to the inclusion of the **Hardell et al. (2013)** [160] study. There is a strong tendency toward ANs appearing on the same side of the head as the phone is generally used, especially as the exposure increases. These findings do not appear to be due to chance. The cohort studies appear to show less of a risk than the case-control studies, but one study is likely to be severely impacted by differential exposure misclassification (**Schuz et al. (2011)** [99]) and the other (**Benson et al. (2013)** [102]) is likely to have a milder differential exposure misclassification. Both studies have very few cases. The case-control studies are possibly impacted by recall bias and this cannot be ruled out for the ANs. Selection bias could have been an issue for **Interphone (2010)** [67], and, unlike their analysis of the glioma data, they have not looked at an alternate referent population for their analyses of AN. Confounding is not an issue here. In conclusion, an association has been established between the use of cellular telephones and the risk of ANs and chance and confounding are unlikely to have driven this finding. Potential recall bias and selection bias may still be an issue with some of these findings.

Laboratory Cancer Studies

There is sufficient evidence from laboratory studies to conclude that RF can cause tumors in experimental animals with strong findings for gliomas, heart Schwannomas and adrenal pheochromocytomas in male rats and harderian gland tumors in male mice and uterine polyps in female mice.

5.1 Chronic Carcinogenicity Studies

5.1.1 Mice

Tillmann et al. (2007) [164] Exposed groups of 50 male and female B6C3F1 mice to four exposure levels (whole body averaged specific absorption rates (SAR) of 0.0, 0.4, 1.3 and 4.0 mW/g) of two different radiofrequency radiation (RF) exposures (902 MHz GSM and 1747

MHz DCS modulated frequencies) for 2 hours per day, 5 days per week for 2 years using head-only exposure in a Ferris wheel/tube-restrained exposure system. The two hours of exposure was done in three phases imitating exposures classified as "basic", "talk" and "environment". All test animals were given a full necropsy and both gross and microscopic lesions identified and characterized. They reported no increases in tumor incidences for any lesion. They did report a significant exposure-related decrease in hepatocellular adenomas in males in the highest exposure group for both GSM (p=0.048) and DCS (p=0.015) exposures. Tumor count data was provided for Pituitary gland, Harderian gland, lungs, liver, adrenals, uterus and hematopoetic/lymphoreticular tissues. Brain tumor data was described as negative but counts were not provided. They reported no difference in survival by treatment group. All data presented were reanalyzed using a one-sided Fisher's exact test for pairwise comparisons and the one-sided exact Armitage linear trend test for increasing or decreasing risk with exposure [165]. The reanalysis showed a decrease in the GSM data in all three treated groups in females in Harderian gland adenomas (p=0.045, <0.01, 0.011; trend test p=0.047), in alveolar/bronchiolar carcinomas at the two lowest exposures (p=0.008, 0.008) and adenomas at the highest exposure (p=0.045), and increased trend in liver adenomas (p=0.033) and a significant increase in uterus endometrial stromal polyps at the two lowest exposures (p=0.004, 0.046) with no increased trend. In the DCS data for females, there was significant effect at the highest exposure for uterus glandular polyps (p=0.013) with a significant trend (p=0.002). In the male GSM exposure groups, Harderian gland adenomas were increased in all groups (p=0.027, 0.003, 0.001) with a significant trend (p=0.004) and a significant decreased trend in liver adenomas (p=0.001) and decreases at all three exposures (p=0.014, 0.014, <0.01). In the male DCS exposure groups, Harderian gland adenomas were decreased for all exposure groups (p=0.001, 0.001, 0.001) with a significant decreased trend (p=0.018), a decrease in liver adenomas at the two highest groups (p=0.03, <0.01) with significant negative trend (p<0.01), and a significant increase in lymphomas in all exposure groups (p=0.004, 0.046, 0.046) with no trend. The increases in Harderian gland adenomas in the male GSM studies may be due to the exposure, but this was not explored by the authors. The large control response for Harderian gland adenomas in males in the DCS exposure studies suggests the incidence for this tumor in these studies is highly variable.

National Toxicology Program (2018) [166] exposed groups of 90 5-6 week old male and female B6C3F1/N mice to sham, GSM-modulated RF (2.5, 5 or 10 W/kg 9 hours/day, 7 days/week) or CDMA-modulated RF (2.5, 5 or 10 W/kg 9 hours/day, 7 days/week) for 106 (males) or 108 (females) weeks. The 9 hours and 10 minutes of exposure was achieved by cycling the fields 10 minutes on and 10 minutes off for 18 hours and 20 minutes each day. The mice exposed GSM-modulated and CDMA-modulated RF used the same sham controls. Exposures were conducted in reverberation chambers and animals were housed in individual cages. Full pathology was conducted on all animals. GSM Study: Survival was significantly higher for the 5 W/kg males than the sham controls; all other groups were not different from controls. There were no body weight differences between exposed animals and controls. They saw a marginal increase in skin fibrosarcoma, sarcoma or malignant fibrous histiocytoma in male mice (p=0.093) (mostly occurring in the tails of these animals), a significant increase in alveolar/bronchiolar adenomas and carcinomas in male mice (p=0.040) but not for adenomas and carcinomas separately, and significant increases in malignant lymphomas in the two lowest exposure groups for females, but the trend test was not significant and the control numbers were substantially smaller than historical controls. To clarify the significance of the lung tumors in males, the NTP historical control data described in the technical report [166] was obtained electronically online, and using Tarone's test for historical controls [167], yields p=0.072. CDMA Study: Survival was significantly higher for the 2.5 W/kg females than the sham controls; all other groups were not different from controls. There were no body weight differences between exposed animals and controls. There were sporadic positive pairwise comparisons that were significant for liver tumors in male mice, but none of these demonstrated any pattern of exposure-response. Also, significant increases in malignant lymphomas in the lowest exposure group for females with increases in all groups, but the trend test was not significantly increased and the control numbers were substantially smaller than historical controls. Two adenomas and 1 carcinoma of the pars distalis in the pituitary gland occurred in the 5 W/kg group but not the other groups (these tumors were not seen in the historical controls). After 14 weeks of exposure, **Smith-Roe et al (2020)** [168] evaluated genotoxicity in several tissues of mice included in these studies for this purpose using the alkaline comet assay (three brain regions, liver, peripheral blood) and the micronucleus assay (peripheral blood). Significant increases in DNA damage were seen in the frontal cortex of male mice (DCMA and GSM) and leukocytes of female mice (CDMA only). NTP uses 5 levels of evidence for classifying the findings of carcinogenicity studies. Equivocal evidence is defined as "*Equivocal evidence of carcinogenic activity is demonstrated by studies that are interpreted as showing a marginal increase of neoplasms that may be test agent related.*" In this study, for GSM-exposed mice, they labeled the skin tumors and lung tumors in males as equivocal and the malignant lymphomas in females as equivocal. For CDMA-exposed mice, they labeled the liver hepatoblastomas in males and the malignant lymphomas in females as equivocal. All of these conclusions seem reasonable. (Note: some text copied directly from **NTP (2018)** [166]).

5.1.2 Rats

Chou et al. (1992) [169] exposed groups of 100 male Sprague-Dawley rats to pulsed microwave radiation at 2450 MHz at 800 pulses per second with a pulse width of 10 µs for 21.5 hours per day, 7 days per week, for 25 months with an appropriate sham control. The exposure was intended to match a military-grade radar system and provide a whole body SAR of about 0.4 w/kg. They saw no changes in survival, body weight, or a number of other measures in the exposed animals and no increased tumor risk in any one organ. They did see a statistically significant increase in total tumors (p<0.001), but it is not clear if this evaluation included multiple findings from the same animal or not (the statistical method used may have been incorrect).

La Regina et al. (2003) [170] exposed groups of 80 male and female Fisher 344 rats (aged 6 weeks) to sham, 835.6 MHz FDMA RF (SAR 1.3 W/kg) or 847.7 MHz CDMA RF (SAR 1.3 W/kg) for 4 hours/day, 5 days/week for 24 months in a tube-restrained Ferris-wheel exposure system. The exposure was predominantly to the head, but all tissues were examined. There were no differences in survival or body weight across appropriate comparison groups. They reported no significant tumor findings.

Anderson et al. (2004) [171] exposed groups of pregnant Fischer 344 rats to RF at 1620 MHz for 2 hours per day, 5 days per week from day 19 of gestation to weaning. At approximately 5 weeks of age, groups of 90 male and female offspring were exposed to the same RF using tubes with predominantly head only exposure for 2 hours per day, 5 days per weeks for 24 months. Targeted head exposure was sham, 0.16 and 1.6 mW/g. They reported no statistically increased differences in reproductive index, litter size, body weight or other clinical signs. There was a slight increase in survival in the highest exposure group in females relative to the sham exposed group. They noted there were no exposure-related significant increases in any tumors and that the highest exposure group of males had a significant increase in mesothelioma of the testis, but that this was within the range of historical controls. A reanalysis of the data presented results in the same findings as those presented by **Anderson et al. (2004)** and also showing a significant trend for mesothelioma of the testis (p=0.003). **Anderson et al. (2004)** compared the oligodentroglioma data in males to the NTP historical control data presented by **Haseman et al. (1990)** [172], however, NTP has a set of controls more closely linked in time to this study that is more appropriate [173] showing the same range of responses (0-2%). Using the range of historical controls is inappropriate in this type of analysis [32, 33, 174] and a direct method of testing, Tarone's historical control test [167], is more appropriate; this test yields a p-value of p<0.001 for the oligodentrogliomas in males. For the mesotheliomas in the testes, the NTP database contains no entries and the source cited by **Anderson et al. (2004)** has a range of 0-2% while the observed response in the highest exposure group was 6/90=6.7%, so well outside the range.

Smith et al. (2007) [175] duplicated the exposure system of **Tillmann et al. (2007)** [164] for groups of 50 male and female Wistar rats. They reported no survival differences and no significant increases in tumors in any tissue evaluated. For the tissues they reported in the paper, a re-analysis using the Armitage linear trend test shows an increase in the incidence of C-cell adenomas in female rats for both GSM (p=0.025) and DCS (p=0.043) exposures, but not for c-cell carcinomas (p=0.50 and p=0.37) and it remains significant for the combined adenomas and carcinomas (p=0.028 and p=0.044).

Bartsch et al. (2010) [176] conducted four separate RF studies in female Sprague-Dawley rats; two long-term (I and II) and two life-long (III and IV) experiments were conducted exposing animals to a low-intensity GSM-like signal (900 MHz pulsed with 217 Hz, 100 µW/cm. average power flux density, 38–80 mW/kg mean specific absorption rate for whole body). Health and survival of unrestrained female Sprague-Dawley rats kept under identical conditions was evaluated. Radiofrequency (RF)-exposure was started at 52–70 days of age and continued for 24 (I), 17 (II) and up to 36 and 37 months, respectively (III/IV). In the first two experiments 12 exposed and 12 sham-exposed animals each were observed until they were maximally 770 or 580 days old (animals either died of natural causes or were sacrificed because they were moribund). In experiment I, no adverse health effects of chronic RF-exposure were detectable, neither by macroscopic nor detailed microscopic pathological examinations. In experiment II no apparent macroscopic pathological changes due to treatment were apparent and microscopic analyses were not conducted. Reductions in pituitary tumors were seen for both experiment I and II but no increases were reported. In experiments III and IV, 30 animals per group showed a significant reduction in survival in the RF-exposed groups relative to the sham-exposed groups and both groups in experiment III showed a significant reduction in survival compared to experiment IV. A reduction in mammary tumors were seen in the RF-exposed animals compared to sham, but this may be due to the survival differences (authors did not evaluate this issue). This study did not perform full pathology, had limited sample sizes and presents very little tumor data.

NTP (2018) [177] exposed groups of 56 time-mated F_0 female Sprague-Dawley rats, housed in specially designed reverberation chambers, to whole-body exposures GSM-modulated cell phone RF or CDMA-modulated RF at power levels of 0 (sham control), 1.5, 3, or 6 W/kg for 7 days per week, continuing throughout gestation and lactation. Exposure was up to 18 hours and 20 minutes per day with continuous cycling of 10 minutes on and 10 minutes off during the exposure periods. At weanling, groups of 90 5-6 week old male and female Sprague-Dawley rats were exposed the same exposures as their F_0 dams for 105 weeks. The rats exposed to GSM-modulated and to CDMA-modulated RF used the same sham controls. Exposures were conducted in reverberation chambers and animals were housed in individual cages. Full pathology was conducted on all animals. GSM Exposures: In F_0 females, there were no exposure-related effects on pregnancy status, maternal survival, or the percentage of animals that littered. During gestation, mean body weight gains of 6 W/kg females were significantly lower than those of the sham controls from GD 15 through 18 and during the overall gestation period (GD 6 through 21). During lactation, the mean body weights of 3 and 6 W/kg females were significantly lower than those of the sham controls for the period of PND 4 through 21. In F_1 offspring, there was no effect on litter size, pup mortality or survival. During lactation, mean pup weights were significantly lower at most timepoints in the 3 W/kg groups and at all timepoints in the 6 W/kg groups. At the end of 2 years, survival of all exposed male groups was significantly greater than that of the sham control group due to the higher severity of chronic progressive nephropathy in the kidney of sham control males (note, almost all male rats had chronic progressive nephropathy). Survival of exposed female groups was similar to that of the sham controls. The mean body weights of all exposed males and females were similar to those of the sham control groups. There were no exposure-related clinical observations. In the heart at the end of the 2-year studies, malignant schwannoma was observed in all exposed male groups and the 3 W/kg female group, but none occurred in the sham controls. Endocardial Schwann cell hyperplasia also occurred in a single 1.5 W/kg male and two 6 W/kg males. There were also significantly increased incidences of right ventricle cardiomyopathy in 3 and 6 W/kg males and females. In the brain of males, there were increased incidences of malignant glioma and glial cell hyperplasia in all exposed groups, but none in the sham controls. There was also increased incidences of benign or malignant granular cell tumors in all exposed groups. There were significantly increased incidences of benign pheochromocytoma and benign, malignant, or complex pheochromocytoma (combined) of the adrenal medulla in males exposed to 1.5 or 3 W/kg. In the adrenal medulla of females exposed to 6 W/kg, there were significantly increased incidences of hyperplasia. In the prostate gland of male rats, there were increased incidences of adenoma or adenoma or carcinoma (combined) in 3 W/kg males and epithelium hyperplasia in all exposed male groups. In the pituitary gland (pars distalis), there were increased incidences of adenoma in all exposed male groups. There were also increased incidences of adenoma or carcinoma (combined) of the pancreatic islets in all exposed groups of male rats, but only the incidence in the 1.5 W/kg group was significant. In female rats, there were significantly increased incidences of C-cell hyperplasia of the thyroid gland in all exposed groups, and significantly increased incidences of hyperplasia of the adrenal cortex in the 3 and 6 W/kg groups. CDMA Exposures: In F_0 females, there were no exposure-related effects on pregnancy status, maternal survival, or the percentage of animals that littered. During gestation, the mean body weights and mean body weight gains of exposed groups were similar to those of the sham controls. During lactation, mean body weights were significantly lower than those of the sham controls at most time points in the 6 W/kg group, at several time points in the 1.5 and 3 W/kg groups, and the mean body weight gains for the period as a whole (PND 1 through 21) were significantly lower in the 3 and 6 W/kg groups. In F_1 offspring, there were no effects on litter size on PND 1. On PND 7 through 21, there were significant decreases in live litter size in the 6 W/kg group when compared to the sham controls. Throughout lactation, the male and female pup mean body weights in the 6 W/kg groups were significantly lower than those of the sham controls. At the end of 2 years, survival in all exposed male groups was greater than that of the sham control group due to the effects of chronic progressive nephropathy in the kidney of the sham control males. In females, there was a small, but statistically significant increase in survival in the 6 W/kg group. Although there were some differences in mean body weights in exposed male groups, at the end of the study, the mean body weights of exposed male and female groups were similar to those of the sham controls. There were no exposure-related clinical observations. At the end of the 2-year study, malignant schwannoma of the heart occurred in all exposed male groups and the incidence in the 6 W/kg group was significantly increased; this neoplasm did not occur in the sham controls. There was also an increased incidence of endocardial Schwann cell hyperplasia in 6 W/kg males. In females, malignant schwannoma occurred in two animals each in the 1.5 and 6 W/kg groups. In the brain, malignant glioma occurred in 6 W/kg males and 1.5 W/kg females; none occurred in the sham control groups. Glial cell hyperplasia also occurred in 1.5 and 6 W/kg males and 3 and 6 W/kg females. In males, there was a significantly increased incidence of pituitary gland (pars distalis) adenoma in the 3 W/kg group, and increased incidences of hepatocellular adenoma or carcinoma (combined) in the liver of all exposed groups. In the adrenal medulla of females, there were increased incidences of benign, malignant, or complex pheochromocytoma (combined) in all exposed groups, but only the incidence in the 1.5 W/kg group was significantly increased compared to the sham controls. In the prostate gland of male rats, there were increased incidences of epithelial hyperplasia in all exposed groups, but only the incidence in the 6 W/kg group was significantly increased compared to the sham control group. After 14 weeks of exposure, **Smith-Roe et al (2020)** [168] evaluated genotoxicity in several tissues of rats included in these studies for this purpose using the alkaline comet assay (three brain regions, liver, peripheral blood) and the micronucleus assay (peripheral blood). Significant increases in DNA damage were seen in the hippocampus of male rats (CDMA-only). For the NTP, clear evidence of carcinogenic activity is "*demonstrated by studies that are interpreted as showing a exposure-related (i) increase of malignant neoplasms, (ii) increase of a combination of malignant and benign neoplasms, or (iii) marked increase of benign neoplasms if there is an indication from this or other studies of the ability of such tumors to progress to malignancy.*" For GSM exposures in males, NTP classified the malignant schwannomas of the heart, the malignant gliomas and the pheochromocytomas of the adrenal medulla as "clear evidence of carcinogenicity" and the granular cell tumors of the meninges, prostate gland tumors, pituitary gland tumors and pancreas islet-cell tumors as "equivocal findings". In females, the NTP classified the malignant schwannomas of the heart as equivocal. For the CDMA exposures in males, NTP classified the malignant schwannomas of the heart and the malignant gliomas as "clear evidence of carcinogenicity" and the pituitary tumors and liver tumors as "equivocal evidence". In females, the NTP classified the malignant schwannomas of the heart, the malignant gliomas and the pheochromocytomas of the adrenal medulla as equivocal. Given the glial hyperplasia, cardiomyopathy in the right ventricle and the magnitude of the effect in the adrenal gland, I agree with the calls by the NTP. It is also worth noting that, when compared to the historical controls (Tarone's test), the lowest exposure CDMA group had a significant (0.016) increase in malignant gliomas. (Note: some text copied from **NTP (2018)** [177]).

Falcioni et al. (2018) [178] exposed groups (number not given) of F_0 female Sprague-Dawley rats, housed in specially designed cages, to whole-body exposures 1.8 GHz GSM-modulated cell phone RF at power levels of 0 (sham control), 5, 25 and 50 V/m for 7 days per week, from PD-12 continuing throughout gestation and lactation. Exposure was for 19 hours per day. At weanling, groups of approximately 200 (highest 2 exposures) or 400 (sham controls and low exposure) 5-6 week old male and female Sprague-Dawley rats were exposed the same exposures as their F_0 dams for 105 weeks (equivalent to 0.001, 0.03 and 0.1 W/kg SAR). Exposures were conducted in circular cage array with an antenna in the middle and animals were housed in individual chambers (5 per cage). Full pathology was conducted on all animals. This report only details the findings in the brain and the heart. They noted non-significant increases in Schwann cell hyperplasia at the high exposure for both males and females and an increase in malignant Schwannomas of the heart in males in the highest treatment group (p=0.037) and, using the Armitage linear trend test, yielded a significant trend (p=0.037). They noted that the rate of schwannomas in untreated males from their historical controls was 19/3160 (0.6%) and they observed 3/207 (1.4%). Heart schwannomas in females showed no trend. There were no increases in premalignant or malignant lesions in the brain for males or females in this study. The females had a slight positive trend in gliomas (p=0.118) but it was clearly not significant.

5.2 Transgenic and Tumor-Prone Models

5.2.1 Eμ-pim1 transgenic mouse

The Eμ-pim1 transgenic mice are prone to getting lymphomas.

Repacholi et al. (1997) [179] exposed groups of 100 to 101 female heterozygous Eμ-pim1 mice to GSM modulated RF at 900 MHz for up to 18 months with SAR values ranging from 0.13 to 1.4 W/kg depending upon animal sizes and the number in a cage. Mice were exposed for 30 minutes twice a day in cages grouped around a central antenna There were no differences in weight by exposure, but there was a difference in deaths prior to study termination with 44/100 sham animals terminated early and 70/101 exposed animals terminated early. They reported a significant increase in the incidence of all lymphomas (p<0.001) and of non-lymphoblastic lymphomas (p=0.002) as a function of exposure. The statistical analysis of the data were unusual with analysis of only animals that died during the course of the study (terminal sacrifice animals were not examined histopathologically) and using a competing risk logistic regression model that is not fully explained in addition to the standard Fisher's exact test. The assumption that animals that did not die prior to terminal sacrifice were free of lymphomas makes this study difficult to interpret.

Utteridge et al. (2002) [180] attempted to replicate the study of Repacholi et al. (1997) [179] but with several differences. They used 120 animals per group, they included groups of wild-type C57BL/6N female mice, their GSM signal was 898.4 MHz, they used a restrained Ferris wheel design, exposed for 1 hour per day, 5 days per week for 104 weeks, and did full histopathological analysis on all mice regardless of survival. They used four different exposure groups at 0.25, 1.0, 2.0 and 4.0 W/kg. No exposure-related differences in body weight or survival were seen. They reported no exposure-related increases in any tumors from this study. The longer duration of this study makes the direct comparison to Repacholi et al. (1997) difficult since most animals in this study had lymphomas at 104 weeks.

Oberto et al. (2007) [181] used the same exposure system as Utteridge et al. (2002) [180] to repeat the study of Repacholi et al. (1997) [179] by exposing groups of 50 male and female heterozygous Eμ-pim1 mice to 900 MHz pulsed RF fields for 18 months at whole-body SAR levels of 0.5, 1.4 and 4.0 W/kg. Exposures were for 30 minutes, twice daily, 7 days per week. Survival was reduced for male mice in all exposures and for female mice exposed at 0.5 W/kg; there were no significant differences in body weights. They reported no significant changes in lymphomas in males or females and a significant increase in Harderian gland adenomas in males that was exposure-dependent (p=0.028). Using the Armitage linear trend test, the data show the change in Harderian gland adenomas in males (p=0.007), liver vascular tumors in males (p=0.015) and lung alveolar/bronchiolar adenomas (p=0.045) in males. The largest difference between Repacholi et al. (1997) (22%) and Oberto et al. (2007) (44%) was in the number of sham controls with lymphomas and this was not due to only looking at decedents since Oberto et al. (2007) provided this analysis as well.

5.2.2 Patched1$^{+/-}$ Mice

The Patched1 heterozygous (Ptc1+/-) knockout mice are prone to getting tumors of the brain and are hypersensitive to ionizing radiation.

Saran et al. (2007) [182] exposed groups of 23-36 male and female Ptc1+/- mice and groups of 22-29 male and female wildtype CD1 mice to 900 MHz RF at whole-body SAR of 0.4 W/kg from postnatal days 2-6 for 30 minutes, twice per day and then followed for their lifespan with full necropsy at death or moribund sacrifice. Exposures were done in a system that constrained the mice during exposure. There were no survival differences with regard to exposure. The authors reported no increases in any tumors as a function of exposure. They reported an increase in Rhabdomyosarcoma in male and female combined in exposed versus sham which was marginally significant when evaluated using the one-sided trend test (p=0.053). This study used a fairly low exposure for a very short exposure window.

5.2.3 AKR/j Mouse

The AKR/j mouse is known to rapidly develop hematopoietic tumors, especially thymic lymphoblastic lymphoma, in the first year of life.

Sommer et al. (2004) [183] exposed groups of 160 female AKR/j mice to either sham or 900 MHz GSM-like RF (0.4 W/kg) for 24 hours/day, 7 days/wk until 46 weeks of age. Mice were housed 6-7 per cage in a Ferris wheel design. There was a significant difference in relative weight change but not in absolute change. There were no survival differences. There were no differences in death from lymphoblastic lymphoma between the sham and RF exposed groups. In a second study using the same design, **Sommer et al. (2007)** [184] used 1966 MHz UMTS RF (0.4 W/kg). There were no significant weight changes, no changes in survival or the incidence of lymphomas although there was a marginal reduction in the number of animals surviving to study end in the RF exposed group (p=0.055).

Lee et al. (2011) [185] exposed groups of 40 male and 40 female AKR/j mice to sham or a combination of 848.5 MHz CDMA (2 W/kg) and 1950 MHz WCDMA (2 W/kg) RF for 45 min/day, 5 days/week for up to 42 weeks. Animals were housed 5 per cage during exposure in a reverberation chamber. No differences in body weight, survival or tumor incidence were observed.

5.2.3 C3H Mice

The C3H mouse carries a virus passed through breast milk that induces tumors of the mammary gland.

Szmigielski et al. (1982) [186] exposed groups of 40 female C3H/HeA mice to 2450 MHz RF from 6 weeks to 12 months at levels of 0, 2-3 W/kg and 6-8 W/kg. Exposure was carried out in an anechoic chamber for 2 hours per day, 6 days per week. The presence of mammary gland tumors was determined by palpation every two weeks. The authors noted a exposure-related increase in the number of mammary tumors ($p<0.01$) and a exposure-related decrease in the time to onset of mammary tumors ($p<0.05$) in their experiments. By their analysis, no other tumors were significantly increased as a function of exposure to the RF.

Toler et al. (1997) [187] exposed groups of 200 female C3H/HeJ mice for 21 months (22 h/day, 7 days/week) to a horizontally polarized 435 MHz pulse-wave (1.0 microsecond pulse width, 1.0 kHz pulse rate) RF environment with an SAR of 0.32 W/kg. An additional 200 mice were sham-exposed. All animals were necropsied and subject to full histpathological analysis. The exposure facility used 50 single housing cages around a central antenna facility to produce uniform circular fields. No survival differences were observed between the groups. There were no significant differences between the two groups with respect to latency to tumor onset, tumor growth rate and overall tumor incidence for mammary tumors. The only significant difference between groups for tumors in other organs was for bilateral ovarian epithelial stromal tumors ($p=0.03$ by their analysis, $p=0.023$ by mine) but became nonsignificant when all animals with stromal tumors were considered ($p=0.24$ by their analysis, $p=0.12$ by mine).

Frei et al. (1998) [188] exposed groups of 100 female C3H/HeJ mice for 18 months to 2450 MHz microwave radiation for 20 hours per day, 7 days per week. Exposure was via the CWG system with 2 animals per cage distributed around a circular field. The SAR targeted in this study was 0.3 W/kg. There were no differences in body weight or survival in the two groups. There were no significant differences between the two groups with respect to latency to tumor onset, tumor growth rate and overall tumor incidence for mammary tumors. There were no significant increases in tumors at any site but they also saw a slight increase in bilateral ovarian stromal tumors. **Frei et al. (1998)** [189] repeated this study using an SAR of 1 W/kg, again seeing no increases in any tumor as a function of exposure. In this second study, mammary tumors in sham-treated animals were much lower (30%) than in the previous study (54%).

Jauchem et al. (2001) [190] exposed groups of 100 female C3H/HeJ mice to pulses composed of an ultra-wideband (UWB) of frequencies, including those in the RF range (rise time 176 ps, fall time 3.5 ns, pulse width 1.9 ns, peak E-field 40 kV/m, repetition rate 1 kHz) at an SAR of 0.0098W/kg for 2 minutes per week for 12 weeks with a follow-up of 64 weeks. They saw no neoplastic changes associated with exposure. [This study uses an incredibly small SAR for a very short period.]

5.3 Initiation-Promotion Studies

In general, initiation promotion studies use two stages of exposure to determine if a particular exposure starts the cancer process (initiates tumors) or makes tumors grow faster or appear more readily (promotion). In most cases in the literature that follows, researchers are testing for the promotional impacts of RF using a known initiator (chemical that starts the cancer process).

5.3.1 Skin Models

The usual initiation-promotion study in skin involves the application of an initiator chemical (7,12-dimethylbenz[a]anthracene (DMBA) or benzo[a]pyrene (BAP)) once to the shaved skin of a mouse followed by frequent exposures to a promotor (in this case RF) for a long period of time. The studies also typically use a known promotor as a positive control (e.g. 12-O-tetradecanoylphorbol-13-acetate or TPA) to demonstrate the experimental setting is working appropriately. The tumors that appear on the back of the animals are tracked over time and the endpoints of interest (tumor frequency and multiplicity) recorded daily.

Chagnaud et al. (1999) [191] exposed groups of 8-18 female Sprague-Dawley rats to GSM 900 MHz RF at an SAR of 75 mW/kg starting 20, 40 or 75 days after initiation by BaP (2 mg) for 2 hours per day, 5 days per week for two weeks. In addition, GSM 900 MHz RF at an SAR of 270 mW/kg was administered 40 days after exposure to BaP (2 mg) for 2 hours per day, 5 days per week for two weeks. The study was terminated approximately 160 days after the BaP exposure. There was no impact of any RF exposure on the survival or time to tumor in these experiments.

Mason et al. (2001) [192] exposed groups of 27-55 female Sencar rats to DMBA (initiator, 2.56 µg) followed by a single 10 second exposure to 94 GHz RF at 1 W/cm^2 or to infrared radiation (IR) at 1.5 W/cm^2, both designed to raise skin temperature by 13-15° C. The animals were followed for 23 weeks and there was no indication of a promotion affect on these animals. In a second experiment using the same basic protocol, exposures of 10 seconds twice per week for 12 weeks to RF at 333 mW/cm^2 and IR at 600 mW/cm^2 (designed to raise skin temperature by 4-5° C) and followed to 25 weeks. There was no indication of a promotion effect of RF in this experiment. The authors also conducted a co-promotional study where the RF and IR exposures were given along with TPA to see if the RF enhanced the TPA promotional effect; this study was also negative.

Imaida et al. (2001) [193] exposed exposed groups of 48 female ICR mice to DMBA (initiator, 100 µg) followed by a TDMA RF field at 1.49 GHz (50 pulse per second) for 90 minutes per day, 5 days per week for 19 weeks at an SAR of 2 W/kg. There was no promotion of tumors by RF in this study.

Huang et al. (2005) [194] exposed a group of 20 male ICR mice to DMBA (initiator, 100 µg) followed by a CDMA signal at 849 MHz for 45 minutes twice per day, 5 days per week for 19 weeks at an SAR of 0.4 W/kg. They exposed a second group of 20 males to CDMA signal at 1763 MHz for 45 minutes twice per day, 5 days per week for 19 weeks at an SAR of 0.4 W/kg. There was no promotion of tumors by RF in this study.

Paulraj and Behari (2011) [195] exposed groups of 10 male Swiss albino mice to DMBA (initiator, 100 µg) to 112 MHz amplitude modulated (AM) at 16 Hz (power density 1.0 mW/cm^2, SAR 0.75 W/kg) or to 2.45 GHz radiation (power density of 0.34 mW/cm2, SAR, 0.1 W/kg), 2 h/day, 3 days a week for a period of 16 weeks. There was no promotion of tumors by RF in this study. In a second experiment, mice were transplanted intraperitoneally (ip) with ascites $8x10^8$ (Ehrlich-Lettre ascites, strain E) carcinoma cells per mouse followed by the same 2 radiation exposures for 14 days. They saw a non-significant increase in the number of ascites in the treated groups compared to the appropriate controls. This study suffers from a very small sample size.

5.3.2 Lymphoma Models

Here, the initiator is ionizing radiation.

Heikkinen et al. (2001) [196] exposed groups of 50 female CBA/S mice to Xrays (initiation, 4-6 MV, 3 weekly exposures of 1.333 Gy) followed by exposure to NMT900-type frequency-modulated RF at 902.5 MHz and a nominal SAR of 1.5 W/kg for 1.5 hours/day, 5 days per week, for 78 weeks. A second group with the same initiation was exposed to GSM-type RF at 902.5 MHz (pulse frequency 217 Hz) at an SAR of 0.35 W/kg with the same exposure pattern. They saw a increase in the median corpuscular hemoglobin concentration in both RF exposure groups (p=0.008 NMT900 and p=0.026 GSM). There were no survival differences. There were several changes in preneoplastic hyperplastic markers related to RF exposure, but no significant increases in tumors related to RF. There was a significant reduction in pheochromocytomas in the adrenal glands in both RF exposure groups. There were no changes in lymphoma incidence.

5.3.3 Mammary-gland Tumor Model

This model typically involves female Sprague-Dawley rats initiated by DMBA.

Bartsch et al. (2002) [197] sequentially conducted three identical studies where groups of 60 female Sprague-Dawley rats were given DMBA as an initiator (50 mg/kg/day) followed by either sham exposure or exposure to GSM RF at 900 MHz (pulse 217 Hz) for 23 hours per day, 7 days per week for 259-334 days. Exposures were in group-housed cages and ranged from 15 to 130 mW/kg depending upon the age of the animals. There were no differences between sham and exposed animals in terms of numbers of benign or malignant tumors at study termination in all three experiments although the experiments themselves differed significantly in overall tumor incidence. In the first experiment, malignant mammary tumors appeared much more rapidly in sham-exposed animals, but this was not reproduced in the two replicates.

Anane et al. (2003) [198] conducted 2 experiments using a GSM signal at 900 MHz with female Sprague-Dawley rats in cages in a chamber for 2 hours/day, 5 days/week for 9 weeks and followed without exposure for 2 more weeks. Initiation was done using DMBA (10 mg) and RF exposures began 10 days after initiation. In the first exposure, 16 animals per group were exposed to 0, 1.4, 2.2 or 3.5 W/kg SAR RF and in the second were exposed to 0, 0.1, 0.7 and 1.4 W/kg SAR RF. The first experiment saw a reduction in time to tumor for the 1.4 W/kg group, a lesser, but still significant reduction in time to malignant tumor for the 2.2 W/kg group and no difference from sham-exposed for the 3.5 W/kg group. This was not seen in the second experiment. The second experiment also saw substantially reduced tumor counts in the treated groups compared to the first experiment.

Yu et al. (2006) [199] exposed four groups of 99-100 female Sprague-Dawley rats to DMBA (initiator, 35 mg/kg) followed by sham exposure or exposure to 900MHz GSM signal RF for 4 hours/day, 5 days/week for 26 weeks in a Ferris wheel tube-restrained exposure system. The four exposures were 0, 0.44, 1.33 and 4.0 W/kg SAR. No differences in body weight, incidence, latency, multiplicity or size of mammary gland tumors was seen in this experiment as a function of RF exposure.

Hruby et al. (2008) [200] conducted an experiment almost identical to that of Yu et al. (2006). Four groups of 100 female Sprague-Dawley rats were exposed to DMBA (initiator, 17 mg/kg) followed by sham exposure or exposure to 900MHz GSM signal RF for 4 hours/day, 5 days/week for 26 weeks in a Ferris wheel tube-restrained exposure system. The four exposures were 0, 0.4, 1.3 and 4.0 W/kg SAR. The results showed a significant shift from benign mammary tumors to malignant mammary tumors for animals with exposure to RF. The highest exposure group saw a significant increase in malignant tumors relative to the sham controls and all three RF exposure groups saw a significant reduction in benign tumors compared to the sham exposure group. No differences in volume or time-to-palpable tumor were seen.

5.3.4 Brain tumor models

Brain tumor initiation-promotion studies generally use rats (Fischer 344 or Sprague-Dawley) initiated for brain tumors using N-ethyl-N-nitrosourea (ENU) in-utero using a single intravenous exposure to the dam.

Adey et al. (1999) [201] exposed two groups of 9 pregnant Fisher 344 rats to ENU (4 mg/kg) on day 18 of gestation and two groups of 9 to sham exposure. Starting on day 19 of gestation to post-natal day (PND) 21, two groups of dams and offspring (one with ENU [denoted EF for ENU-Field] and the other without [denoted SF for Sham-Field]) were exposed in cages to far field TDMA (836.55 MHz) for 2 hours/day, 7 days/week (SAR not provided) and two groups (no enu [denoted SS] and with ENU [denoted ES]) were given smam exposure to RF. Starting on PND 33 until two years of age, groups of 30 male and 30 female mice were exposed to near-field TDMA exposures at 836.55 MHz in the same groups as with the dams (SS, ES, SF, EF). Near field exposures (animals held in tubes with predominantly head exposure) had an SAR from 1.1-1.6 W/kg. Animals administered ENU had a reduction in survival in all groups and animals with RF exposure survived longer than their respective controls in all groups (not statistically significant). All RF exposed groups had reduced central nervous system tumors relative to their appropriate controls except for meningiomas (without ENU there was 1 tumor in RF exposed and no tumors in control and with ENU there were 2 tumors in RF exposed and none in control) and granular cell tumors (without ENU there was 1 tumor in RF exposed and no tumors in control). A reanalysis of the data using the exact trend statistic (one-sided) shows a significant reduction in CNS tumors with RF exposure with ($p=0.036$) and without ($p=0.016$) ENU, almost entirely due to glial tumors. No numbers were provided for any differences by sex.

Adey et al. (2000) [202] repeated this study with a larger number of offspring (45 males and 45 females) in each of the exposure groups and using an FM signal (836.55 MHz). The survival patterns were the same as for their previous study. Unlike the previous study, RF exposure yielded approximately the same incidence as sham exposure for all CNS and brain tumors. Differences between sexes were not provided.

Zook and Simmens (2001) [203] exposed pregnant female Sprague-Dawley rats to ENU at a exposure of 0, 2.5 or 10 mg/kg on day 15 of gestation. At 8 weeks of age, groups of 30 male and 30 female rats with in-utero ENU exposure were exposed to sham, pulsed-wave RF exposure (860 MHz) at a brain SAR of 1 W/kg or pulsed-wave RF exposure (860 MHz) at a brain SAR of 1 W/kg for 6 hours per day, 4 days per week for 22 months. The exposure was 'head only' and used a tube-restrained system in a Ferris wheel design. Results were presented for males and females combined. There were no significant findings in the brain or central nervous system. There was a significant increase in thyroid tumors in males (p=0.016, all sham controls grouped and all ENU exposures grouped) and a marginal increase in female mammary tumors (p=0.057).

Zook and Simmons (2006) [204] repeated this experiment where they exposed pregnant female Sprague-Dawley rats to ENU at a exposure of 6.35 or 10 mg/kg on day 15 of gestation. At 8 weeks of age, groups of 90 male and 90 female rats with in-utero ENU exposure were exposed to sham or pulsed-wave RF exposure (860 MHz) at a brain SAR of 1 W/kg for 6 hours per day, 4 days per week for 22 months. The exposure was 'head only' and used a tube-restrained system in a Ferris wheel design. Results were presented for males and females combined. There were no significant findings in the brain or central nervous system.

Shirai et al. (2005) [205] exposed pregnant female Fisher 344 rats to ENU as done in Adey et al. (1999). At 5 weeks of age, groups of 50 male and 50 female rats with in-utero ENU exposure were exposed to sham, TDMA RF exposure (1439 MHz) at a brain SAR of 0.67 W/kg or at a brain SAR of 2 W/kg for 90 minutes per day, 5 days per week until age 104 weeks. The exposure was "head only" as in **Adey et al. (1999)**. In females, there was a non-significant increase in survival with RF exposure but not in males. The authors reported no significant changes in any CNS tumors in the RF-exposed animals relative to sham-exposed animals. However, a reanalysis of the data using the Armitage linear trend test shows a marginal decrease in any type of brain tumor in females (p=0.057) that is driven by a reduction in astrocytomas (p=0.032). This was not seen in males. They noted a significant reduction in pituitary tumors in the highest exposure group for males, but tumor numbers were not provided.

Shirai et al. (2007) [206] used the exact same exposure scenario to examine the effects of WCDMA RF at 1.95 GHz at SAR 0.67 W/kg and 2.0 W/kg. There were no obvious survival differences among the treated groups and the sham controls and some mild organ weight differences in females but none in males. The authors reported no significant changes in tumor rates for any organ however they did not do trend tests. Using the Armitage linear trend test, female rats saw a significant increase in any brain tumor (p=0.030) driven primarily by an increase in astrocytomas (p=0.027). Males saw an increase in astrocytomas that was not statistically significant (p=0.181).

5.3.5 Liver Tumor Models

Imaida et al. (1998) [207] exposed groups of 48 five-week old male Fisher 344 rats to a single exposure of 200 mg/kg diethylnitrosamine (DEN) followed two-weeks later by exposure to 1.439 GHz TDMA RF at a whole body SAR of 0.453-0.680 W/kg 90 minutes a day, 5 days/week for six weeks. At three weeks the rats received a 2/3 partial hepatectomy and at the end of the six weeks of RF exposure, the study was terminated and all rats examined in their liver for the number and size of glutathione S-transferase placental form positive focal lesions that are considered precursors for liver cancer. They saw significant increases in corticosterone ($p<0.001$), melatonin ($p<0.05$) and adrenocorticotropic hormone ($p<0.001$) and a significant reduction ($p<0.05$) in the number of GST-positive foci/cm2. Similar findings were seen for the exact same experimental design using 929.2 MHz TMDA RF with whole body SARS between 0.58-0.80 W/kg [208].

5.4 Co-Carcinogenesis

Co-carcinogenesis studies are conducted by administering RF exposure along with another substance already known to be carcinogenic to see if the RF exposure enhances the carcinogenic findings. Usually, these models are targeted to a specific type of cancer.

Szmigielski et al. (1982) [186] exposed groups of 40 6-week old male Balb/c mice to 5% solution of 3,4-benzopyrene (BP) on depilated skin every second day for 5 months. Groups of these mice were exposed to 2450 MHz microwaves for 2 hours/day for the same 5 months at exposure of 5 mW/cm2 or 15 mW/cm2. Two other groups of mice were exposed to 1 or 3 months of the same RF exposure of 5 mW/cm2 followed by exposure to BP until 5 months. All animals were observed until 10 months. Exposures were in anechoic chamber. The target of these exposures was skin tumors. There were clear exposure-related and age-related increases in skin tumors in all RF-exposed groups compared to their sham-exposed groups. It is not clear if the sham-exposed controls in the 1- and 3-month RF exposure experiments were properly done. In addition, the presentation of the results from this study are sufficiently confusing that misinterpretation of the findings is possible.

Szudzinski et al. (1982) [209] performed a similar experiment to that done by Szmigielski et al. (1982) (they are in the same research group). They exposed groups of 100 6-week old male Balb/c mice to 1% solution of 3,4-benzopyrene (BP) on depilated skin every second day for 6 months. Groups of these mice were exposed to 2450 MHz microwaves for 2 hours/day for the same 6 months at exposures of 2 mW/cm2 or 6 mW/cm2. Three other groups of mice were exposed to 1, 2 or 3 months of the same RF exposure of 4 mW/cm2 followed by exposure to BP until 6 months. All animals were observed until 10 months of age. Exposures were in anechoic chambers. The target of these exposures was skin tumors. There were clear exposure-related and age-related increases in skin tumors in all RF-exposed groups compared to their sham-exposed groups. It is not clear the sham-exposed controls in the 1-, 2- and 3-month RF exposure experiments were properly done. In addition, the presentation of the results from this study are sufficiently confusing that misinterpretation of the findings is possible.

Wu et al. (1994) [210] exposed two groups of 26-32 male and 26-32 female BALB/c mice to dimethylhydrazine for 14 weeks (15 mg/kg subcutaneous injection oncer per week) and then an additional 8 weeks (20 mg/kg subcutaneous injection oncer per week). Three weeks after the first injection, one groups of mice was sham exposed and the other exposed to 2450 MHz RF (10-12 W/kg SAR) for 3 hours/day, 6 days/week for 5 months. The focus was on colon tumors and there was no difference between groups.

Heikennen et al. (2003) [211] exposed groups of female K2 transgemic mice (overexpressing human ornithine decarboxylase gene) and their wild-type littermates (strain not provided) were exposed to UV radiation (240 J/m2) 3 times per week for 52 weeks. The separate groups were exposed to sham RF, D-AMPS RF (849 MHz, 0.5 W/kg SAR) or GSM RF (902.4

MHz, 0.5 W/kg SAR) 1.5 hours/day, 5 days/week for 52 weeks. The target of the experiment was skin lesions. There were no survival differences when compared to appropriate controls in transgenic or wild-type RF-treated animals and no changes in skin lesion incidence was observed.

Heikennen et al. (2006) [212] exposed groups of 72 female Wistar rats (age 7 weeks) to 3-chloro-4-(dichloromethyl)-5-hydroxy-2(5H)-furanone (MX) via drinking water at a exposure of 1.7 mg/kg/day for 104 weeks. Separate groups were exposed to pulsed RF at 900 MHz (pule frequency 217 Hz) in a circular array of small cages for 2 hours per day, 5 days per week, for 104 weeks at whole body SARs of 0 (sham), 0.3 or 0.9 W/kg. There were no survival differences, body weight gain differences or MX consumption differences between sham-exposed and RF-exposed rats. By Peto's test, the combined incidence of vascular tumors in the mesenteric lymph nodes was significantly increased in trend (p=0.036). Using the Armitage linear trend test, the combined incidence was also significant (p=0.001, one-sided) driven by the increase in hemangiomas (p=0.023). The authors argued this was not significant since the incidence in the cage controls was higher than the sham controls. There was a significant increase in vacuolated foci in the liver by the Armitage linear trend test (p=0.002) but no increases in tumors in the liver.

Tillmann et al. (2010) [213] exposed pregnant B6C3F1 mice and 54-60 of their female offspring to whole-body UMTS RF at 1966 MHz (4.8 W/m2 or 48 W/m2) from GD6 to 2 years of age. The dams exposed to 4.8 W/m2 also received a exposure of 40 mg/kg ENU on GD 14 as did a group with sham exposure to the RF. A full necropsy was performed on each animal. No differences in survival were seen between RF-exposed groups and their appropriate controls. The 48 W/m2 group did not show any increases in tumors relative to the appropriate controls although they did see a significant increase in liver focal lesions (p=0.002 one-sided). The ENU-treated groups were terminated after 75 weeks due to mortality and all animals necropsied. The RF-exposed group saw an increase in bronchiolar-alveolar carcinomas (p=0.005), adenomas (p=0.032), adenomas or carcinomas combined (0.017) and a marginal increase in hyperplasias (p=0.098). They also saw an increase in liver adenomas (p<0.001), not carcinomas or blastomas, but an increase in combined adenomas/carcinomas/blastomas (p=0.023) and an increase in liver foci (p=0.005). There were no increases in brain tumors in any treated groups. Tumor multiplicity in both the lung and the liver was increased as was the incidence of metastasizing lung tumors.

5.5 Summary and Conclusions for Laboratory Cancer Studies

The central question to ask of animal cancer studies is "Can RF increase the incidence of tumors in laboratory animals?" The answer, with high confidence, is yes. Table 20 summarizes the findings from the chronic exposure carcinogenicity studies for RF.

For rats, the **NTP (2018)** [177] chronic exposure bioassay in male Sprague-Dawley rats, including in-utero exposure, is clearly positive for acoustic neuromas of the heart, malignant gliomas of the brain and pheochromocytomas of the adrenal gland. These findings are further supported by the presence of preneoplastic lesions and tissue toxicity in the heart, brain glial cells and adrenal glands. The less convincing findings in the study by **Falcioni et al. (2018)** [178] of heart acoustic neuromas in male Sprague-Dawley rats and a marginal increase in malignant gliomas in females provides additional support for this finding. The study by **Anderson et al. (2004)** [171] with a significant increase in oligodentrogliomas in male Fischer 344 rats when compared against historical controls provides additional strong support for an increase in gliomas from exposure to RF. This study also saw an increase in testis mesothelioma which may have been due to exposure. The lack of any brain pathology or tumors in any organ or tissue within the study by **La Regina et al. (2003)** [170], which was also in Fischer 344 rats, weakens the findings from the Anderson et al. (2004) study, but cannot fully negate them since these are different exposures at different frequencies. The **Bartsch et al. (2010)** [176] study, done using Sprague-Dawley rats, is too limited to challenge the findings of the **NTP (2018)** study. Finally, the lack of brain and heart tumors in the **Smith et al. (2007)** [175] study, done in Wistar rats, could easily be due to the different strain of rat. This study did see an exposure-related increase in thyroid C-cell tumors that was not seen in the other studies in rats.

In B6C3F$_1$ mice (the only strain tested for chronic exposure), the strongest findings are for the Harderian gland tumors in males for GSM but not DCS RF and the increase in uterine polyps in females for both GSM and DCS in the **Tillmann et al. (2007)** study [164] and the increase in rare tumors of the pars distalis in the pituitary of females in the **NTP (2018)** [166] study which were also seen for the male rats in the other NTP study [177]. The variability of the Harderian gland increases and decreases between males and females and the different types of RF in the **Tillmann et al. (2007)** study suggest that the Harderian gland is a sensitive target in these animals or that the response is highly variable in these mice for these tumors. The NTP historical controls [214] for Harderian gland tumors for this period include 29 studies and range between 6% and 26% with a mean of 16% for adenomas and carcinomas combined; the exposed groups in the **Tillmann et al. (2007)** GSM study showed responses of 24%, 32% and 36% for the low, medium and high male exposure groups, beyond the range of the historical control data supporting the conclusion this is a real, exposure-related finding. The **NTP (2018)** study did not see an increase in Harderian gland tumors in males nor an increase in uterine polyps in females. However, this study used a very different exposure system and this may have contributed to the differences.

The studies in transgenic and tumor-prone mice show mixed results. The initial positive finding of lymphomas in Eμ-pim1 transgenic mice by **Repacholli et al. (1997)** [179] were not seen in two subsequent studies [180, 181] that used better designs and better methods. It is interesting to note that the **Oberto et al. (2007)** study [181] saw an increase in Harderian gland tumors in male mice, supporting the finding from **Tillmann et al. (2007)** [164]. The one study in Patched1+/- transgenic mice was negative for brain tumors but saw a marginal increase in Rhabdomyosarcomas. The two studies in AKR/j mice were negative. The study with the highest SAR exposure levels in C3H mice [186] was positive for mammary tumors, but the remaining four [187-190] were not. It is of note that two of these studies [187, 188] saw increases in uterine stromal polyps supporting the findings from **Tillmann et al. (2007)** [164].

The initiation-promotion studies in skin [191-195] were uniformly negative as was the one study using a lymphoma model [196]. The initiation-promotion studies using a mammary tumor model [197-200] were also uniformly negative although the study by **Hruby et al. (2006)** [200] saw an exposure-related shift from benign mammary tumors to malignant tumors. The initiation-promotion studies using ENU-based brain tumor models [201-206] were negative for brain tumors with the exception of one study [206] showing an increase in brain tumors driven by an increase in astrocytomas. One of these studies [203] saw an increase in thyroid tumors in males as a function of exposure that supports the one finding in the chronic study by **Smith et al. (2007)** [175] who saw an increase in thyroid tumors in females. The one initiation-promotion study using a liver tumor model [207] saw increases in liver foci and several changes in endocrine hormones, but no liver tumors.

Four of the co-carcinogenesis studies were positive [186, 209, 212, 213] and two were negative [210, 211]. Two of the positive studies [186, 209] showed skin tumors (not surprising since the co-carcinogen was BP applied to the skin) and another positive study [212] showed increases in lymph nodes and blood vessel tumors. Another positive study [213] saw increases in lung tumors and liver tumors in female mice exposed in-utero supporting findings seen in the **Tillmann et al. (2007)** [164] study and the **NTP (2018)** [166] study.

In conclusion, there is sufficient evidence from these laboratory studies to conclude that RF can cause tumors in experimental animals with strong findings for gliomas, heart Schwannomas and adrenal pheochromocytomas in male rats and harderian gland tumors in male mice and uterine polyps in female mice. There is also some evidence supporting liver tumors and lung tumors in male and possibly female mice.

Table 30: Summary of Chronic Exposure Carcinogenicity Studies for Radiofrequency Radiation

Study	Species/Strain	RF Exposure	Sex	Tumor Finding	Notes
Tillmann et al. (2007) [164]	Mouse B6C3F1	GSM 902 MHz	M	Harderian Gland ^ Liver Adenoma ↓	
			F	Harderian Gland ⌄ Lung Tumors ↓ Liver adenomas^ Uterus polyps ^	All exposures, no trend Two lowest exposures, no trend
		DCS 1747 MHz	M	Harderian Gland ⌄ Liver Adenoma ↓ Lymphomas ↑	All exposure groups, no trend
			F	Uterus polyps ^	
National Toxicology Program (2018) [166]	Mouse B6C3F1	GSM 1.9 GHz	M	Lung tumors ↑	
			F	Malignant lymphomas ↑	Lowest 2 exposures, no trend
		CDMA 1.9 GHz	M	Liver tumors ↑	Sporadic, no trend or pattern
			F	Malignant lymphomas ↑ Pituitary pars distalis ^	Low group, increased in all, no trend Rare tumor
Chou et al. (1992) [169]	Rats S-D	Pulsed 2450 MHz	M	Total tumors ↑	No individual tumor findings
La Regina et al. (2003) [170]	Rats F344	FDMA 835.6 MHz	M		No tumor findings
			F		No tumor findings
		CDMA 847.7 MHz	M		No tumor findings
			F		No tumor findings
Anderson et al. (2004) [171]	Rats F344	Iridium 1.62 GHz	M	Testis mesothelioma ^ Oligodentroglioma ↑	Using HC, p<0.001
			F		No tumor findings
	Rats	GSM	M		No tumor findings

Smith et al. (2007) [175]	Wistar	902 MHz	F	C-cell tumors ↑	Adenomas & combined, not carc.
		DCS	M		No tumor findings
		1747 MHz	F	C-cell tumors ↑	Adenomas & combined, not carc.
Bartsch et al. (2010) [176]	Rats S-D	GSM 900 MHz	F		No tumor findings (four separate experiments, small sample sizes, not full pathology)
NTP (2018) [177]	Rats S-D	GSM 900 MHz	M	Heart schwannoma ^	
				Brain glioma ↑	Rare tumor, biological call
				Adrenal pheochromocytoma ↑	Lowest 2 exposures, no trend
				Brain meninges ^	Biological call
				Prostate gland ↑	Rare tumor, biological call
				Pituitary pars distalis ^	No trend, extensive hyperplasia
				Pancreas islets ^	Low exposure group, no trend
			F	Heart schwannoma ^	One exposure only, rare tumor
		CDMA 900 MHz	M	Heart schwannoma ^	
				Brain glioma ↑	Rare tumor, biological call
				Pituitary pars distalis ^	One exposure, no trend
				Liver tumors ^F	Rare tumor, increased but not significant
				Heart schwannoma ^	Marginal finding
				Brain glioma ↑	Rare tumor, 3 in lowest group, no sig, no trend
				Adrenal pheochromocytoma ↑	Low exposure only, no trend
Falcioni et al. (2018) [178]	Rats S-D	GSM 1.8 GHz	M	Heart schwannoma ^	No tumor findings (slight ↑ in malignant gliomas)
			F		

6. Mechanisms Related to Carcinogenicity

There is sufficient evidence to suggest that both oxidative stress and genotoxicity are caused by exposure to RF and that these mechanisms could be the reason why RF can induce cancer in humans.

6.1 Introduction

Many human carcinogens act via a variety of mechanisms causing various biological changes, taking cells through multiple stages from functioning normally to becoming invasive with little or no growth control (carcinogenic). **Hanahan and Weinberg (2011)**[215] identified morphological changes in cells as they progress though this multistage process and correlated these with genetic alterations to develop what they refer to as the "hallmarks of cancer." These hallmarks deal with the entire process of carcinogenesis and not necessarily with the reasons that cells begin this process or the early stages in the process where normal protective systems within the cells remove potentially cancerous cells from the body. While tumors that arise from a chemical insult to the cell may be distinct from other tumors by mutational analysis, they all exhibit the hallmarks as described by **Hanahan and Weinberg (2011)**.

Systematic review of all data on the mechanisms by which a chemical causes cancer is complicated by the absence of widely accepted methods for evaluating mechanistic data to arrive at an objective conclusion on human hazards associated with carcinogenesis. Such systematic methods exist in other contexts [216], but are only now being accepted as a means of evaluating literature in toxicological evaluations [32, 217-220].

In this portion of the report, I am focusing on the mechanisms that can cause cancer. **Smith et al. (2015)** [39] discussed the use of systematic review methods in identifying and using key information from the literature to characterize the mechanisms by which a chemical causes cancer. They identified 10 "Key Characteristics of Cancer" useful in facilitating a systematic and uniform approach to evaluating mechanistic data relevant to carcinogens. These 10 characteristics are presented in Table 21 (copied from Table 1 of **Smith et al. (2015)** [39]). While there is limited evidence on RF exposure for most of the key characteristics, genotoxicity (characteristic two) and oxidative stress (characteristic five) have sufficient evidence to warrant a full review.

Table 21: Key characteristics of carcinogens, Smith et al. (2016)[65]

Characteristic	Examples of relevant evidence
1. Is electrophilic or can be metabolically activated	Parent compound or metabolite with an electrophilic structure (e.g., epoxide, quinone), formation of DNA and protein adducts
2. Is genotoxic	DNA damage (DNA strand breaks, DNA–protein cross-links, unscheduled DNA synthesis), intercalation, gene mutations, cytogenetic changes (e.g., chromosome aberrations, micronuclei)

3. Alters DNA repair or causes genomic instability	Alterations of DNA replication or repair (e.g., topoisomerase II, base-excision or double-strand break repair)
4. Induces epigenetic alterations	DNA methylation, histone modification, microRNA expression
5. Induces oxidative stress	Oxygen radicals, oxidative stress, oxidative damage to macromolecules (e.g., DNA, lipids)
6. Induces chronic inflammation	Elevated white blood cells, myeloperoxidase activity, altered cytokine and/or chemokine production
7. Is immunosuppressive	Decreased immunosurveillance, immune system dysfunction
8. Modulates receptor-mediated effects	Receptor in/activation (e.g., ER, PPAR, AhR) or modulation of endogenous ligands (including hormones)
9. Causes immortalization	Inhibition of senescence, cell transformation
10. Alters cell proliferation, cell death or nutrient supply	Increased proliferation, decreased apoptosis, changes in growth factors, energetics and signaling pathways related to cellular replication or cell cycle control, angiogenesis

Abbreviations: AhR, aryl hydrocarbon receptor; ER, estrogen receptor; PPAR, peroxisome proliferator-activated receptor. Any of the 10 characteristics in this table could interact with any other (e.g., oxidative stress, DNA damage, and chronic inflammation), which when combined provides stronger evidence for a cancer mechanism than would oxidative stress alone.

6.2 Oxidative Stress

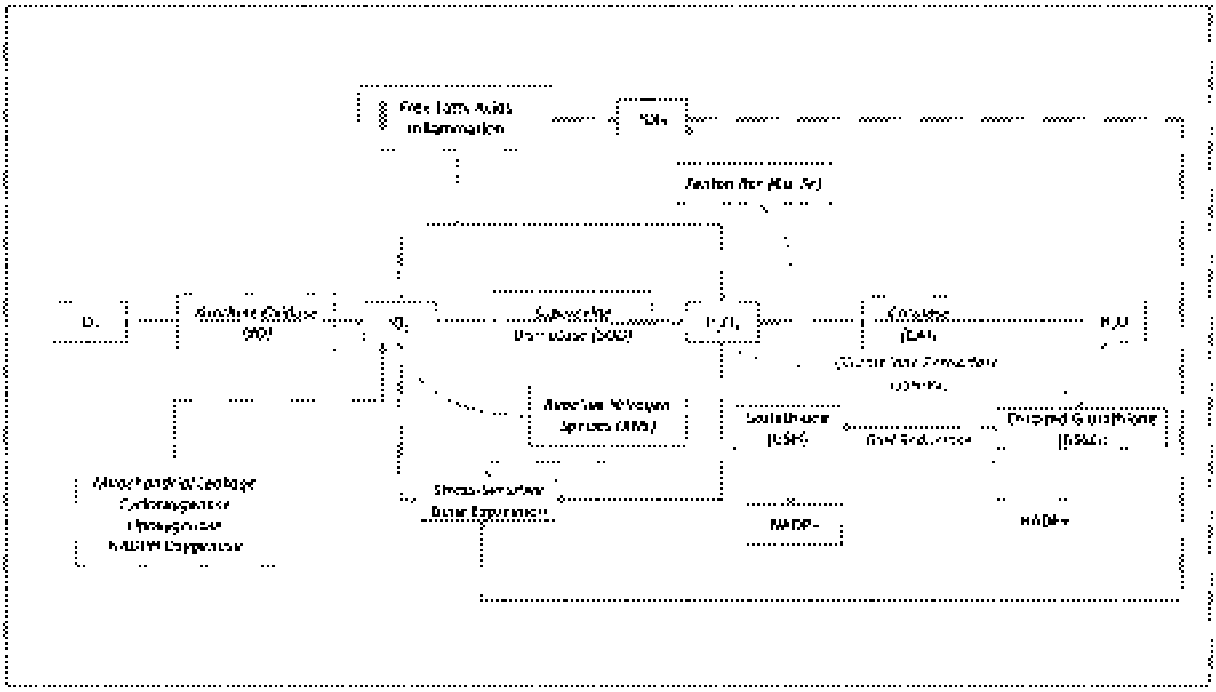
6.2.1 Introduction

Oxidative stress refers to an imbalance between the production of reactive oxygen species (free radicals) in a cell and the antioxidant defenses the cell has in place to prevent this. Oxidative stress has been linked to both the causes and consequences of several diseases [221-226] including cancer [39, 227-231]. Multiple biomarkers exist for oxidative stress; the most common being increased antioxidant enzyme activity, depletion of glutathione or increases in lipid peroxidation. In addition, many studies evaluating oxidative stress used antioxidants following exposure to RF to demonstrate that the effect of the oxidative stress can be diminished.

Measuring oxidative stress can be difficult due to redundant pathways of a highly interconnected system. Molecular oxygen is essential to the proper function of a cell. During the course of normal oxidative phosphorylation, between 0.4 and 4% of all oxygen consumed is converted into the free radical superoxide ($^{\bullet}O_2$). This $^{\bullet}O_2$ can be converted into other ROS and reactive nitrogen species (RNS) and is normally eliminated by antioxidant defenses. $^{\bullet}O_2$ molecules are quickly converted to hydrogen peroxide (H_2O_2) by superoxide dismutase (SOD). H_2O_2 is then either detoxified to H_2O and O_2 by glutathione peroxidase or diffuses into the cytosol and is detoxified by catalase. However, in the presence of reduced transition metals such as copper (Cu) or iron (Fe), H_2O_2 can be converted to the highly reactive hydroxyl radical ($^{\bullet}OH$). These linkages are illustrated in Figure 5.

The three reactive oxygen species (ROS) in the cell ($^{\bullet}O_2$, $^{\bullet}OH$, H_2O_2) can be measured directly, changes in the activity of the major enzymes (XO, SOD, CAT, GSH-Px, GSH reductase) can be measured, changes in GSH or GSSG can be measured, changes in gene expression can be measured, changes in nitrogen oxide (NO) can be measured and changes in other enzymes (e.g. cyclooxygenase) can be measured. No one study measures all of these components. Most studies measure two or more components of this system in animals or cells exposed to RF to see if they have changed due to the RF exposure.

[illegible] Exogenous and endogenous stimuli leading to ROS generation and activation of stress-sensitive gene expression. (modified from [232])



6.2.2 International Agency for Research on Cancer (IARC)

The IARC reviewed the potential for carcinogenicity from RF in 2011 [35]. They evaluated the scientific literature prior to 2011 and concluded "there was weak evidence that exposure to RF radiation affects oxidative stress and alters the levels of reactive oxygen species." This conclusion was driven by methodological shortcomings in the studies, lack of a sham-controlled group in some studies, use of mobile phones for exposures and poor dosimetry. Having looked over the IARC review (I was an *Invited Specialist*[a] for this review), I agree with their assessment of these data and will not discuss any studies prior to 2010.

[illegible] (2011-2020)

[illegible]

Five studies evaluated the effects of RF on humans, two studies using blood, two using saliva and one using seminal plasma. Gulati et al. (2018) [232] compared 116 individuals in India living near cellular towers to 106 controls living more than 800 meters from towers. They saw significant decreases in SOD, CAT and a significant increase in lipid-peroxidation

[a] *Invited Specialists* are experts who have critical knowledge and experience 3 but who also have a conflict of interest that warrants exclusion from 4 developing or influencing the evaluations of carcinogenicity

(LP) in plasma associated with being close to cellular towers. **Zothansiama et al. (2017)** [233] studied 40 people living close to cellular towers (<80 meters) with people living further away (>300 meters) in a different population in India and measured RF power-density in the bedrooms of all of the participants. They saw the same changes in SOD, CAT and LP. In addition, increasing power-density measurements were associated with increased micronuclei (MN) in peripheral blood lymphocytes. **Khalil et al. (2014)** [234] and **Abu et al. (2015)** [235] reported on the same set of 12 individuals whose saliva was sampled before and after 15 and 30 minutes of use of a specific cellular phone (1800 MhZ Nokia with an SAR of 1.09). They saw an increase in SOD, but no change in malondialdehyde (MDA) or 8-hydroxydeoxyguanosine (8-OHdG, a measure of oxidative damage). **Malini (2017)** [236] compared usage in 47 males in India in groupings of 1-5 hours/day (20 men), 5-10 hours/day (22 men) and >10 hours/day (5 men) and saw no changes in ROS, ROS scavengers or DNA damage in semen.

6.2.3.2 Mouse

In the discussion that follows, unless otherwise mentioned, SAR values used in the studies are generally less than 1 W/kg either whole body or tissue specific. Details can be found in Supplemental Table 1.

6.2.3.2.1 BALB/c Mice

Khalil et al. (2011) [237] saw no changes in oxidative stress in brain, spleen or serum in BALB/c mice exposed for 30 days to 900 MHz RF at 1 W/kg SAR. **Bahreyni et al. (2018)** [238] saw changes in reactive oxygen species (ROS) and/or ROS-scavenging enzymes in heart, liver, kidney, cerebellum and hippocampus in the dams and heart, liver, kidney, and cerebellum of their offspring from pregnant female BALB/c mice exposed for 20 days to joint 900/1800 MHz RF for which the SAR was not provided.

6.2.3.2.2 Parkes Mice

Shahin et al. (2013) [239] saw the expected changes in ROS and ROS-scavenging enzymes (SOD, CAT, GST) in the liver, kidney ovaries and blood of pregnant Parkes mice exposed for 45 days to 0.023 W/kg of 2450 MHz RF and saw associated DNA damage in the brains from the same exposure.

6.2.3.2.3 Swiss Mice

Shahin et al. (2014) [240] saw an increase in ROS and associated changes in ROS scavengers in the hypothalamus, liver, kidney and testis of male Swiss mice exposed for 30 days to 0.018 W/kg 2450 MHz RF and saw significant tissue toxicity in the testis. **Shahin et al. (2017)** [241] also saw an increase in ROS and associated changes in ROS scavengers in the hypothalamus, uterus and ovaries of female Swiss mice exposed for 100 days to an unknown SAR from a 1800 MHz cellular phone. They also saw significant tissue changes in the uterus and a modification of reproductive hormones. **Shahin et al. (2018)** [242] saw changes in stress-related hormones and associated markers in the hippocampus and blood of male Swiss mice exposed for 15, 30 or 60 days to 0.0146 W/kg 2450 MHz RF. These stress changes, probably associated with induced nitrous oxide, led to reductions in learning and spatial memory in these mice. **Shahin et al. (2018)** [243] saw an increase in ROS and associated changes in ROS scavengers , increased apoptosis, and tissue toxicity in the testis of male Swiss mice exposed for 120 days to 0.05 W/kg 1800 MHz (using a mobile phone). **Pandey et al. (2017)** [244] saw mitochondrial damage, other cellular damage and DNA damage in spermatocytes of male Swiss mice exposed for 35 days to 0.0045-0.0056 W/kg 900 MHz RF; they attributed these changes to oxidative stress.

Esmekaya et al. (2016) [245] exposed Swiss mice with chemically-induced epileptic seizures (induced by pentylenetetrazole) for 15 or 30 minutes to a 900 MHz cellular phone with a head SAR of 0.301 W/kg and saw changes in ROS and ROS scavengers in the brain.

[illegible]

Zong et al. (2016) exposed male ICR mice for 7 days to 0.05 W/kg 900 MHz RF and saw no changes in ROS in liver, lung and blood. **Zong et al. (2015)** [246] exposed male mice to 0.05 W/kg 900 MHz RF for 4 hours/day for 7 days and saw no significant changes in ROS, ROS scavengers or DNA damage in liver, lung and blood.

[illegible]

Jeong et al. (2018) exposed 14 month old female C57BL/6 mice for 8 months to 5 W/kg 1950 MHz RF and saw no changes in ROS, apoptosis or DNA damage in the brain and no change in locomotor activity.

[illegible]

The best-studied strain of mouse is the Swiss-albino mouse and all studies using these mice demonstrated indications of oxidative stress induced by RF in multiple studies in the brain and testis and in single studies to the uterus, ovaries, liver and kidney at multiple frequencies and very low SARs. Three of the seven studies in Swiss mice used cellular phone exposure systems. In BALB/c mice, there is one negative study in brain, serum and spleen at 1 W/kg SAR, 900 MHz and 1 positive study in brain, heart, liver and kidney at 900/1800 MHz but an unknown SAR. One study in Parkes mice shows clear oxidative stress in liver, kidney and ovaries, DNA damage in the brain and changes in blood chemistry for a low SAR at 2450 MHz. In ICR mice, there is one study showing no changes in oxidative stress in liver, lung and blood at a low SAR at 900 MHz. Finally, in C57BL/6 mice, there is one study with no indication of oxidative stress in the brain at a much higher SAR at 1950 MHz.

In summary, RF can cause oxidative stress in the brain, testis, liver, kidney, uterus, heart and ovaries of Swiss-albino mice and the liver, kidney, ovaries and brain of ICR mice. There is insufficient data to support a causal linkage between RF exposure and oxidative stress in other strains of mice

[illegible]

In the discussion that follows, unless otherwise mentioned, SAR values used in the studies are generally less than 1 W/kg either whole body or tissue specific. Details can be found in Supplemental Table 1

[illegible]

There are 60 studies of RF in Wistar rats of which 35 used laboratory exposure systems and 23 used cellular phones. These can be further divided by frequency and by organ to provide a summarized view of the findings. Fifteen (15) studies with laboratory exposure systems used 900-915 MHz RF, 1 used 1500 MHz, 11 used 1800 MHz, 4 used 2100 MHz, 18 used 2450 MHz, 1 used 2600 MHz and 1 used 2856 MHz (NOTE, this adds up to more than 33 studies because some studies used multiple frequencies). Seven (7) of the studies using cell phones or wifi devices used 900 MHz, 2 used cell phones with joint 900/1800 MHz, 2 used cell phones with joint 900/1800/1900 MHz, 1 used 1910.5 MHz, 3 used a 2450 MHz device, 1 used 2115 MHz and one used 2437 MHz.

All of the 8 studies in Wistar rats using laboratory systems at 900-915 MHz that evaluated oxidative stress in the brain showed changes in both ROS and ROS scavengers [247-254] with three examining and demonstrating tissue changes in the brain [250, 251, 253] (none examined DNA damage) and 2 examining and demonstrating behavioral changes [252, 253]. All 3 of the studies at only 900 MHz using a cellular phone showed changes in both ROS and ROS scavengers [255-257] with one examining and demonstrating tissue changes in the brain [256] but no significant change in DNA damage. One study at 1500 MHz showed decreases in SOD in the brain, changes in learning and spatial memory and brain tissue toxicity [258].

All of the 5 studies in Wistar rats using laboratory systems at 1800 MHz that evaluated oxidative stress in the brain showed changes in ROS and/or ROS scavengers [249-251, 259, 260] with three examining and demonstrating tissue changes in the brain [250, 251, 260] (none examined DNA damage). The one study at 900/1800 MHz using a cellular phone showed changes only in catalase activity with no other changes in either ROS or ROS scavengers [261] although they did see changes in animal behavior. Two studies in Wistar rats using laboratory systems at 2450 MHz that evaluated oxidative stress in the brain showed changes in ROS but not ROS scavengers [262, 263], one saw both change [254], one saw both change with brain toxicity [251], and one study showed no changes in ROS but used an unusual marker that appears to be focused entirely on nitrous oxides [264]. Two studies using 2450 MHz devices (wifi) were positive for both ROS and ROS scavengers with one showing changes in spatial memory from prenatal exposure [265] and the other not showing behavioral changes using adult exposure [266]. Studies were also clearly positive for the brain at 2100 MHz [267], 2115 MHz [268, 269] and 2856 MHz [258].

Sixteen (16) studies in Wistar rats looked at oxidative stress in the testis or sperm. Four (4) studies using laboratory-created 900 MHz saw changes in ROS and/or ROS scavengers (depending on what was measured) [270-273] and one saw changes in ROS but not ROS scavengers [274], two measured and demonstrated changes in tissue [272, 273] and one measured and demonstrated damage to DNA [272]. The two studies using 900 MHz cellular phones saw changes in ROS and ROS scavengers [275, 276] with one measuring and demonstrating both tissue damage and DNA damage [275]. One study with laboratory-generated 1800 MHz RF had no statistically significant change in ROS, but did see changes in ROS scavengers and apoptosis [277] and one study saw both ROS and ROS scavengers changed [271]. The one study using a 900/1800 MHz cellular phone saw changes in ROS and ROS scavengers and tissue toxicity [278]. One study with a combined 900//1800/1900 MHz cellular phone examined only ROS scavengers and saw changes and tissue toxicity [279]. The one study with a laboratory generated 2450 MHz signal saw changes in both ROS and ROS scavengers [271]. Single studies at 1950 MHz [280], 2100 MHz [281] and 2437 MHz

[282] saw changes to both ROS and ROS scavengers with two examining and demonstrating tissue toxicity [280, 282].

Heart tissue was examined in 4 studies. One, using 2450 MHz saw changes in ROS and ROS scavengers, tissue toxicity and apoptosis [283]. Another, also at 2450 MHz, saw changes in ROS and ROS scavengers, but not for all markers examined [284], and another at 2450 MHz saw changes in ROS but not ROS scavengers. The final study used laboratory generated 900 MHz and saw changes in ROS and ROS scavengers [270].

Liver tissue was examined in 7 studies in Wistar rats. Two studies using laboratory-created 900 MHZ [249, 270] and one using a 900 MHz cellular phone [285] saw changes in ROS and ROS scavengers. One study at 1800 MHz saw changes in ROS and ROS scavengers [249] while another showed no significant changes [286]. The one study using laboratory-created 2450 MHz showed an increase in ROS and tissue toxicity but did not look for changes in ROS scavengers [287] and another using laboratory-created 2600 MHz saw no significant change in ROS or ROS scavengers but did see tissue changes [288]. The one study using 1910.5 MHz saw an increase in ROS (scavengers not evaluated) and increased DNA damage.

Kidney tissue was examined in 3 studies; two were positive for changes in both ROS and ROS scavengers, one using 2450 MHz [289] and the other examining the frequencies of 900, 1800 and 2450 MHz [271]. One study showed no change in ROS (ROS scavengers not examined) using 1800 MHz [286].

Three studies evaluated the effect of RF in the eye epithelium of Wistar rats and all were effectively negative [290-292].

One study using laboratory-generated 2450 MHz saw increased ROS in the spleen (ROS scavengers were not examined) [287]. One study using laboratory-generated 900 MHz saw changes in ROS and ROS scavengers in the lung [270]. The Laryngotracheal mucosa was examined in one study using 2450 MHZ showing increased ROS but no significant change in ROS scavengers [293]. The ovary was examined in one study using 2450 MHZ showing increased ROS (ROS scavengers were not examined) [294]. One study using the three frequencies 900, 1800 and 2450 MHz saw changes in ROS for all three frequencies but no significant changes in ROS scavengers [295] in uterus and blood. A single study using 900 MHz saw changes in ROS and ROS scavengers in lymphoid tissues and blood [296]. A cell phone at 900 MHz only was used for one study and at a combined 900/1800/1900 MHz phone for one other study. Finally, one study used a combined 848.5/1950 MHz signal that was laboratory generated.

6.2.3.3.2 Sprague-Dawley Rats

There are 37 studies in Sprague-Dawley (SD) rats. Laboratory-generated RF at 900 MHz was used in 21 studies, 1800 MHz in 4 studies, 2100 MHz in 2 studies, and 2450 MHz in 5 studies [297-301].

Five studies evaluated oxidative stress in the brain using a laboratory-generated 900 MHz signal, and all of them demonstrated some degree of stress. Three studies demonstrated changes in both ROS and ROS scavengers [297, 299, 301] with 2 also demonstrating tissue changes in the brain [299, 301]. One study [298] saw no significant change in ROS but changes in ROS scavengers and tissue toxicity and one only examined a single ROS scavenger (significantly decreased) and saw changes in learning, spatial memory and the blood-brain barrier. One study [302] using laboratory-generated 900, 1800 and 2100 MHZ saw changes in ROS and ROS scavengers at all three frequencies in the brain and significant DNA damage at 2100 MHz. One last study [303] using laboratory-generated 2450 MHz RF saw changes in gene expression and protein levels in the brain linked to oxidative stress and tissue response.

Three studies [304-306] examined oxidative stress in the testis or sperm using a laboratory-generated 900 MHz signal with all showing changes to ROS and ROS scavengers and 2 examining and demonstrating tissue changes and increased apoptosis [304, 306]. One study using a 900 MHz cellular phone demonstrated changes in ROS, ROS scavengers, tissue toxicity and apoptosis [307], whereas another using a 900/1800/1900 MHz cellular phone failed to demonstrate any significant changes in ROS, ROS scavengers or tissue toxicity [308]. A single study using a laboratory-generated 2450 MHZ signal with a moderate SAR (3.21 W/kg) demonstrated increases in ROS, decreases in ROS scavengers and increased tissue toxicity [309]. The final study evaluating oxidative stress in the testis used a combined 848.8/1950 MHz signal and a moderate SAR (4 W/kg) and failed to see any changes in ROS or tissue toxicity (ROS scavengers were not evaluated) [310].

Four studies examined oxidative stress in the kidney using laboratory-generated 900 MHz signals, 2 saw changes in ROS, ROS scavengers and tissue toxicity [299, 311], one saw increased ROS, tissue toxicity and apoptosis (ROS scavengers not examined) [312], and one saw no significant changes in ROS or ROS scavengers although they did see kidney toxicity [313]. One other study in the kidney used 2100 MHz and demonstrated changes in ROS, ROS scavengers, tissue toxicity and apoptosis [314]. **Turedi et al. (2017)** [312] also examined the bladder and saw clear changes in oxidative stress.

Four studies examined oxidative stress in the liver using laboratory-generated 900 MHz signals, 2 saw changes in ROS, ROS scavengers and tissue toxicity [299, 315], one saw increased ROS and decreased ROS scavengers (tissue toxicity not examined) [316], and one saw no significant changes in ROS, some changes in ROS scavengers and kidney toxicity [317]. One other study in the liver used 1800 MHz demonstrated changes in ROS, ROS scavengers and tissue toxicity [318].

Two studies looked at ovaries, one using 900 MHZ [319] and one using 2450 MHZ [320], saw changes in ROS and tissue toxicity but no changes in ROS scavengers. **Saygin et al. (2018)** [320] also looked at uterus and fallopian tubes and saw no significant changes in any oxidative stress markers.

Two studies in SD rats examined oxidative stress in the heart using laboratory-generated 900 MHz signals. One study, using in-utero exposure, saw clear increases in ROS and decreases in ROS scavengers with tissue toxicity and apoptosis [321]. The other study, using young rats, saw increased ROS, increased apoptosis, but no changes in ROS scavengers or in tissue toxicity [322].

Two studies in SD rats examined oxidative stress in the spinal cord using laboratory-generated 900 MHz signals with almost identical protocols. Both studies saw clear increases in ROS and weak or non-significant changes in ROS scavengers with tissue toxicity and apoptosis[323, 324]. One study using laboratory-generated RF looked at the sciatic nerve and saw changes in ROS and ROS scavengers, apoptosis and tissue toxicity [325].

Single studies evaluated the ear (increased ROS, no other changes) [326], pancreas (ROS, ROS scavengers and tissue changes) [327], spleen and thymus (ROS, ROS scavengers and tissue changes) [328] and eyes (ROS, ROS scavengers) [305].

6.2.3.3.3 *Other* Rat Strains

Three studies examined RF oxidative stress in Fischer rats. One study used laboratory-generated signals at 900, 1800 and 2450 MHz and saw changes in ROS and ROS scavengers, DNA damage and inflammation in the brain [329]. A second study evaluated blood using a 900 MHz signal and saw changes in ROS and ROS scavengers in blood and changes in learning and spatial memory [330]. The final study used 900 and 1800 MHz signals and recorded changes in ROS, ROS scavengers, and tissue changes in the brain with associated learning and spatial memory deficits [331].

Two studies listed their rats as albino; these could have been Wistar rats. One study evaluated serum exposed to a 900 MHz laboratory-derived field and saw a decrease in ROS scavengers (ROS was not evaluated) [332]. The second examined parotid glands in rats exposed to a 900 MHz cellular phone and observed an increase in ROS and a decrease in ROS scavengers with associated tissue changes [333].

The only study in Long-Evans rats used a laboratory-generated 900 MHz signal and saw changes in stress hormones in the brain but no significant changes in learning or spatial memory [334].

One study appears to have used locally-caught wild rats, exposed them to a 2100 MHz mobile phone and demonstrated an increase in creatinine kinase-MB (indicator of oxidative stress in the heart) and a decrease in cardiomyocytes [335].

Four studies failed to identify the strain of rat [336-339].

6.2.3.3.4 Summary in Rats

The best-studied strains of rat are the Wistar and SD rats and these show clear indications of oxidative stress induced by RF in multiple studies in the brain and testis and some indication of oxidative stress in the heart. The SD rats also seem to have consistent evidence of oxidative stress in the liver and kidney. Other findings in female reproductive organs, spinal cord, eye and other tissues are shown in 1 or 2 studies each. In other strains of rat, the most prominent findings are in the brain where there is generally increased oxidative stress. Most of these findings are at SARs below 1 W/kg and seem to occur regardless of the frequency used.

In summary, RF can cause oxidative stress in the brain, testis, and heart of SD and Wistar rats and the liver and kidney of SD rats. Brain appears to be a target for oxidative stress in Fischer rats. There is insufficient data to support a causal linkage between RF exposure and oxidative stress in other strains of rat.

6.2.3.4 Other Laboratory Species

Three studies looked at the effects of RF on oxidative stress in New Zealand White rabbits. **Guler et al. (2016)** [340] used laboratory-generated 1800 MHz signals and saw increases in brain ROS (ROS scavengers were not examined) in male rabbits exposed both in-utero and after birth but not in females. **Guler et al. (2012)** [341] used the same laboratory set up and study design and saw changes in liver ROS and ROS scavengers and an increase in 8-OHdG in females, but no direct DNA damage. **Ogur et al. (2013)** [342] in an earlier study used the same exposure and saw increased ROS in blood for males and females with in-utero exposure and for females (not males) with exposure 1 month after birth. This same research group had done an earlier study with a similar design and saw no significant changes in blood [343].

One study examined laboratory-generated 900 MHz signals in Guinea pigs and saw a reduction in ROS scavengers in the liver but no significant change in ROS.

There is insufficient data to support a causal linkage between RF exposure and oxidative stress in laboratory species other than rats and mice.

6.2.4 *In Vitro* Studies in Mammalian Cells

6.2.4.1 Human Cells

6.2.4.1.1 Primary Cells

In vitro studies in primary cells refer to the use of cells taken directly from humans, then exposed in a laboratory to RF where oxidative stress is evaluated. Three studies exposed human sperm to RF and evaluated oxidative stress. Using a 900 MHZ mobile phone led to changes in ROS (ROS scavengers not examined) and DNA damage [344]. Using a laboratory-generated 1950 MHz signal resulted in no significant changes in ROS [345]. Using a 2450 MHz cellular phone resulted in clear oxidative stress with changes in both ROS and ROS scavengers [346].

Three studies used peripheral blood. Monocytes showed changes in ROS, ROS scavengers and apoptosis after being exposed to a laboratory-generated 900 MHz signal [347]. In another study, monocytes, but not lymphocytes, saw an increase in ROS (ROS scavengers not evaluated) after exposure to a laboratory derived 900 MHz signal [348]. The third study, both monocytes and lymphocytes exposed to a laboratory-derived 1800 MHz signal showed changes in ROS scavengers (ROS was not directly measured) [349]. A single study used umbilical cord blood exposed using a 900 MHz cellular phone resulting in an increase in ROS [350].

A single study used astrocytes from human brains exposed to 918 MHz RF and saw a decrease in ROS (ROS scavengers not examined) [351] (Note, this study was aimed at RF as a therapy for Alzheimer's).

Human stem cells exposed to 900, 1950 or 2535 MHz RF saw no significant changes in ROS apoptosis or DNA damage except for DNA damage that was shown at 900 MHz [352].

One study used primary cells from human skin, umbilical veins and amniotic fluid and saw no increase in ROS, saw binucleated nuclei in skin but no DNA damage via comet assay [353]

The final study of human primary cells used thyroid gland cells exposed to 900 or 895 MHz RF and saw no significant increase in oxidative stress [354].

Three (3) of these studies used SAR above 1 W/kg.

[illegible]

Two studies using the same basic design of 1 hour exposure to 2450 MHz RF saw a significant change in ROS and ROS scavengers [355, 356]. The only other study used a 940 MHz signal and also resulted in significant change in ROS and ROS scavengers [357].

[illegible]

Two studies, one at 900 MHz [358] and the other at 2450 MHz [359] both demonstrated increases in ROS and changes in ROS scavengers. The 900 MHz study [358] also saw damage to mitochondrial DNA. Finally, HL-60 cells exposed to 900, 1950 or 2535 MHz RF saw no significant changes in ROS or apoptosis [352]. Only 1 study used SARs above 1 W/kg.

[illegible]

Two studies, one with 935 MHz [360] and the other with 1800 MHz [361], saw no changes in oxidative stress. Two studies, one with 837 and 1950 MHz [362] and the other with 1800 MHz wifi device [363], saw changes in ROS only (changes in ROS scavengers were not evaluated). Finally, two studies, one with 935 MHz [364] and the other with 1800 MHz [365], saw changes in both ROS and ROS scavengers. Five of these studies used SARs greater than 1 W/kg.

[illegible]

Studies in AC5 cells (adipose tissue), Huh7 cells (liver), and U87 cells (glioma) all studied only ROS and demonstrated a significant increase in ROS [362, 366]. Studies in U-87 MG cells (glioma), MCF-7 cells (breast cancer), MDA-MB-231 cells (breast cancer) and HLE B3 cells (lens epithelium) studied a full spectrum of ROS and ROS scavengers and saw significant indications of oxidative stress [361, 362, 367-369]. A single study in MCF10A cells (breast) so no increase in ROS or ROS scavengers[370].

[illegible]

[illegible]

One study in Leydig cells saw changes in ROS and ROS scavengers after exposure to RF [371]. Another study of preantral follicles (ovaries) also saw changes in ROS and ROS scavengers after exposure to RF [372]. A study of spermatocytes saw an increase in ROS associated with an increase in DNA damage [373].

[illegible]

Three studies used NIH/3T3 cells. All three saw increases in ROS but did not study ROS scavengers [362, 374, 375] with two also showing an increase in apoptosis [374, 375].

[illegible]

Four studies evaluated the effects of RF on mouse derived spermatocyte cell line GC1 and/or GC2. All four saw increases in ROS [373, 376-378], 2 of these showed increases in DNA damage [376, 377], 2 saw increases in 8-OhdG [373, 377] and one saw an increase in apoptosis [378].

[illegible]

Two studies in N9 cells saw significant changes in ROS and ROS scavengers [364, 379] and one study demonstrated an increase in NO [380].

[illegible] Other Neural Cell Lines

One study with Neuro-2A cells (neuroblastoma) saw an increase in ROS (did not study ROS scavengers), but no significant change in DNA damage [381]. Two studies in the same laboratory evaluated RF and HT22 cells (hippocampus), neither study evaluated ROS scavengers, one saw a significant increase in ROS and a change in cell cycle [382] while the other with lower SAR values and two frequencies combined saw no significant change in ROS [383]. One study in RAW 264.7 cells (macrophage) saw an increase in ROS but did not study ROS scavengers [384]. Finally, one study using TM3 cells (leydig) saw changes in ROS and ROS scavengers but no change in apoptosis [385].

[illegible]

Two studies used rat primary cells from the brain. One saw a decrease in ROS (scavengers not evaluated) in astrocytes when exposed to 918 MHz RF and challenged with hydrogen peroxide [351]. One study of rat neonatal spinal ganglia and neurons exposed to 1800 MHz RF saw an increase in ROS but no DNA damage [386].

One additional study used PC12 cells (rat derived pheochromocytoma cell line) exposed simultaneously to 837 MHz and 1950 MHz RF saw significant increased ROS at 12 hours but not at other times in a 24 hour window.

[illegible] Cells Derived from Hamsters

Two studies exposed V79 cells (hamster lung cells) to 1800 MHz with one seeing increased ROS (nothing else studied) [387] and the other showing increased ROS and ROS scavenger activity [388]. A final study using CHO cells (ovaries) exposed to 900 MHz saw increased ROS (scavengers not evaluated) that remained 12 hours after exposure stopped [389].

8.2.5 Summary for Oxidative Stress

Most of the in-vivo and in-vitro studies of oxidative stress saw significant increases in ROS. Most of the studies that evaluated ROS scavengers saw significant changes in these markers that is associated with oxidative stress, the tissue or cells. Nineteen (19) in-vivo studies, 18 done in rats or mice and one in rabbits, evaluated oxidative stress as well as DNA damage, about half with SARs below 1 and a mix of exposure durations and almost all of them showed an increase in DNA damage.

Although reactive oxygen species can potentially cause damage to cellular function and structure and thereby impair its functionality, their presence and production cannot be immediately considered as harmful because changes in the levels of ROS and ROS scavengers is a normal part of cellular metabolism and physiology. Thus, many of the studies in this section simply demonstrate a change and not necessarily harm. However, tissue toxicity, increased DNA damage and changes in apoptosis do indicate that the changes in ROS are sufficient to impair cellular function and damage cellular components.

Many of the studies presented in this section did address these issues. With respect to cancer, of greatest concern would be damage to DNA. Twelve (12) of these in-vivo studies showed an increase in DNA damage associated with oxidative stress [239, 244, 256, 268, 272, 275, 302, 329, 338, 390-392], seven (7) did not see a significant change in DNA damage [236, 246, 256, 337, 341, 393, 394] and one saw a significant decrease in DNA damage after 15 days of exposure and an increase after 30 days of exposure [336]. Eight (8) in-vitro studies evaluated some aspect of oxidative stress as well as DNA damage, all of them with rather short exposure periods and most with SARs greater than 1. Five (5) of these studies demonstrated increases in DNA damage [344, 346, 352, 376, 377] and three (3) saw no significant increase in DNA damage [353, 381, 386].

There is sufficient evidence in the literature to conclude that oxidative stress is a possible mechanism by which RF causes cancer in humans.

6.3 Genotoxicity

6.3.1 Introduction

Genotoxicity refers to the ability of an agent (chemical or otherwise) to damage the genetic material within a cell, thus increasing the risks for a mutation. Genotoxic agents interact with the genetic material, including DNA sequence and structure, to damage cells. DNA damage can occur in several different ways, including single- and double-strand breaks, cross-links between DNA bases and proteins, formation of micronuclei and chemical additions to the DNA.

Just because a chemical can damage DNA does not mean it will cause mutations. So, while all chemicals that cause mutations are genotoxic, all genotoxic chemicals are not necessarily mutagens. Does that mean that the genotoxicity of a chemical can be ignored if all assays used for identifying mutations in cells following exposure to a chemical are negative? The answer to that question is no and is tied to the limitations in tests for mutagenicity (the ability of a chemical to cause mutations in a cell). It is unusual to see an evaluation of the sequence of the entire genome before exposure with the same sequence after exposure to determine if the genome has been altered (mutation). There are assays that can evaluate a critical set of genes that have previously been associated with cancer outcomes (e.g. cancer oncogenes), but these are seldom applied. In general, mutagenicity tests are limited in the numbers of genes they actually screen and the manner in which these screens work.

Because screening for mutagenicity is limited in scope, any genetic damage caused by chemicals should raise concerns because of the possibility of a mutation arising from that genetic damage. In what follows, the scientific findings available for evaluating the genotoxic potential of RF will be divided into four separate sources of data based on the biological source of that data: (1) data from exposed humans, (2) data from exposed human cells in a laboratory setting, (3) data from exposed mammals (non-human), and (4) data from exposed cells of mammals (non-human) in the laboratory. These four areas are based upon the priorities one would apply to the data in terms of impacts. Seeing genotoxicity in humans is more important than seeing genotoxicity in other mammals. In addition, seeing genotoxicity in whole, living organisms (*in vivo*) carries greater weight than seeing responses in cells in the laboratory (*in vitro*). Basically, the closer the findings are to real, living human beings, the more weight they should be given.

6.3.2 International Agency for Research on Cancer (IARC)

The IARC reviewed the potential for carcinogenicity from RF in 2011 [35]. They evaluated the scientific literature prior to 2011 and concluded "*there was weak evidence that RF radiation is genotoxic, and no evidence for the mutagenicity of RF radiation .*" This conclusion was driven by methodological shortcomings in the studies, lack of a sham-controlled group in some studies, use of mobile phones for exposures, poor dosimetry and contradictory results. Having looked over the IARC review, I agree with their assessment of these data and will not discuss any studies prior to 2010.

6.3.3 *In Vivo* Studies in Mammals

6.3.3.1 Humans

Several studies have addressed the presence of DNA damage directly in humans using the duration or frequency of cellular phone usage and comparing easily obtained human tissues (e.g. buccal swaps, sperm/semen, peripheral blood). **Vanishree et al. (2018)** [395] examined buccal swabs from 86 18-30 year-old cell phone users (46 M, 40 F) for micronuclei (MN). They compared low mobile phone users (<5 years and <4-5 hr/week) to high mobile phone users (>5 years and more than 10 hr/week) and saw an increase in MN in the high exposure group. They also saw an increase in MN on the side of the mouth where the mobile phone is used (ipsilateral) and in those who failed to use a headphone. **de Oliviera et al. (2017)** [396] examined buccal swabs from 30 male and 30 female 20-28 year-old cell phone users for MN. They saw no increase in MN by duration of use, frequency of use or ipsilateral vs. contralateral exposure. The categories for duration of use were unbalanced and they found no relationship with smoking (which is a known risk factor). Gulati et al. (2016) [397] examined buccal swabs from 116 people (68 M, 48F) residing near mobile towers (not defined but Table 1 suggests ≤400 meters) to 106 people living >800 meters from mobile towers (age range not provided). They found an increase in MN in buccal cells associated with distance to the cell tower and duration of use but saw no association with tobacco use. **Bannerjee et al. (2016)** [398] examined buccal swabs from 300 male 20-30 year-old cell phone users for MN. They compared low mobile phone users (<5 years and <3 hr/week) to high mobile phone users (>5 years and more than 10 hr/week). They saw an increase in MN in the high exposure group, an increase in MN on the ipsilateral side and in those who failed to use a headphone; they did not adjust for other risk factors. **Daroit et al. (2015)** [399] examined oral mucosa swabs from 3 different regions of the mouth of 60 people (24 M, 36 F) aged 19-33 years for MN and other genetic damage markers (broken eggs, binucleated cells, karyorrhexis). They saw increased MN on the whole mucosa and lower lip and increased binucleated cells (BN) on the border of the tongue for those using cellular phones for >60 minutes per week and increased broken eggs (BE) on the border of the tongue for those using cell phones for >8 years; all other comparisons were non-significant and no other risk factors were evaluated. **Sousa et al. (2014)** [400] examined ipsilateral-only oral mucosa cells in three groups (> 5 hr/week, >1 and ≤5 hr/week, ≤ 1 hr/week) of 15 individuals (sexes not specified) for the presence of MN, BE and degenerative nuclear anomalies (DN). They saw no changes in MN or DN but did see an increase in BE as a function of duration of usage per week (no other risk factors were examined). **Ros-Lior et al. (2012)** [401] examined buccal swabs from 50 (16 M, 34 F)

Caucasian 20-40 year-old cell phone users for MN. They compared short-term mobile phone users (<10 years) to long-term mobile phone users (>10 years). They saw no increase in MN, BN or DN in the long-term users nor did they see any relationship to ipsilateral use; they did not adjust for other risk factors and saw no relationship with smoking.

Radwan et al. (2016) [402] studied the effect of stress on sperm DNA damage in 286 males. They saw no indication of an increase in DNA fragmentation in sperm as a function of years of cell phone use (≤5, >5 to ≤10, > 10 years). In an earlier study from the same group using 344 men (286 in the 2016 study are included here) **Jurewicz et al. (2014)** [403] had a similar finding.

Gulati et al. (2016) [397] also examined peripheral blood lymphocytes (PBL) from 116 people (68 M, 48F) residing near mobile towers (not defined but Table 1 suggests ≤400 meters) to 106 people living >800 meters from mobile towers (age range not provided). They found an increase in tail moment (TM) (comet assay) associated with distance to the cell tower and duration of use but saw no association with tobacco use. **Gandhi et al. (2015)** [404] used the comet assay to evaluate DNA damage in PBL from 63 (38 M, 25 F) people with residences near (50-300 meters) a mobile phone tower and 28 controls (15 M, 13 F) with no nearby towers at home or work. All evaluations of DNA damage regarding distance to towers as well as mobile phone usage were significantly higher in the high exposure categories.

Cam and Seyhan (2012) [405] examined the hair roots of 8 individuals (6 women, 2 men) before and after 15 minutes exposure to a cellular phone and then 2 weeks later, before and after exposure for 30 minutes to a cellular phone. The comet assay showed a clear increase in single strand breaks after both 15 and 30 minutes of use with 30 minutes of use showing the greatest amount of damage.

6.3.3.2 Mice

In the NTP Study [166] using B6C3F1 mice, after 14 weeks of exposure, **Smith-Roe et al (2020)** [168] evaluated genotoxicity in several tissues of mice included in these studies for this purpose using the alkaline comet assay (three brain regions, liver, peripheral blood) and the micronucleus assay (peripheral blood). Significant increases in DNA damage were seen in the frontal cortex of male mice (DCMA and GSM) and leukocytes of female mice (CDMA only).

Jiang et al. (2013) [406] exposed groups of 10 male ICR mice to 900 MHz RF, SAR 0.548 W/kg, for 4 hr/day for 7 days and examined for MN in erythrocytes and bone marrow. They saw no significant changes in MN in either tissue, however, they did not use a sham control group. **Jiang et al. (2012)** [407] exposed groups of 5 male ICR mice to 900 MHz RF, SAR 0.548 W/kg, for 4 hr/day for 1,3,5,7 or 14 days and examined for general DNA damage (comet assay) in leukocytes. They saw no significant changes for any duration of exposure, however, they also did not use a sham control.

Chaturvedi et al. (2011) [408] exposed groups of 5 male Parks mice to 2450 MHz, SAR 0.0356 W/kg RF for 2 hr/day for 5 days. They saw an increase in tail moment, tail DNA and tail length in brain tissue using the comet assay.

6.3.3.3 Rats

In the NTP Study [166] using Sprague-Dawley rats, after 14 weeks of exposure, **Smith-Roe et al (2020)** [168] evaluated genotoxicity in several tissues of rats included in these studies for this purpose using the alkaline comet assay (three brain regions, liver, peripheral blood) and the micronucleus assay (peripheral blood). Significant increases in DNA damage were seen in the hippocampus of male rats (CDMA-only). **Usikalu et al. (2013)** [409] exposed groups of 2 male and 2 female Sprague-Dawley rats to 2450 MHz RF at SARs of 0, and 2.39 W/kg for 10 minutes and evaluated the induction of DNA damage by comet assay in the ovaries (F) and testis (M). Both tissues showed a significant increase in DNA damage as a function of exposure.

Akdag et al. (2016) [410] exposed groups of 8 male Wistar rats to 2450 MHz RF for 24 hr/day for 12 months at SARs of 0 or $1.41 \bullet 10^{-4}$ W/kg. Using the comet assay, they examined DNA damage in the brain, liver, kidney and testis and only saw increased DNA damage in the testis. **Gurburz et al. (2014)** [411] exposed groups of 6 male Wistar rats to 1800 MHz, SAR 0.23 or 2100 MHz, SAR 0.23 for 1 or 2 months. They examined only the urinary bladder and saw no increases in MN. **Atli et al. (2013)** [412] exposed groups of 2-week old and 10-week old Wistar rats (sex not provided) to 900 MHz RF, SAR 0.76 (2-week old) or 0.37 (10-week old) W/kg for 2 hr/day, 45 days with and without a recovery period of 15 days. Significant DNA damage (chromosomal aberrations, MN, and polychromatic erythrocytes) in bone marrow was seen for all of the experimental groups. Using the same experimental design with 1800 MHz RF, SAR 0.37 (2-week) and 0.49 (10-week), **Sekeroglu et al. (2012)** [413] saw the same significant DNA damage. **Trosic et al. (2011)** [414] exposed groups of 9 male Wistar rats to 915 MHz RF, SAR 0.6 W/kg, for 1 hr/day, 7 d/week, 2 weeks. They saw increases in DNA damage (comet assay) in liver and kidney, but not in brain.

Gouda et al. (2013) [415] exposed groups of 15 male albino (probably Wistar) rats to 1800 MHz RF, SAR 0.3 W/kg, from a cellular phone for 2 h/day either continuous or discontinuous (30 min on, 30 min off) for 2, 4 or 6 weeks. Using genomic DNA from the liver, they saw a significant increase in mutations to two genes (TP53 and BRCA1) after 6 weeks of exposure in the continuous group and a significant increase in DNA fragmentation at all durations for continuous exposure.

In a series of 3 studies, **Deshmukh et al. (2013, 2015, 2016)** exposed groups of 6 male Fischer rats to 900 MHz RF, SAR $5.95 \bullet 10^{-4}$ W/kg, 1800 MHz RF, $5.83 \bullet 10^{-4}$ W/kg, or 2450 MHz RF, $6.67 \bullet 10^{-4}$ W/kg, for 2 h/day, 5 d/week, 30 days [416], 90 days [417] or 180 days [418]. Increases in DNA damage in the brain in the 30-day study and hippocampus in the other two studies were seen using the comet assay.

6.3.3.4 Summary for DNA Damage In-Vivo

DNA damage was seen from exposure to RF in humans (5 studies of oral mucosa cells, 2 in PBL and 1 in hair follicles), mice (2 studies) and in rats (8 studies). Four studies in humans (2 oral mucosa cells, 2 sperm cells), 2 studies in mice which failed to use sham controls, and 1 study in rats saw no increases in DNA damage. In laboratory animals, 2 studies at 900 MHz saw no DNA damage while 6 were positive, one study using 1800 and 2100 MHz RF was negative while 5 using 1800 MHz were positive and all 6 studies using 2450 MHz were positive. In humans, most studies failed to control for confounders and failed to find an association with smoking that should have been apparent. The strongest study, using hair follicles, used the individuals as their own control and this study was positive.

6.3.4 *In Vitro* Studies in Mammalian Cells

6.3.4.1 Humans

6.3.4.1.1 Primary Cells

Five studies exposed human PBL to RF. One study using laboratory-generated 900 MHz for 30 minutes with 60 minutes recovery saw no change in DNA repair [419]. One multi-laboratory study using laboratory-generated 1800 MHz RF for 28 hours saw no changes in MN, sister-chromatid exchange, chromosomal aberrations or comet assay tail moment [420]. Two studies with laboratory-generated 1950 MHz RF and 20 or 24-hr exposure with a 28-hr recovery saw no changes in micronuclei [421, 422]. One study with laboratory-generated 2450 MHz RF for 72 hr and a high SAR (10.9 W/kg) saw no change in MN or binucleated DNA [423].

Both studies using semen/sperm, one using an 850 MHz phone for 60 minutes and the other using a 900/1800 MHz phone for 1 to 5 hours saw an increased DNA fragmentation index.

The final human primary cell study using amniotic cells exposed to 900 MHz RF for 24 hours at 4 different SAR values and saw no change in aneuploidy in chromosomes 1 and 17.

6.3.4.1.2 Human Cell Lines

One study using SH-SY5Y neuroblastoma cells exposed to laboratory-generated 1950 MHz RF for 20 hours saw no change in tail behavior using the comet assay [424]. In contrast, a second study using the same cell line and exposure for 16 hours saw a non-significant increased tail length in the comet assay for not only SH-SY5Y cells, but also U87, U251 and U373 glioma cells and NCH421K glioblastoma cells [425]. They also observed an increase in DNA repair but no change in double strand breaks. Another study using A172 and U251 glioblastoma cells and SH-SY5Y neuroblastoma cells using 1800 MHz for 1, 6 or 24 hours saw no increase in DNA repair [426].

Two studies used HepG2 liver cells, one at 1950 MHz for 16 hours exposure saw no changes [425] while the other using 900 or 1800 MHz RF for 1-4 hours saw morphological changes in DNA at 4 hours [427].

One study used HMy2.CIR lymphoblastoma cells exposed to laboratory-generated 1800 MHz RF for 24 hours and observed changes in DNA repair proteins [428].

A study in HL-60 leukemia cells exposed to laboratory-generated 1800 MHz RF for 24 hours saw no changes in MN or DNA damage via the comet assay [429].

One study in HaCat skin cells exposed to 900 MHz RF for 30 minutes with a 4 or 24 hour recovery saw no change in MN [430].

Two studies in human/hamster AL hybrid ovary cells exposed to 900 MHz RF for 30 minutes saw different responses; one saw aberrant spindles [431] and the other saw no changes in MN but waited at least 4 hours after exposure before evaluation [430].

Mouse

Mouse Primary Cells

Three studies from the same laboratory exposed bone marrow cells extracted from bone marrow stromal cells from male Kumming mice and exposed them to 900 MHz RF. In the first study, the cells were exposed for 3 hours/day for 5 days and poly(ADP-ribose) polymerase-1 mRNA expression (*PARP-1*) was shown to be significantly elevated for 10 hours after the final exposure (this is an indication of breaks in strands of DNA) [432]. The second study exposed the cells for 4 hr/day for 5 days, allowed the cells to recover for 4 hours and then, after measuring DNA damage (comet assay, γ-H2AX foci) saw no differences between sham controls and the RF-exposed cells [433]. The final study exposed cells for 3 hours/day for 5 days, had a three-hour recovery then measured DNA damage (comet assay, *PARP-1*) and found a large, time-dependent change in both measures but did not provide statistical p-values [434].

Another study used oocytes and spermatozoa from $B6D2F_1$ mice, exposed for 60 minutes to 1950 MHz RF, combined to allow fertilization, and then allowed 17 to 20 hours to recover. They saw no chromosomal aberrations in the resulting one-cell embryos [435].

Mouse Cell Lines

One study exposed GC-2 mouse spermatocyte cells to 1800 MHz RF for 24 hours at SARs of 1,2 and 4 W/kg and saw an increase in DNA damage (comet assay, 4 W/kg) but no change in DNA double strand breaks (g-H2AX foci) [436]. A second study exposed GC-2 cells to a 900 MHz cellular phone signal for 24 hours to four different modes of cell phone use and saw DNA damage (comet assay) for three of the modes [437].

One study exposed ataxia telangiectasia mutated (Atm-/-) and Atm+/+ mouse embryonic fibroblast cells to 1800 MHz RF for 1 to 36 hours, SAR 4 W/kg, and saw increased DNA damage (comet assay) and DNA fragmentation in the Atm-/- cells at multiple times [438].

Rat

Rat Primary Cells

One study exposed astrocytes extracted from Wistar rats to 872 MHz RF, SAR 0.6 or 6 W/kg, for 24 hours and saw no significant increase in micronuclei or DNA damage (comet assay) [439]

One study exposed femur and tibia lymphocytes extracted from Sprague-Dawley rats to 900 MHz RF for 30 minutes and saw no significant increase in DNA damage (comet assay) [440].

Rat Cell Lines

One study exposed PC12 rat pheochromocytoma cells to 1950 MHz, SAR 10 W/kg, for 24 hours and saw no significant DNA damage (comet assay) [441]

Hamster

Hamster Primary Cells

There were no studies of hamster primary cells.

6.4.3.4 Hamster Cell Line

One study using V79 hamster lung fibroblast cells exposed to laboratory-generated 2450 MHz RF for 15 minutes saw an increase in aberrant spindles and apoptosis [442]. Another study using V79 cells exposed to 1950 MHz RF for 20 hours, SAR 0.15, 0.3, 0.6 and 1.25 W/kg, saw an increase in micronuclei at the two lowest SAR values [443].

6.4.4 Conclusions for DNA Damage In Vitro

About half of the in-vitro studies showed some form of DNA damage and about half demonstrated no significant effects. There was no pattern by cell type, species, SAR or frequency. Very few of the studies used the same cell and frequency so it is difficult to give greater weight to the positive findings or the negative findings.

6.4.5 Summary for Genotoxicity

In addition to the many studies cited above and in the IARC Monograph [35], Lai (2021) [444] has compiled literature on other genetic effects (e.g. changes in gene expression) and downstream changes (e.g. cell-cycle arrest) that also point toward RF having an impact on cellular genetics and their control of cellular function.

A majority of the *in vivo* studies evaluating genotoxicity and RF, either with oxidative stress or independent of evaluating oxidative stress, showed a significant increase in DNA damage. In contrast, only about half of the *in vitro* studies of genotoxicity and RF were positive with no obvious pattern of why this might have happened.

Overall, there is sufficient evidence to suggest that genotoxicity, probably due to oxidative stress, is caused by RF and could be a mechanism by which cancer is induced by RF.

6.5 Summary for Mechanism of Carcinogenicity

There is sufficient evidence to suggest that both oxidative stress and genotoxicity are caused by exposure to RF and that these mechanisms could be the reason why RF can induce cancer in humans.

There is the possibility of publication bias in this body of literature on mechanism. Publication bias occurs when studies that are positive tend to get published whereas negative studies are either never submitted for publication or they are rejected because they are negative (rejection is less of a problem since journals are now very aware of problems with publication bias). This potential problem cannot be resolved with the data in hand. There is also a possible bias in these results based upon a small collection of laboratories providing a majority of the studies; this could also create a small amount of bias in the direction of the positive results since scientists seldom pursue negative findings but will generally continue to pursue reasons for positive findings.

7. Summary of Bradford Hill Evaluation

RF exposure probably causes gliomas and acoustic neuromas and, given the human, animal and experimental evidence, I assert that, to a reasonable degree of scientific certainty, the probability that RF exposure causes these cancers is high.

Table 22 summarizes the information for each of Hill's aspects of causality. For these data, causality is strengthened because the available epidemiological studies show a **consistent positive association** between brain tumors and RF exposure. Analyzed collectively with meta-analyses using the most reasonable combinations of studies show positive responses. And, in answer to Hill's question, the relationship between brain tumors and RF exposure has been observed by different persons, in different places, circumstances, and times. Using meningiomas as controls in some case-control studies suggests recall bias is minimal.

Causality is strengthened for these data because **the strength of the observed associations**, when evaluated simultaneously in meta-analyses, are statistically significant and the results are unlikely to be due to chance. Even though only one of the individual studies provides odds ratios that are large and precise, the meta-analyses have objectively shown that the observed association across these studies is significant and supports a positive association between brain tumors and RF.

Biological plausibility is strongly supported by the animal carcinogenicity data and the mechanistic data on genotoxicity and oxidative stress. When addressing biological plausibility, the first question generally asked is "Can you show that RF causes cancers in experimental animals?" In this case, the answer to that question is clearly yes. RF can cause tumors in experimental animals with strong findings for gliomas, heart Schwannomas and adrenal pheochromocytomas in male rats and harderian gland tumors in male mice and uterine polyps in female mice. There is also some evidence supporting liver tumors and lung tumors in male and possibly female mice. Thus, it is biologically plausible that RF can cause cancer in mammals.

The next question generally asked is "Does the mechanism by which RF causes cancer in experimental animals also work in humans?" The best understood mechanism by which agents cause cancer in both humans and animals is through damaging DNA that leads to mutations in cells that then leads to uncontrolled cellular replication and eventually cancer. It is absolutely clear from the available scientific data that RF causes oxidative stress in humans and experimental mammals. This has been amply demonstrated in humans that were exposed to RF, in human cells *in vitro*, and in experimental animal models and their cells *in vitro* and *in vivo*. One possible consequence of oxidative stress is damage to DNA and potentially mutations. RF induces DNA damage as measured in multiple ways, in humans, animals and cells, providing additional support for a biological mechanism that works in humans.

Table 22: Summary conclusions for Hill's nine aspects of epidemiological data and related science

Aspect	Conclusion	Reason
Consistency of the observed association	Strong	Multiple studies, many are positive, meta-analyses with little heterogeneity show positive findings at higher exposures, different research teams, different continents, different questionnaires, no obvious bias in case-control studies, no obvious confounding, laterality is significant
Strength of the observed association	Strong	Significant meta-analyses

Biological plausibility	Very Strong	Multiple cancers in multiple species, same tumors as humans in male rats, not due to chance, increased risk of rare tumors, convincing evidence for genotoxicity and oxidative stress
Biological gradient	Strong	Clearly seen in some case-control studies, clearly seen in the meta-analyses and met-regressions, not seen in the cohort studies, clearly seen in animal studies
Temporal relationship of the observed association	Satisfied	Exposure clearly came before cancers
Specificity of the observed association	Strong	The only cancers linked to RF exposure are gliomas and acoustic neuromas
Coherence	Strong	Cancers seen in the rats have strong similarity to human gliomas and acoustic neuromas, laterality and brain location support coherence
Evidence from human experimentation	No data	No studies are available
Analogy	No data	No studies available in the literature

In general, there is support that a **biological gradient** exists for the epidemiological data and thus support from this aspect of the Bradford-Hill evaluation. RF mRRs increased with duration of cellular phone use and with cumulative hours of exposure when studies are combined in both meta-analyses and meta-regressions. In addition, laterality is strengthened when duration of use of a cellular phone increases. The animal studies clearly demonstrate dose-response.

The proper **temporal relationship** exists with the exposure coming before the cancers.

The human evidence is **coherent**. The cancer findings in humans agree with the cancer findings in rats. Also, studies focused on the temporal lobe appear to support this area as a target for cellular phone usage. Finally, laterality, when evaluated in meta-analyses shows that tumors are more closely associated with the predominant side of the head used by people with their cellular phones.

Glioma and acoustic neuroma are not **specific** to RF exposure; however, RF exposure is specific to these two tumors. There is no **experimental evidence** in humans and I did not find any references where researchers looked for analogous exposures with similar toxicity.

Hill (1965)[34] asks "*is there any other way of explaining the set of facts before us, is there any other answer equally, or more, likely than cause and effect?*" There is no better way of explaining the scientific evidence relating RF exposure to an increase in gliomas and acoustic neuromas in humans than cause and effect.

In my opinion, RF exposure probably causes gliomas and neuromas and, given the human, animal and experimental evidence, I assert that, to a reasonable degree of scientific certainty, the probability that RF exposure causes gliomas and neuromas is high.

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417. Deshmukh PS, Nasare N, Megha K, Banerjee BD, Ahmed RS, Singh D, Abegaonkar MP, Tripathi AK, Mediratta PK: **Cognitive impairment and neurogenotoxic effects in rats exposed to low-intensity microwave radiation**. *Int J Toxicol* 2015, **34**(3):284-290.

418. Deshmukh PS, Megha K, Nasare N, Banerjee BD, Ahmed RS, Abegaonkar MP, Tripathi AK, Mediratta PK: **Effect of Low Level Subchronic Microwave Radiation on Rat Brain**. *Biomed Environ Sci* 2016, **29**(12):858-867.

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effect on DNA double strand breaks (DSB) in human lymphocytes. *Ann Transl Med* 2017, **5**(13):272.

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422. Zeni O, Sannino A, Romeo S, Massa R, Sarti M, Reddy AB, Prihoda TJ, Vijayalaxmi, Scarfi MR: **Induction of an adaptive response in human blood lymphocytes exposed to radiofrequency fields: influence of the universal mobile telecommunication system (UMTS) signal and the specific absorption rate**. *Mutation research* 2012, **747**(1):29-35.

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mobile communication frequency range signal. *Bioelectromagnetics* 2011, **32**(4):291-301.

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433. Ji Y, He Q, Sun Y, Tong J, Cao Y: **Adaptive response in mouse bone-marrow stromal cells exposed to 900-MHz radiofrequency fields: Gamma-radiation-induced DNA strand breaks and repair**. *J Toxicol Environ Health A* 2016, **79**(9-10):419-426.

434. He Q, Zong L, Sun Y, Vijayalaxmi, Prihoda TJ, Tong J, Cao Y: **Adaptive response in mouse bone marrow stromal cells exposed to 900MHz radiofrequency fields: Impact of poly (ADP-ribose) polymerase (PARP)**. *Mutation research* 2017, **820**:19-25.

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438. Sun C, Wei X, Fei Y, Su L, Zhao X, Chen G, Xu Z: **Mobile phone signal exposure triggers a hormesis-like effect in Atm(+/+) and Atm(-/-) mouse embryonic fibroblasts**. *Sci Rep* 2016, **6**:37423.

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440. Kumar G, Wood AW, Anderson V, McIntosh RL, Chen YY, McKenzie RJ: **Evaluation of hematopoietic system effects after in vitro radiofrequency radiation exposure in rats**. *Int J Radiat Biol* 2011, **87**(2):231-240.

441. Zeni O, Sannino A, Sarti M, Romeo S, Massa R, Scarfi MR: **Radiofrequency radiation at 1950 MHz (UMTS) does not affect key cellular endpoints in neuron-like PC12 cells**. *Bioelectromagnetics* 2012, **33**(6):497-507.

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443. Sannino A, Zeni O, Romeo S, Massa R, Scarfi MR: **Adverse and beneficial effects in Chinese hamster lung fibroblast cells following radiofrequency exposure**. *Bioelectromagnetics* 2017, **38**(4):245-254.

444. Lai H: **Genetic effects of non-ionizing electromagnetic fields**. *Electromagn Biol Med* 2021:1-10.

Appendix I: Current CV: Christopher J. Portier

CURRICULUM VITAE
Christopher J. Portier, Ph.D

Personal Data: Birth Date April 3, 1956
Birthplace Houma, Louisiana

Addresses: 4224 Midvale Ave N.
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Education:

1981	**Ph.D.**	(Biostatistics), University of North Carolina, Chapel Hill
1979	**M.S**	(Biostatistics), University of North Carolina, Chapel Hill
1977	B.S.	(Mathematics), summa cum laude, Nicholls State University

Employment:

2018-present	**Scientific Advisor**, World Health Organization, Environment Program - Europe
2016–present	**Scientific Advisor on Pesticide Policies**, multiple European Non-Government Organizations
2013-present	**Consultant** to various governmental agencies (multiple countries) and law firms
2013–2014	**Senior Visiting Scientist**, International Agency for Research on Cancer, Lyon, France
2013–present	**Senior Contributing Scientist**, Environmental Defense Fund, New York City, NY
2010-2013	**Director**, National Center for Environment Health, Centers for Disease Control and Prevention, Atlanta, GA
2010–2013	**Director**, Agency for Toxic Substances and Disease Registry, Atlanta, GA
2009 – 2010	**Senior Advisor to the Director**, National Institute of Environmental Health Sciences and National Toxicology Program, Research Triangle Park, North Carolina.
2009 – 2010	**Visiting Scientist**, National Research Centre for Environmental Toxicology (EnTox), Queensland, Australia
2006 - 2009	**Associate Director**, National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina.

2006 - 2009	**Director, Office of Risk Assessment Research,** National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina.
1993 – 2010	**Head, Environmental Systems Biology** (originally Stochastic Modeling), Laboratory of Molecular Toxicology, National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina.
2000 - 2006	**Associate Director, National Toxicology Program**, National Institute of Environmental Health Sciences, Division of Intramural Research, Research Triangle Park, North Carolina.
2000 - 2006	**Director, Environmental Toxicology Program**, National Institute of Environmental Health Sciences, Division of Intramural Research, Research Triangle Park, North Carolina.
2006-2007	**Scientific Advisor to the Director**, Public Health and the Environment Department, World Health Organization, Geneva, Switzerland (detail from NIEHS – four months)
1993 - 2005	**Chief, Laboratory of Computational Biology and Risk Analysis** (originally the Laboratory of Quantitative and Computational Biology), National Institute of Environmental Health Sciences, Division of Intramural Research, Research Triangle Park, North Carolina.
1996 - 2000	**Associate Director for Risk Assessment**, Environmental Toxicology Program National Institute of Environmental Health Sciences, Division of Intramural Research, Research Triangle Park, North Carolina.
1990 - 1993	**Head, Risk Methodology Section**, National Institute of Environmental Health Sciences, Division of Biometry and Risk Assessment, Research Triangle Park, North Carolina.
1987, 1992, 1990	**Guest Scientist**, German Cancer Research Center, Heidelberg, Germany.
1978 - 1990	**Principal Investigator**, National Institute of Environmental Health Sciences, Division of Biometry and Risk Assessment, Research Triangle Park, North Carolina.
1977	**Mathematician**, Computer Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
1976	**Undergraduate Research Trainee**, Neutron Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

University Affiliations:

2014 – present	Visiting Professor, Department of Toxicogenomics, Maastricht University, The Netherlands
2013 – 2016	Honorary Professor, National Research Centre for Environmental Toxicology, University of Queensland, Brisbane, Australia
2011 – present	Adjunct Professor, Department of Environmental Health, Emory University, Atlanta, GA, USA
2009 – 2010	Visiting Professor, University of Queensland, Brisbane, Australia
1986 - 2007	Adjunct Professor of Biostatistics, University of North Carolina, School of Public Health, Chapel Hill, North Carolina.
1990-1992	Adjunct Professor of Statistics, University of Waterloo, Waterloo, Ontario, Canada

Honors & Awards:

- 2016 Elected Fellow, Collegium Ramazzini
- 2013 President's Dream Green Team Award for "A Human Health Perspective on Climate

Change"
- Fellow, World Innovation Foundation, 2006
- Society of Toxicology, Risk Assessment Specialty Section, Paper of the Year, 2006
- Society of Toxicology, Risk Assessment Specialty Section, Paper of the Year, 2005
- Outstanding Risk Practitioner Award, International Society for Risk Analysis, 2000.
- Elected Fellow, International Statistical Institute, 2000.
- Outstanding Performance Award, National Institute of Environmental Health Sciences, numerous dates.
- Commendation for Sustained High Quality Work Performance, National Institute of Environmental Health Sciences, numerous dates.
- Merit Award, National Institute of Health, 1998.
- Board of Publications, Best Paper Award, Society of Toxicology, 1995.
- Distinguished Achievement Award, Section on Statistics and the Environment, American Statistical Association, 1995.
- Spiegelman Award presented by the American Public Health Association to the most outstanding public health statistician under the age of 40, 1995.
- Best-applied statistics paper, Centers for Disease Control, 1993.
- Elected Fellow, American Statistical Association, 1992.
- Elected Foreign Correspondent, Russian National Academy of Natural Sciences, 1992.
- First recipient of the James E. Grizzle Distinguished Alumnus Award, The Department of Biostatistics, The University of North Carolina, 1991.

Professional Societies Membership:

Society of Toxicology, American Public Health Association, International Statistics Institute, Bioelectromagnetics Society

Editorial Activities:

- Editor in Chief - The Open Environmental Journal (2008 to 2010)
- Associate Editor – Frontiers in Predictive Toxicity (2010 to present)
- Associate Editor - Environmental Health Perspectives (1987-2006)
- Associate Editor - Risk Analysis: An International Journal (1989-2003)
- Editorial Board – Environmental and Ecological Statistics (2004-2007)
- Associate Editor – Statistics in Medicine (1998-2002)
- Associate Editor - Biometrics (1997-99)
- Editorial Board Member/Reviewer (different dates): Biometrika, Cancer Research, Communications in Statistics, Fundamental and Applied Toxicology, Journal of Applied Toxicology, Journal of the American Statistical Association, Journal of Toxicology and Environmental Health, Science, Mathematical Biosciences, Journal of Mathematical Biology, Carcinogenesis, Science, PNAS, Toxicological Sciences and others

Advisory & Review Committees:

2019-present	Member, UCSF PHRE Science Response Network
2016-2020	Member, World Health Organization Regional Office Europe, Setting research priorities in environment and health
2015 – 2016	Member, Committee to Review the Draft Interagency Report on the Impacts of Climate Change on Human Health in the United States, National Research Council, National Academy of Sciences, USA
2010 – 2016	Member, Science Advisory Group on Electromagnetic Fields and Health, Netherlands Organisation for Health Research and Development

2009 – 2010	Coordinating Lead Author, Interagency Working Group on Climate Change and Health
2009 – 2013	Member, Institute of Medicine Roundtable on Environmental Health Sciences Research and Medicine
2009 – 2012	Member, National Academies of Science Roundtable on Science and Technology for Sustainability
2009	Member, WHO Advisory group on the health implications of the use of DDT to reduce risks of malaria.
2005 – 2010	Chair, Subcommittee on Toxics and Risk, President's National Council on Science and Technology
1997 - 2012	Advisor, *World Health Organization*, International Program on Chemical Safety, EMF Project.
2008 – 2010	Member, Environmental Protection Agency, Science Advisory Board
2007 – 2010	Member, International Life Sciences Institute, Health and Environmental Sciences Institute, Subcommittee on Susceptible Populations
2008	Center Review Committee, Canadian National Science and Engineering Research Council Chair in Risk Assessment
2008	Chair, International Agency for Research on Cancer Monographs Advisory Group, Lyon, France
2008	Advisory Group, Center for Environmental Oncology, University of Pittsburgh Cancer Institute
2007.	Chair, WHO Workshop on Low Cost Options for Reducing Exposures to ELF-EMF, Geneva
2007.	Invited Participant, International Program on Chemical Safety Workshop on Aggregate and Cumulative Risk Assessment, Washington, DC.
2006	Rapporteur, International Agency for Research on Cancer, Scientific Advisory Group to Plan Volume 100 of the IARC Monograph Series
2005	Chair, International Agency for Research on Cancer, Scientific Advisory Board on the Preamble to the Cancer Monograph Series
2005	Chair, World Health Organization Expert Panel on Health Criteria Document for Extremely Low Frequency Electric and Magnetic Fields
2003 – 2005	Co-Chair, Subcommittee on Health and Environment, President's National Council on Science and Technology
2003	Ad-Hoc member, EPA Science Advisory Board, Review of Children's Cancer Risk Assessment Supplement to Cancer Guidelines
2002 – 2006	Co-Chair, Subcommittee on Mercury, President's National Council on Science and Technology
2000 – 2007	Member, Finish Academy of Sciences Centers of Excellence Program Science Advisory Committee
2000	Reviewer, *Congressional Research Service, Library of Congress*; Research needs relevant to children's environmental health risks.
1998 - 2004	Member and Chair, *Environmental Protection Agency*, FIFRA Science Advisory Panel.
1997 - 2006	Member, National Occupational Research Agenda Team, *National Institute of Occupational Safety and Health.*
1995 - 2000	Advisor, *Australian Health Council,* Risk Assessment Methodology, Member *NHMRC* Steering Committee on Cancer Risk Assessment Guidelines.
1992 - 2000	Member, *EPA* Dioxin Reassessment Working Group.

1985 - 2007	Thesis director for graduate students, Department of Biostatistics, *University of North Carolina - Chapel Hill, North Carolina.*
1997	Advisor, *Netherlands National Health Council,* Risk Assessment Methodology.
1997	Reviewer, *Air Force Office of Scientific Research.*
1996 - 1997	Temporary Advisor, *World Health Organization,* Expert Committee on Food Additives.
1996	Advisor, *Environmental Protection Agency;* Evaluation of the benchmark dose methodology.
1996	Advisor, *Environmental Protection Agency;* Evaluation of risks from exposure to PCBs.
1996	Expert Review Committee, *Environmental Protection Agency;* Cancer dose-response for PCB's.
1995 - 1996	Member, *California Environmental Protection Agency,* Risk Assessment Advisory Committee.
1994 - 1997	Science Advisory Panel, *Public Broadcasting System Production* "Poisons in the Womb".
1991 - 1995	Ad-Hoc Member, *Environmental Protection Agency,* Science Advisory Panel.

Legislative Hearings:

- Glyphosate Hearing, European Parliament, Brussels, October, 2017
- Glyphosate Carcinogenicity, European Parliament, Brussels, December 2015
- Glyphosate Carcinogenicity, German Parliament, Berlin, July 2015
- Lead and Children's Health, Senate Committee on Environment and Public Works, July, 2012
- Asthma and Children's Health, Senate Committee on Environment and Public Works, May, 2012
- Contaminated Drywall, Senate Committee on Commerce, Science and Transportation, December, 2012.
- Camp Lejeune Contaminated Drinking Water, House Committee on Science and Technology, September, 2010.
- Autism and Vaccines, House Committee on Government Reform, December, 2002.

US Government Service Activities:

- Member, President's Task Force on Environmental Justice 2010-2013
- Member, President's Task Force on Children's Environmental Health 2009-2013
- Member, National Toxicology Program Executive Committee 2010-2013
- Financial Support and International Press Conference for research on "The Health Benefits of Tackling Climate Change" appearing as a series in Lancet, November 25, 2009
- Organizing Committee, White House Stakeholder briefing on Climate Change and Human Health, Old Executive Office Building, November 2009.
- Member, US Delegation, World Climate Congress, Geneva (September 2009)
- Member, US Delegation, Global Risk Communication Dialogue (2008-2009)
- Member, NIEHS Corrective Action Plan Management Committee (2008-2009)
- Primary focus, all interagency activities on hazards and risk (2006 to present)
- Co-Organizer, NIEHS/EPA Workshop on Children's Environmental Health, RTP, NC, January, (2007)
- Co-Organizer, NIEHS/NTP Workshop on the Identification of Targets for the HTS Roadmap Project (2007)
- Coordinator, NIEHS/EPA Review of the Children's Environmental Health Centers Program (2006-2007)
- Organizing Committee, Global Environmental Health Initiative, NIEHS (2006 to 2009)

- NIEHS Leadership Council (2005 to 2009)
- Organizer, formal collaborative agreements between NTP and Ramazzini Foundation (2001 to 2006)
- Organizer, formal collaborative agreements between NTP and Korean NTP (2002 to 2006)
- NIEHS Title 42 Review Committee (2003 to 2004)
- NIEHS Executive Committee and Operations Update Committee (2000 to 2005)
- NIEHS Leadership Retreats, DERT Retreats, DIR Retreats (all years since 1997)
- Presenter, NIEHS-sponsored National Academy of Sciences Committee on Emerging Issues in Environmental Health, November, 2001
- Organizer and presenter, National Toxicology Program Executive Committee Meetings (multiple dates since 2000)
- Organizer and presenter, National Toxicology Program Board of Scientific Counselors (multiple dates since 1998)
- Organizer, Joint NIEHS/US Geological Survey Interagency Program on Exposure Assessment, April 2001 to present)
- Organizer, US-Vietnam Scientific Conference on the Health and Environmental Effects of Agent Orange/Dioxin in Vietnam, March, 2002
- Organizing Committee, National Toxicology Program/EPA/FDA Scientific Conference on the Allergenicity of Genetically Modified Food, November, 2001
- NIEHS Town Hall Meeting, Los Angeles California, November, 2001
- NTP Research Directions, NAEHSC, Research Triangle Park, NC. May, 2001.
- NCI Study Section Center Presite Meeting, Seattle, Washington, January, 2001.
- Program committee member, *NIEHS/Colorado State University* conference on the Application of Technology to Chemical Mixture Research, 2001.
- Coordinating Core Committee, National Center for Toxicogenomics, NIEHS, 2000 to present
- Organizer, Joint US-Vietnam Consultation on Research on Agent Orange Health Effects in Vietnam. Singapore, 2000
- *ICCVAM/NICEATM*, Up-and-Down Procedure Peer Review Meeting, 2000.
- Chairman, *NIEHS* Risk Assessment Research Committee, 1995-present.
- Discussant, *NIEHS/PNNL* Workshop on Human Biology Models for Environmental Health Effects, 2000.
- Risk Assessment Coordinator, *NIEHS* US *RAPID* Program for the Evaluation of Health Risks from Exposure to Electric and Magnetic Fields, 1996-99.
- Organizer and Chair, Four Public Comment Sessions on the report of the *NIEHS/DOE* Working Group on the Health Effects of Exposure to Electric and Magnetic Fields, 1998.
- Organizer and Co-Chair, *NIEHS/DOE* Working Group on the Health Effects of Exposure to Electric and Magnetic Fields, 1998.
- Scientific Organizing Committee, *NIEHS* Workshop on Risk Assessment Issues Associated with Endocrine Disrupting Chemicals, 1998.
- Organizer, *NIEHS/DOE* Science Research Symposium on the Health Effects of Exposure to Electric and Magnetic Fields I: Biophysical Mechanisms and *In Vitro* Experimentation, 1998.
- Organizer, *NIEHS/DOE* Science Research Symposium on the Health Effects of Exposure to Electric and Magnetic Fields II: Epidemiological Findings, 1998.
- Organizer, *NIEHS/DOE* Science Research Symposium on the Health Effects of Exposure to Electric and Magnetic Fields III: *In Vitro* and Clinical Research Findings, 1998.
- Head, Toxicokinetics Faculty, *NIEHS,* 1994-97.
- Coordinator/Director, *NIEHS/ATSDR* Interagency Course on Mechanistic Modeling in Environmental Risk Assessment, 1996.
- Organizer, *NIEHS/EPA* Workshop on Research Priorities for New Risk Assessment Guidelines,

1996.

- Co-Organizer, *National Institute of Statistical Sciences*, *NIEHS/EPA* Workshop on Mechanistic Modeling in Risk Assessment, 1995.
- Scientific Coordinator and Mission Director, *NIEHS* "Mission to Vietnam" to assess the potential for scientific collaboration on the impact of Agent Orange on the Vietnamese Population, 1995.
- Chairman, *NIEHS* Computer Science Focus Group, 1995.
- Discussant, National Toxicology Program Workshop on Mechanistic Modeling in Toxicology, *NIEHS*, 1995.
- Discussant, National Toxicology Program Workshop on Mechanisms of Carcinogenesis, *NIEHS*, 1995.
- Co-Organizer, International Conference on The Role of Cell Proliferation in Carcinogenesis, co-sponsored by *NIEHS*, *The Chemical Industry Institute of Toxicology*, *The International Life Sciences Institute* and *The American Industrial Health Council*, 1992.
- Organizer and Director, Scientific Basis of Animal Carcinogenicity Testing, Moscow, Russia, co-sponsored by the *International Agency for Research on Cancer*, *NIEHS*, *Health and Welfare Canada* and *The All-Union Cancer Research Center*, 1991.
- Chairman, Computer Technology Advisory Forum, *NIEHS*, 1989.
- Organizer and Director, Design and Analysis of Long-Term Animal Carcinogenicity Experiments, Lyon, France, co-sponsored by the *International Agency for Research on Cancer* and the *NIEHS*, 1988.

Non-Governmental (US) Activities:

- Member, NRC Committee to review the Draft Interagency Report on the Impacts of Climate Change on Human Health in the United States, Washington, DC, 2015
- Expert Scientist, International Agency for Research on Cancer Monograph Meeting on Some Organophosphate Pesticides and Herbicides, Lyon, France, March, 2015
- Overall Chair, International Agency for Research on Cancer Monograph Meeting on Diesel and Gasoline Engine Exhausts and related compounds, Lyon, France, June, 2012
- Advisor to Wellcome Trust at "International Research Futures Symposium on Global Change, Economic Sustainability, and Human Health", London, England, March, 2012.
- Expert Panel Member for review of Hollings Marine Laboratory, National Oceanographic and Atmospheric Agency, Charleston, USA, February, 2012.
- Chair, Mechanism Subgroup, International Agency for Research on Cancer Monograph Meeting on Radiofrequency Electric and Magnetic Fields, Lyon, France, May, 2011
- Advisor, Greek Ministry Health, Working group on hexavalent chromium in the environment, January, 2011
- Member, WHO Consultation on Human Health Risks from DDT, Geneva, Switzerland, November, 2010
- Associate Editor, Frontiers in Predictive Toxicity, 2010 – 2011
- Scientific Advisor, Health Investigation Levels Workshop, Canberra, Australia, January, 2010
- Chair, IARC Working Group, IARC Monograph 100-G, Lyon, France, October, 2009
- Scientific Organizing Committee, VII World Congress on Alternatives and Animal Use in Life Sciences, Rome, Italy, September, 2009
- Chair, Research Directions Working Group, World Health Organization Consultation on Global Research on Climate Change and Health, October, 2008.
- Editor-in-Chief, The Open Environment Journal, May 2008-August, 2010
- Member, EPA Science Advisory Board, July, 2008-present
- Working Group Member, IARC Monograph 98 - Fire-fighting, Painting and Shift-work, Lyon, France, November, 2007

- Chair, WHO Extremely Low Frequency Magnetic and Electric Fields Workshop on Intervention Strategies, June, 2007
- Special Advisor to the Director, Program on Public Health and the Environment, WHO, Geneva, May-July, 2007
- Member, International Life Sciences Institute Working Group on Susceptible Populations, March, 2007 – present
- Special Advisor to the Director, Program on Public Health and the Environment, WHO, Geneva, November, 2006-January, 2007
- Breakout Group Chair, International Workshop on Uncertainty and Variability in PBPK Modeling, RTP, NC USA, October, 2006
- Member, Health Effects Sciences Institute Committee on Sensitive Subpopulations and Groups, Washington, DC, 2006 to present
- Rapporteur, Steering Committee for developing the 100th Monograph of the International Agency for Research on Cancer, Lyon, France, September, 2006
- Co-Organizer, parallel workshops on the advancement of PBPK modeling in risk assessment, Research Triangle Park, November, 2006, Corfu, Greece, April, 2007.
- Organizer, Alternative Models in Developmental Neurotoxicity, Alexandria, Virginia, March, 2006.
- Organizer, NTP High Throughput Screening Workshop, Washington, DC, December, 2005
- Organizer, ISRTP Meeting on Alternative Methods in Toxicology, Baltimore, Maryland, November, 2005
- Organizer, NTP 25th Anniversary Meeting, Washington, DC, May, 2005
- Organizer, IPCS/WHO Workgroup on Dose-Response Modeling, Geneva, Switzerland, September, 2004
- Organizer, Consultation on harmonization of toxicological research between the NTP, Ramazzini Foundation and the European Union, European Congress of Toxicology, Florence, Italy, September, 2003.
- Member, WHO Workgroup on the epidemiology of cellular phone toxicity, Tskuuba, Japan, September, 2003.
- Program Committee, 12th International Conference on Global Warming, Boston, Massachusetts, May 2003
- Program Committee, International Conference on Cancer Risk Assessment, Athens, Greece, August, 2003
- Chair, WHO Public Consultation on Risk Communication, Luxembourg, February, 2003.
- Chair, WHO Committee on Establishing a Plan for Implementation of the Precautionary Principle in Risk Management. Luxembourg, February, 2003.
- Presenter (on behalf of US Government), National Academy of Sciences Panel on the Use of Third Party Toxicity Research with Human Research Participants, December, 2002
- Member, US Science Delegation, United Nations Environmental Program Consultation on Organic Mercury, September, 2002
- Science Panel Member, IARC Carcinogenicity Review of ELF-EMF, Lyon, France, June, 2001.
- Reviewer, Finish Ministry of Health Centers of Excellence Program, Helsinki, April, 2001.
- *EPA* dioxin reassessment peer review workshop and public comment session, Washington, DC, 2000.
- Organizer: Dioxin Dose-Response Working Group Meeting, Fort Collins, Colorado, February, 2000.
- Chair, Spiegelman Award Committee, *American Public Health Association,* 1998.
- Chair, *Bioelectromagnetics Society* Symposium on the use of Transgenic Animals in Evaluating Health Risks from Exposure to Cellular Phones, St. Petersburg, Florida, 1998.

- Member, *World Health Organization* International Program on Chemical Safety, Workshop on Issues in Cancer Risk Assessment, 1998.
- Advisor, *Joint Committee on Food Additives, World Health Organization/Food and Agriculture Organization*. Evaluation of certain food additives and contaminants
- Member, US Government Methylene Chloride Risk Characterization Science Committee, 1996-1998.
- Scientific Organizing Committee, *Colorado State University* Workshop on Biomedical Advances on Chemical Mixtures, 1997.
- *National Academy of Sciences*, Institute of Medicine, Committee on Funding Future Agent Orange Research in Vietnam, 1996.
- Discussant, Workshop on the role of Endocrine Disruptors in Human Health, 1995.
- Advisor to *Australian Health Council* on Risk Assessment Methodology, Member *NHMRC* Steering Committee on Cancer Risk Assessment Guidelines
- Participant, International Program on Chemical Safety of the *World Health Organization* Workshop on Chemical Risk Assessment, London, England, 1995.
- Participant, *IARC* Workshop on Receptor-Mediated Carcinogenesis, Lyon, France, 1994.
- Co-Organizer, Symposium on Quantitative Risk Assessment, *German Cancer Research Center*, Heidelberg, Germany, 1993.
- Participant, *IARC* Monograph on Risk Assessment Methodology, *International Agency for Research on Cancer*, Lyon, France, 1993.
- Thesis advisor for graduate student, *University of Waterloo*, Waterloo, Ontario, Canada. 1991-93.
- Co-Organizer, *Russian Academy of Sciences* Informatics and Cybernetics Research Award, 1992.
- Official Observer, IARC Monograph on the Biological Effects of Ultraviolet Radiation, *International Agency for Research on Cancer*, Lyon, France, 1992.
- Member, *International Life Sciences Institute*, Dose-Response Working Group, 1991.
- Participant in Banbury Conference on Human Health Risks from Exposures to Dioxins, Banbury Conference Center, Cold Spring Harbor, New York, 1990.
- Co-Chairman, Session on Biostatistical Developments in Cancer Research, *15th International Cancer Congress*, Hamburg, Germany, 1990.
- Participant in *Environmental Protection Agency* Workshop on Risk Assessment Guidelines, Virginia Beach, Virginia, 1989.

Direction of Ph.D. Theses:

A Bailer. *The effects of treatment lethality on tests of carcinogenicity*. Department of Biostatistics, University of North Carolina, Chapel Hill, North Carolina, 1986.

P Williams. *Estimating tumor incidence rates using the method of moments and maximum likelihood estimation combined*. Department of Biostatistics, University of North Carolina, Chapel Hill, North Carolina, 1989.

G Carr. *The analysis of data on adverse reactions to chemicals in developmental toxicology*. Department of Biostatistics, University of North Carolina, Chapel Hill, North Carolina, 1989.

S Liu. *Estimating parameters in a two-stage model of carcinogenesis using information on enzyme-altered foci from initiation-promotion experiments*. Department of Biostatistics, University of North Carolina, Chapel Hill, North Carolina, 1993.

CD Sherman. *Multipath/multistage models of carcinogenesis*. Department of Statistics and Actuarial Sciences, University of Waterloo, Waterloo, Ontario, Canada, 1994.

C Lyles. *Cell labeling data: Models and parameter estimation*. Department of Biostatistics, University of North Carolina, Chapel Hill, North Carolina, 1995.

F Ye. *The equal slopes test for benchmark doses*. Department of Biostatistics, University of North Carolina, Chapel Hill, North Carolina, 2001

S Whitaker. *Development of a biologically-based mathematical model of fetal development*. Department of Mathematics, North Carolina State University, Raleigh, North Carolina, 2000.

R Hehns. *Homeostatic feedback control of growth in multistage cancer models*. Department of Biostatistics. University of North Carolina. Chapel Hill. North Carolina. 2001

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Appendix II: Previous Cases Resulting in Depositions and Court Appearances

Glyphosate multidistrict litigation under Judge Vince Chhabria. MDL 2741, Case 3:16-md-02741-VC, US District Court, Northern District of California

Edwin Hardeman (plaintiff) v. Monsanto Company (defendant), MDL 2741, Case 3:16-cv-00525-VC, US District Court, Northern District of California

Edwin Hardeman (plaintiff) v. Monsanto Company (defendant), MDL 2741, Case 3:16-cv-00525-VC, US District Court, Northern District of California

Alva and Alberta Pilliod (plaintiffs) v. Monsanto Company (defendant), Alameda County Superior Court, Case A158228

Walter Winston et al. (plaintiffs) v. Monsanto Company (defendant), Circuit Court of the City of St. Louis, State of Missouri, Case No. 1822-CC00515

Depositions from Winston v. Monsanto were also to be used for the following

Bellah v. Monsanto, Lake C., CA
Caballero v. Monsanto, Alameda County, CA
Bargas v. Monsanto, Alameda County, CA
Wade v. Monsanto, St. Louis City, MO
Stevick v. Monsanto, San Francisco, CA

Seitz v. Monsanto, St. Louis City, MO
Kane v. Monsanto, St. Louis City, MO
Bogner v. Monsanto, St. Louis County, MO
Neal v. Monsanto, St. Louis CCity, MO

Appendix III: Compensation

Billing is at $500.00 per hour in 30-minute increments for all activities including depositions and trial testimony with the exception of travel time which will be billed at $200.00 per hour with a maximum of 8 hours per day. Reasonable expenses incurred including transportation costs, hotels and meals will be reimbursed.

Certification

I hereby certify that this report is a complete and accurate statement of all of my opinions, and the basis and reasons for them, to which I will testify under oath.

3/1/2021

Christopher J. Portier Date

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Genetic susceptibility may modify the association between cell phone use and thyroid cancer: A population-based case-control study in Connecticut

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ABSTRACT

Emerging studies have provided evidence on the carcinogenicity of radiofrequency radiation (RFR) from cell phones. This study aims to test the genetic susceptibility on the association between cell phone use and thyroid cancer. Population-based case-control study was conducted in Connecticut between 2010 and 2011 including 440 thyroid cancer cases and 465 population-based controls with genotyping information for 823 single nucleotide polymorphisms (SNPs) in 176 DNA genes. We used multivariate unconditional logistic regression models to estimate the genotype-environment interaction between each SNP and cell phone use and to estimate the association with cell phone use in populations according to SNP variants. Ten SNPs had $P < 0.01$ for interaction in all thyroid cancers. In the common homozygote groups, no association with cell phone use was observed. In the variant group (heterozygotes and rare homozygotes), cell phone use was associated with an increased risk for rs11070256 (odds ratio (OR): 2.36, 95% confidence interval (CI): 1.30–4.30), rs1695147 (OR: 2.52, 95% CI: 1.30–4.90), rs6732673 (OR: 1.59, 95% CI: 1.01–2.49), rs396746 (OR: 2.53, 95% CI: 1.13–5.65), rs12204529 (OR: 2.62, 95% CI: 1.33–5.17), and rs3800537 (OR: 2.64, 95% CI: 1.30–5.36) with thyroid cancers. In small tumors, increased risk was observed for 5 SNPs (rs1063639, rs1695147, rs11070256, rs12204529 and rs3800537), In large tumors, increased risk was observed for 3 SNPs (rs11070256, rs1695147, and rs396746). Our result suggests that genetic susceptibilities modify the associations between cell phone use and risk of thyroid cancer. The findings provide more evidence for RFR carcinogenic group classification.

1. Introduction

The International Agency for Research on Cancer (IARC) classified radiofrequency radiation (RFR) emitted from cell phone as possible human carcinogen (Group 2B) in 2011 based on limited evidence from humans (IARC Working Group, 2013). One cohort study (Schuz et al., 2006) and five case-control studies (Auvinen et al., 2002; Hardell et al., 2011; Inskip et al., 2001; INTERPHONE Study Group, 2010; Muscat et al., 2000) were evaluated by the IARC Working Group. Brain tumors including glioma, acoustic neuroma, and meningioma were evaluated in these studies. Two studies observed an increased risk of brain tumor in people with the highest cumulative cell phone use (Hardell et al., 2011; INTERPHONE Study Group, 2010). Though these studies were vulnerable to methodological limitations and possible biases, such as no appropriate evidence-based metric for cell phone use, the working group stated that positive associations have been observed between exposure to radiofrequency radiation and glioma, and acoustic neuroma (IARC Working Group, 2013). Most group members agreed that positive associations in these studies could not be dismissed and that it was appropriate to classify RFR as a Group 2B carcinogen (Baan et al., 2011).

Since 2011, emerging studies have offered additional evidence on

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the carcinogenicity of RFR. An animal experiment published in 2018 by the National Toxicology Program (NTP) concluded that there was clear evidence to support an association between RFR exposure from cell phones and tumors in the hearts and brains of male rats (National Toxicology Program, 2018a; National Toxicology Program, 2018b; Wyde et al., 2018). These findings were confirmed by another animal study from the Ramazzini Institute (Falcioni et al., 2018). Additional population studies have also been published since the IARC classification. Nine articles using data from case-control studies concluded that long-term cell phone use was associated with an increased risk of brain tumor (Aydin et al., 2011; Cardis et al., 2011; Carlberg and Hardell, 2012; Coureau et al., 2014; Grell et al., 2016; Hardell and Carlberg, 2015; Hardell et al., 2013; Momoli et al., 2017). Two cohort studies did not observe an association between cell phone use and brain tumor (Benson et al., 2013; Frei et al., 2011). However, one study (Benson et al., 2013) only provided baseline exposure and another study (Frei et al., 2011) used mobile phone subscription. The limitations of exposure assessment suffered from these two cohort studies might render their null associations uninformative (Söderqvist et al., 2012). These new findings build up researchers' concerns about health effects of cell phone use and support the effort to reclassify RFR as a Group 1 carcinogen (Miller et al., 2018). A new report from IARC advisory group also recommended a re-evaluation of RFR classification (IARC, 2019).

Cell phone technology has changed over the past three decades. The analog cell phone was introduced to the US in 1983 and then digital cell phone in 1993. In 2008, the US Federal Communications Commission officially let American carriers decommission analog network (Scherer, 2018). Cell antennas tend to be located at the bottom of cell phones since the introduction of smartphone around 2010, and thus the peak RFR exposure is more likely to occur in the neck than in the brain (Carlberg et al., 2016). Thyroid gland located in the neck is the most radiation-sensitive organ (Zhang et al., 2015); and the only established exogenous risk factor for thyroid cancer is ionizing radiation (Sinnott et al., 2010). A recent study linked cell phone use with thyroid cancer (Luo et al., 2019), though only borderline significant results were observed. Thyroid cancer incidence rates have been rising substantially over the past several decades, paralleling the increased use of cell phones. Therefore, more studies are needed to investigate whether RFR from cell phones contributes to the increase.

It is suggested that in addition to thermal effects, the energy from RFR is sufficient to alter the structure and function of proteins involved in DNA damage repair (Phillips et al., 2009). Recent studies indicated that exposure to RFR increased DNA damage (Smith-Roe, 2019; Yakymenko et al., 2016). However, genetic factors were not considered in previous epidemiologic studies. To our knowledge, no epidemiologic studies have examined gene-environment interactions.

Given the potential relationships between RFR from cell phone use, thyroid cancer and DNA damage repair, this study aims to investigate the role of DNA repair genes in the association between cell phone use and thyroid cancer using data from a population-based case-control study in Connecticut, USA. We hypothesize that variants of single nucleotide polymorphisms (SNPs) within DNA repair genes can modify the effects of RFR from cell phone use.

2. Method

2.1. Study population

Details of the population-based case-control study were described in previous publications (Luo et al., 2019; Sandler et al., 2018). In brief, the study included 462 histologically confirmed incident thyroid cancers (papillary (ICD-O-3: 8050, 8052, 8130, 8260, 8340–8344, 8450, and 8452), follicular (ICD-O-3: 8290, 8330–8332, and 8335), medullary (ICD-O-3: 8345, 8346, and 8510), or anaplastic (ICD-O-3: 8021)) diagnosed between 2010 and 2011 in Connecticut (375 females and 87 males), and 498 population-based controls (344 females and 154 males). All cases were between 21 and 84 years old, without previous cancer except nonmelanoma skin cancer, and were alive at the time of interview. A total of 701 eligible cases were identified and 462 (65.9%) completed in-person interviews. Controls were recruited through random digit dialing. A total of 498 controls joined the study with a participation rate of 61.5%. All participants, including cases and controls in this study, were interviewed by trained study interviewers using a standardized and structured questionnaire to collect information on demographics, cell phone use, radiation exposure, lifestyle factors, occupation, and diet. Cases and controls were frequency-matched by age (± 5 years). The study was approved by the Human Investigations Committee at Yale and the Connecticut Department of Public Health. Written informed consent was obtained from all participants.

Table 1
Distribution of selected characteristics of the study population.

	Case (n = 440) n (%)	Controls (n = 465) n (%)	P value[c]
Age (years)			
Mean (SD)	50.9 (12.1)	54.1 (13.1)	< 0.01
< 40	84 (19.1)	61 (13.1)	
40–49	112 (25.5)	117 (25.2)	
50–59	140 (31.8)	126 (27.1)	
60–69	78 (17.7)	94 (20.2)	
≥70	26 (5.9)	67 (14.4)	< 0.01
Sex			
Male	84 (19.1)	145 (31.2)	
Female	356 (80.9)	320 (68.8)	< 0.01
Race			
White	396 (90.0)	427 (91.8)	
Black	16 (3.6)	20 (4.3)	
Other	28 (6.4)	18 (3.9)	0.21
Body mass index (kg/m^2)			
< 25	140 (31.8)	185 (39.8)	
25 to < 30	138 (31.4)	160 (34.3)	
30 +	159 (36.1)	112 (24.1)	
Missing	3 (0.7)	8 (1.7)	< 0.01
Years of education			
High school or lower	152 (34.6)	101 (21.7)	
College	176 (40.0)	226 (48.6)	
Graduate school	110 (25.0)	133 (28.6)	
Missing	2 (0.4)	5 (1.1)	< 0.01
Family history of thyroid cancer among first-degree relatives			
Yes	71 (16.1)	46 (9.9)	
No	369 (83.9)	419 (90.1)	0.03
Prior benign thyroid disease[a]			
Yes	56 (12.7)	12 (2.6)	
No	384 (87.3)	453 (97.4)	< 0.01
Alcohol consumption[b]			
Yes	185 (42.0)	251 (54.0)	
No	255 (58.0)	214 (46.0)	< 0.01

SD: standard deviation.

[a] Benign thyroid disease included hyperthyroidism, hypothyroidism, goiter, thyroid nodules, and thyroid adenoma.

[b] Ever alcohol consumption was defined as ever had more than 12 drinks of alcoholic beverages such as beer, wine, or liquor. 1 drink of beer = 1 can or bottle; 1 drink of wine = 14 oz glass; 1 drink of liquor = 1 shot.

[c] p values from chi-square test were used to test the difference between cases and controls.

2.2. Cell phone use assessment

The participants were asked the following questions regarding the frequency, duration, and protective behaviors of cell phone use: (1) Have you ever used a cell phone at least once a week for 6 months prior to one year before diagnosis? (2) What calendar year did you start regularly using a cell phone? (3) What calendar year did you stop regularly using a cell phone? (4) Excluding the time period that you did not use a cell phone, altogether how many years have you regularly used a cell phone? (5) What proportion of the time did you use a hands-free device when you regularly used a cell phone? (6) On average, how

Table 2
Associations between cell phone use and thyroid cancer risk according to SNP variants that had an P < 0.01 for interaction with cell phone use.

Gene	SNP	Cell phone non-user			Cell phone user			P value for interaction[b]	Q value for interaction[c]
		Case	Control	OR[a] (95% CI)	Case	Control	OR[a] (95% CI)		
PAK6	rs11070256								
	AA	72	59	1.00	211	227	0.66 (0.39, 1.12)		
	AC/CC	23	53	1.00	133	125	2.36 (1.30, 4.30)	0.0008	0.0497
MDM2	rs1695147								
	AA	72	69	1.00	212	245	0.76 (0.50, 1.15)		
	AC/CC	23	43	1.00	131	106	2.52 (1.30, 4.90)	0.0027	0.0497
HDAC4	rs6732673								
	TT	46	33	1.00	115	127	0.62 (0.34, 1.14)		
	TC/CC	48	80	1.00	226	224	1.59 (1.01, 2.49)	0.0026	0.0497
HDAC4	rs1063639								
	GG	27	14	1.00	80	86	0.35 (0.11, 1.08)		
	GA/AA	69	98	1.00	264	264	1.46 (0.98, 2.18)	0.0022	0.0497
HDAC4	rs843458								
	AA	48	73	1.00	238	222	1.60 (0.96, 2.67)		
	AC/CC	47	40	1.00	105	130	0.65 (0.37, 1.15)	0.0072	0.0719
GATA4	rs3757949								
	GG	46	78	1.00	204	191	1.70 (0.98, 2.95)		
	GC/CC	47	35	1.00	137	158	0.62 (0.35, 1.09)	0.0066	0.0719
UBE2V1	rs6125888								
	TT	71	100	1.00	274	265	1.41 (0.95, 2.08)		
	TG/GG	24	13	1.00	69	86	0.39 (0.14, 1.08)	0.0077	0.0719
LINC00336	rs396746								
	AA	82	82	1.00	251	275	0.87 (0.59, 1.30)		
	AC/CC	13	31	1.00	93	77	2.53 (1.13, 5.65)	0.0084	0.0719
DACT2	rs12204529								
	CC	73	72	1.00	239	255	0.76 (0.50, 1.17)		
	CG/GG	22	40	1.00	104	97	2.62 (1.33, 5.17)	0.0025	0.0497
DACT2	rs3800537								
	AA	76	75	1.00	248	257	0.81 (0.53, 1.22)		
	AG/GG	19	38	1.00	96	95	2.64 (1.30, 5.36)	0.0046	0.0705

[a] Adjusted for age (continuous), sex (male, female), education (< college, college, > college), family history of thyroid cancer (yes, no), alcohol consumption (yes, no), body mass index (BMI, < 25, 25–29.9, ≥30), and previous benign thyroid diseases (yes, no).
[b] Interaction between cell phone use and SNP variants.
[c] Q values are adaptive P values that control for the positive false discovery rate.

many phone calls did you make or receive per day? (7) On average, how many hours per day did you use a cell phone? If a participant answered "Yes" to question (1), he/she was defined as a "cell phone user" and otherwise a "cell phone non-user". Information on cordless phone use was not collected in our study. Phone use hours per day, phone calls per day and phone use years were calculated from these variables. These variables were categorized into two halves based on the median values.

2.3. SNP genotyping

After undergoing the standardized interview process described previously, a total of 448 thyroid cancer cases (356 females and 84 males) and 465 controls (320 females and 145 males) donated samples of whole blood by venipuncture. Peripheral blood leukocyte DNA was extracted using the Qiagen Phenol-Chloroform Extraction Kit (Qiagen, N.V.) according to standard manufacturer protocol. DNA was then genotyped using a custom-made Illumina GoldenGate assay. Genotyping data were successfully obtained for 440 thyroid cancer cases and 465 controls. The GoldenGate assay included analysis of 878 SNPs in 177 gene regions involved in DNA repair. Quality control duplicate samples were also included in the genotyping platform. All duplicate samples yielded a concordance rate of ≥99%. The Hardy–Weinberg equilibrium (HWE) was assessed in controls for each SNP using a chi-squared test. SNPs with a $P > 0.00001$ from the chi-squared test were considered to be in HWE. Of the 878 SNPs tested, 55 SNPs were not in HWE and were excluded from the final analyses.

2.4. Statistical analysis

Unconditional logistic regression models were employed to evaluate the associations of SNP variants and cell phone use. Each SNP was categorized into two groups: common group (common homozygote) and variant group (heterozygote and rare homozygote combined). First, we evaluated the interaction between cell phone use and SNP variants by adding a cross-product term between SNP variant (common/variant) and cell phone use (user/non-user) as well as product terms between SNP variant and all covariates in the model, including cell phone use. SNPs with a $P < 0.01$ for interaction with cell phone use were selected. A significance level of 0.01 was used for the interaction term rather than a Bonferroni correction because the Bonferroni correction is usually conservative (Bender and Lange, 1999; Perneger, 1998). The Bonferroni correction was used for independent SNP test but rarely for interactions (Conneely and Boehnke, 2007). Currently, there is no consensus on the magnitude of significance level for interaction and a conservative P value may go against the precautionary principle. Additionally, Bonferroni correction fails to simultaneously address type 1 errors as well as the correlated nature in multiple tests (Conneely and Boehnke, 2007). In this case, a significance level of 0.01 can substantially reduce the false claims of significance and thus it is used for interaction. Further, we computed the Q values to control for positive false discovery rate (Storey, 2002; Storey et al., 2004). The Q value is proposed as an alternative to control for multiple tests and reduce false positive.

Second, we stratified the study population according to each selected SNP and re-run the regression to evaluate the associations of cell phone use in each stratum. Odds ratios (OR) and 95% confidence interval (95% CI) of cell phone use were calculated. Considering these

Table 3
Associations of cell phone use on small and large thyroid tumors in populations stratified by SNP variants.

Gene	SNP	Small tumor (≤10 mm)			Large tumor (> 10 mm)		
		Non-user	User		Non-user	User	
		Case[b]	Case[b]	OR[a] (95% CI)	Case[b]	Case[b]	OR[a] (95% CI)
PAK6	rs11070256						
	AA	33	99	0.75 (0.42, 1.32)	39	108	0.53 (0.27, 1.04)
	AC/CC	11	64	2.33 (1.06, 5.12)	12	69	2.48 (1.14, 5.37)
MDM2	rs1695147						
	AA	31	99	0.83 (0.49, 1.42)	41	111	0.69 (0.41, 1.15)
	AC/CC	13	63	2.29 (1.01, 5.19)	10	66	2.64 (1.10, 6.34)
HDAC4	rs6732673						
	TT	20	52	0.67 (0.31, 1.42)	26	62	0.55 (0.26, 1.13)
	TC/CC	24	109	1.64 (0.93, 2.89)	24	114	1.50 (0.85, 2.67)
HDAC4	rs1063639						
	GG	13	40	0.28 (0.08, 1.01)	14	39	0.39 (0.14, 1.04)
	GA/AA	31	123	1.68 (1.00, 2.82)	38	138	1.24 (0.76, 2.03)
HDAC4	rs843458						
	AA	25	112	1.51 (0.86, 2.68)	23	122	1.72 (0.95, 3.12)
	AC/CC	19	50	0.81 (0.40, 1.67)	28	55	0.56 (0.28, 1.10)
GATA4	rs3757949						
	GG	19	95	1.95 (0.97, 3.92)	27	105	1.45 (0.83, 2.54)
	GC/CC	24	66	0.61 (0.31, 1.22)	23	71	0.62 (0.31, 1.26)
UBE2V1	rs6125888						
	TT	34	127	1.39 (0.85, 2.28)	37	143	1.31 (0.81, 2.13)
	TG/GG	10	35	0.58 (0.19, 1.74)	14	34	0.37 (0.13, 1.04)
LINC00336	rs396746						
	AA	35	123	1.06 (0.64, 1.76)	47	126	0.73 (0.45, 1.17)
	AC/CC	9	40	1.42 (0.53, 3.78)	4	51	4.64 (1.40, 15.4)
DACT2	rs12204529						
	CC	36	113	0.79 (0.47, 1.34)	37	123	0.71 (0.42, 1.21)
	CG/GG	8	49	3.52 (1.37, 9.09)	14	54	1.99 (0.90, 4.41)
DACT2	rs3800537						
	AA	38	119	0.83 (0.50, 1.39)	38	126	0.75 (0.44, 1.27)
	AG/GG	6	44	4.10 (1.44, 11.70)	13	51	1.92 (0.85, 4.33)

[a] Adjusted for age (continuous), sex (male, female), education (< college, college, > college), family history of thyroid cancer (yes, no), alcohol consumption (yes, no), body mass index (BMI, < 25, 25–29.9, ≥30), and previous benign thyroid diseases (yes, no).
[b] The number of controls can be found in Table 2.

selected SNPs might be correlated, we used Haploview to analyze the linkage disequilibrium (LD) and haplotype among these SNPs (Barrett et al., 2005).

Because small and large thyroid cancers may represent different disease entities, the cases were further stratified by tumor size into small group (≤10 mm) and large group (> 10 mm). The analysis was performed again in the small and large groups, respectively. Additionally, cell phone users in this study were further stratified based on the median values of daily use hours, daily phone calls and phone use years, aiming to examine the impacts of cell phone use frequency and duration on thyroid cancer. A trend test was performed using stratum-specific median values.

All models were adjusted for age (continuous), sex (male, female), education (< college, college, > college), family history of thyroid cancer (yes, no), alcohol consumption (yes, no), body mass index (BMI, < 25, 25–29.9, ≥30), and previous benign thyroid diseases (yes, no). Additional adjustment for variables, including occupational radiation exposure, radiation treatment, race, smoking, family income, diagnostic radiation exposure, dietary intake of seafood and iodine intake did not substantially change (10%) the observed associations; therefore, these variables were not included in the final models. Less than 2% participants had missing values in education and BMI. Multiple imputation was used to generate missing values in covariates. 10 simulated datasets were generated and standard analytical procedures were performed for complete data as proposed (Yuan, 2010).

A significance level of 0.05 was used for statistical inferences other than interaction in this study. All P values in this study are two-sided. All analyses were performed using SAS (version 9.4; SAS Institute Inc., Cary, North Carolina, USA).

3. Results

Table 1 shows the distributions of selected demographic characteristics in cases and controls. The distribution was similar in this subset with blood samples and genotyping compared to those from the full study population (Luo et al., 2019). The independent association of cell phone use in this population can be found in Supplementary Table S1. Supplementary Table S2 lists all SNPs analyzed in this study grouped by genes. The associations between SNPs and thyroid cancer among this population were evaluated and the result can be found in another previous study (Sandler et al., 2018).

Table 2 shows the association between cell phone use and thyroid cancer risk stratified by SNP variants that were observed to have $P < 0.01$ for interaction. In total, there were 10 SNPs from 7 genes including *PAK6* (rs11070256), *MDM2* (rs1695147), *HDAC4* (rs6732673, rs1063639, rs843458), *GATA4* (rs3757949), *UBE2V1* (rs6125888), LINC00336 (rs396746) and *DACT2* (rs12204529, rs3800537). All these SNPs had a Q value less than 0.10, a threshold value that was widely used for interaction (Brouwers et al., 2013). None of these SNPs was independently associated with thyroid cancer in this study population (Supplementary Table S3). In the common SNP group, no association was observed. In the variant group, cell phone use was observed to be significantly associated with an increased risk of thyroid cancer for 6 SNPs: *PAK6* rs11070256 (OR: 2.36, 95% CI: 1.30–4.30), *MDM2* rs1695147 (OR: 2.52, 95% CI: 1.30–4.90), *HDAC4* rs6732673 (OR: 1.59, 95% CI: 1.01–2.49), *LINC00336 rs396746* (OR: 2.53, 95% CI: 1.13–5.65), *DACT2* rs12204529 (OR: 2.62, 95% CI: 1.33–5.17) and *DACT2* rs3800537 (OR: 2.64, 95% CI: 1.30–5.36). SNPs with an interaction $P < 0.10$ can be found in Supplementary Table S4.

Table 4
Associations of cell phone use daily use hour on the risk of thyroid cancer in populations stratified by SNP variants.

Gene	SNP	Cell phone non-user			Daily use hour						
					≤1 h/day			> 1 h/day			P value for trend
		Case	Control	OR[a] (95% CI)	Case	Control	OR[a] (95% CI)	Case	Control	OR[a] (95% CI)	
PAK6	rs11070256										
	AA	33	59	1.00	73	88	0.66 (0.38–1.14)	71	61	0.91 (0.51–1.62)	0.8862
	AC/CC	11	53	1.00	48	41	2.67 (1.31–5.42)	44	33	3.01 (1.44–6.30)	0.0041
MDM2	rs1695147										
	AA	31	69	1.00	71	92	0.78 (0.47–1.30)	73	60	1.18 (0.69–2.02)	0.5074
	AC/CC	13	43	1.00	50	37	2.76 (1.26–6.06)	41	34	2.86 (1.30–6.32)	0.0156
HDAC4	rs6732673										
	TT	20	33	1.00	43	48	0.61 (0.29–1.28)	40	32	1.08 (0.50–2.36)	0.7358
	TC/CC	24	80	1.00	76	80	1.63 (0.95–2.78)	74	62	2.00 (1.15–3.46)	0.0154
HDAC4	rs1063639										
	GG	13	14	1.00	27	35	0.25 (0.06–1.02)	26	20	0.54 (0.19–1.54)	0.3825
	GA/AA	31	98	1.00	94	94	1.63 (1.01–2.65)	89	73	1.94 (1.18–3.18)	0.0106
HDAC4	rs843458										
	AA	25	73	1.00	41	46	0.88 (0.44, 1.75)	26	36	0.85 (0.40, 1.81)	0.6847
	AC/CC	19	40	1.00	79	83	1.53 (0.89, 2.63)	89	58	2.28 (1.09, 4.77)	0.1024
GATA4	rs3757949										
	GG	19	78	1.00	48	64	0.62 (0.32, 1.20)	45	37	0.89 (0.43, 1.85)	0.2846
	GC/CC	24	35	1.00	71	63	1.90 (0.90, 4.01)	69	57	2.25 (1.28, 3.96)	0.0853
UBE2V1	rs6125888										
	TT	34	100	1.00	18	30	0.68 (0.42, 1.10)	21	25	0.45 (0.16, 1.23)	0.2951
	TG/GG	10	13	1.00	102	98	1.59 (0.95, 2.66)	94	69	1.89 (0.91, 3.93)	0.1231
LINC00336	rs396746										
	AA	35	82	1.00	83	105	0.80 (0.50–1.30)	87	73	1.23 (0.75–2.02)	0.3380
	AC/CC	9	31	1.00	38	24	4.15 (1.57–11.0)	28	21	3.31 (1.21–9.12)	0.1044
DACT2	rs12204529										
	CC	36	72	1.00	80	92	0.75 (0.45–1.25)	80	67	1.13 (0.67–1.89)	0.5611
	CG/GG	8	40	1.00	41	37	3.11 (1.38–7.00)	34	27	3.37 (1.42–8.03)	0.0074
DACT2	rs3800537										
	AA	38	75	1.00	82	91	0.82 (0.50–1.36)	83	68	1.17 (0.70–1.96)	0.4758
	AG/GG	6	38	1.00	39	38	2.93 (1.28–6.72)	32	26	3.38 (1.39–8.22)	0.0088

[a] Adjusted for age (continuous), sex (male, female), education (< college, college, > college), family history of thyroid cancer (yes, no), alcohol consumption (yes, no), body mass index (BMI, < 25, 25–29.9, ≥30), and previous benign thyroid diseases (yes, no).

Table 3 shows the results between cell phone use and thyroid cancer according to SNP variant groups when the cases are restricted to small or large tumors. In the common SNP group, no increased risk of thyroid cancer was observed, which is consistent with previous findings. In the variant group, the results were interesting. In small tumors, cell phone use was observed to be associated with increased risk of thyroid cancer for *PAK6* rs11070256 (OR: 2.33, 95% CI: 1.06–5.12), *MDM2* rs1695147 (OR: 2.29, 95% CI: 1.01–5.19), *HDAC4* rs1063639 (OR: 1.68, 95% CI: 1.00–2.82), *DACT2* rs12204529 (OR: 3.52, 95% CI: 1.37–9.09), and *DACT2* rs3800537 (OR: 4.10, 95% CI: 1.44–11.70). In large tumors, cell phone use was observed to be associated with increased risk of thyroid cancer for *PAK6* rs11070256 (OR: 2.48, 95% CI: 1.14–5.37), *MDM2* rs1695147 (OR: 2.64, 95% CI: 1.10–6.34), and *LINC00336* rs396746 (OR: 4.64, 95% CI: 1.40–15.4). The associations were observed in both small and large tumors for *PAK6* rs11070256 and *MDM2* rs1695147.

Table 4, 5 and 6 show the associations of cell phone use frequency (daily use hours and daily phone calls) and duration (cell phone use years), respectively. In the variant group, some trends were observed. As the daily use hour increased, the risk of thyroid cancer increased for *PAK6* rs11070256 (P_{trend} = 0.0041), *MDM2* rs1695147 (P_{trend} = 0.0156), *HDAC4* rs6732673 (P_{trend} = 0.0154), *HDAC4* rs1063639 (P_{trend} = 0.0106), *DACT2* rs12204529 (P_{trend} = 0.0074) and *DACT2* rs3800537 (P_{trend} = 0.0088). Similarly, as the number of daily phone call increased, the risk of thyroid cancer increased for *PAK6* rs11070256 (P_{trend} = 0.0016), *MDM2* rs1695147 (P_{trend} = 0.0076) and *LINC00336* rs396746 (P_{trend} = 0.0077). For the phone use duration, as the cell phone use year increased, the risk of thyroid cancer increased for *LINC00336* rs396746 (P_{trend} = 0.0340), *DACT2* rs12204529 (P_{trend} = 0.0099) and *DACT2* rs3800537 (P_{trend} = 0.0164).

In Haplotype analysis, no correlation was observed among the 10 selected SNPs, except for rs12204529 and rs3800537, which are both on gene *DACT2*.

4. Discussion

In this first study examining the combined influence of genetic susceptibility and cell phone use in relation to thyroid cancer, we observed interactions between cell phone use and SNP variants. In the variant groups for 6 SNPs, cell phone use was associated with a higher risk of thyroid cancer. The increased risk varied across tumor sizes depending on the SNPs: the increased risk was observed in both small and large thyroid tumors for *PAK6* rs11070256 and *MDM2* rs1695147, but only in small tumors for *HDAC4* rs1063639, *DACT2* rs12204529 and *DACT2* rs3800537, and only in large tumors for *LINC00336* rs396746. Furthermore, associations of increased thyroid cancer risk within variant groups were also observed for increasing cell phone use frequency and duration. Our results suggest that genetic susceptibilities modify the associations between cell phone use and risk of thyroid cancer and identify potential susceptible subgroups.

Proteins encoded by genes selected in this study play important roles in tumor suppression or growth. The PAK6 protein is a member of the p21-activated kinases family and associated with apoptosis. PAK6 can either promote tumor growth by inhibiting cell apoptosis (Chen et al., 2015), or suppress tumor growth through Ser-578 phosphorylation of the androgen receptor and Thr-158 and Sre-186 phosphorylation of the AR-E3 ligase MDM2 (Liu et al., 2013).

MDM2 protein is a key regulator of cell apoptosis. It controls p53 in an autoregulatory feedback loop (Oliner et al., 1993). Furthermore, p53 is a tumor suppressor and can regulate apoptosis and ferroptosis (Xie et al., 2017), an apoptosis-independent form of cell death. By repressing

Table 5
Associations of daily phone call on the risk of thyroid cancer in populations stratified by SNP variants.

Gene	SNP	Cell phone non-user			Daily phone call						
					≤5 calls/day			> 5 calls/day			P value for trend
		Case	Control	OR[a] (95% CI)	Case	Control	OR[a] (95% CI)	Case	Control	OR[a] (95% CI)	
PAK6	rs11070256										
	AA	33	59	1.00	123	128	0.70 (0.43–1.15)	74	85	0.58 (0.33–1.01)	0.0572
	AC/CC	11	53	1.00	73	83	1.82 (0.96–3.44)	51	40	3.12 (1.53–6.37)	0.0016
MDM2	rs1695147										
	AA	31	69	1.00	124	150	0.75 (0.48–1.18)	74	85	0.72 (0.43–1.20)	0.2249
	AC/CC	13	43	1.00	71	60	2.25 (1.11–4.57)	51	40	2.97 (1.38–6.40)	0.0076
HDAC4	rs6732673										
	TT	20	33	1.00	62	73	0.61 (0.31–1.17)	47	49	0.66 (0.32–1.36)	0.3208
	TC/CC	24	80	1.00	134	138	1.52 (0.94–2.44)	76	75	1.59 (0.93–2.74)	0.1102
HDAC4	rs1063639										
	GG	13	14	1.00	41	55	0.29 (0.12–0.69)	34	24	0.53 (0.20–1.41)	0.4384
	GA/AA	31	98	1.00	155	155	1.46 (0.95–2.24)	91	100	1.35 (0.84–2.18)	0.2638
HDAC4	rs843458										
	AA	25	73	1.00	61	73	0.69 (0.37, 1.27)	35	50	0.63 (0.31, 1.25)	0.7835
	AC/CC	19	40	1.00	135	138	1.47 (0.90, 2.38)	90	75	1.69 (0.98, 2.93)	0.3263
GATA4	rs3757949										
	GG	19	78	1.00	76	97	0.56 (0.30, 1.03)	51	54	0.65 (0.33, 1.29)	0.4335
	GC/CC	24	35	1.00	119	112	1.72 (1.05, 2.81)	73	70	1.67 (0.97, 2.89)	0.6795
UBE2V1	rs6125888										
	TT	34	100	1.00	39	47	0.46 (0.19, 1.11)	25	35	0.45 (0.18, 1.13)	0.8957
	TG/GG	10	13	1.00	157	163	1.34 (0.88, 2.04)	100	90	1.52 (0.95, 2.43)	0.3572
LINC00336	rs396746										
	AA	35	82	1.00	144	163	0.83 (0.55–1.27)	88	102	0.83 (0.52–1.34)	0.4731
	AC/CC	9	31	1.00	52	48	2.43 (1.01–5.86)	37	23	3.81 (1.45–10.0)	0.0077
DACT2	rs12204529										
	CC	36	72	1.00	133	156	0.70 (0.44–1.10)	90	87	0.88 (0.53–1.46)	0.7812
	CG/GG	8	40	1.00	62	55	2.95 (1.43–6.08)	35	38	2.00 (0.89–4.49)	0.1301
DACT2	rs3800537										
	AA	38	75	1.00	141	157	0.75 (0.48–1.18)	90	88	0.91 (0.55–1.49)	0.8120
	AG/GG	6	38	1.00	55	54	2.97 (1.38–6.35)	35	37	2.07 (0.90–4.76)	0.1304

[a] Adjusted for age (continuous), sex (male, female), education (< college, college, > college), family history of thyroid cancer (yes, no), alcohol consumption (yes, no), body mass index (BMI, < 25, 25–29.9, ≥30), and previous benign thyroid diseases (yes, no). s.

p53 (Boyd et al., 2000), MDM2 can promote tumor growth.

HDAC4 protein promotes deacetylation of histone and non-histone proteins, leading to chromatin condensation and transcriptional repression (Glozak and Seto, 2007). HDAC4 upregulation has been reported to promote cancer in many studies (Colarossi et al., 2014) and its inhibitors have also been reported to suppress tumor growth (Ahn et al., 2012).

GATA4 was selected for interaction though no significant association with cell phone use was observed in *GATA4* variant group. *GATA4* can activate the transcription factor NF-κB to initiate the senescence-associated secretory phenotype, a pro-inflammatory response linked to tumor promotion (Kang et al., 2015). It has been reported to promote ovarian tumors and testicular tumors.

UBE2V1 is also selected in the study but no significant association was observed in the variant group. *UBE2V1* mediates degradation of Sirt1 by ubiquitination, inhibiting histone H4 lysine 16 acetylation, and then epigenetically suppresses autophagy gene expression and promotes cancer metastasis (Shen et al., 2018). Meanwhile, it has also been reported to suppress differentiation of carcinoma cell lines by inhibiting CDK1 then altering cell cycle distribution (Sancho et al., 1998).

LINC00336 is under-investigated and its relevant molecular pathways are unknown. *LINC0*0336 has been observed to be associated with ferroptosis in a recent study. In lung cancer, overexpression of *LINC00336* inhibits ferroptosis and hence promotes tumor growth (Wang, 2019).

DACT2 protein is regulated by promoter region hypermethylation and serves as a tumor suppressor in various cancers including thyroid cancer (Zhao et al., 2014), through intervention in the Wnt and/or TGF-β signaling pathways (Hou et al., 2013).

We observed significant associations between cell phone use and thyroid cancer in variant groups for some SNPs, though none of the SNPs are involved in gene editing. SNP rs1063639 is a synonymous variant and the other SNPs are within introns. However, genetic variants within introns can also be correlated with variants within exons or other regions that directly affect gene expression. In this study, except for SNPs in gene *HDAC4*, other SNPs are highly correlated (LD $r^2 > 0.90$) with at least one SNP in functional genetic regions within a window size of 500,000 bases (Table S5; Correlations were calculated using Ensembl (Zerbino et al., 2018)). Moreover, SNPs within introns might affect RNA splicing patterns and thus downregulate or upregulate key protein products (Chorev and Carmel, 2012). Overall, though SNPs selected in this study are within introns, they may still imply possible genetic interactions with environmental factors.

When interpreting the study findings, potential limitations must be considered. First, we used a significance level of 0.01 for interaction rather than the conservative Bonferroni correction. However, we used the Q value to control for false discovery rate. All selected SNPs in this study had a Q value less than 0.10, a threshold value that was widely used for interaction (Brouwers et al., 2013), suggesting one false positive be expected in this study. Therefore, false positive is not a major concern in this study. A strong significance test should lie on the biological plausibility and reproduction of our observations in independent cohorts. Given the public health importance, we call for more studies to continue the investigation on the interaction between cell phone use and genetic variants. Second, cell phone use was assessed using questionnaires in this study and thus the exposure classification and recall bias cannot be ruled out. As discussed in the previous article (Luo et al., 2019), there was no evidence linking cell phone use and thyroid cancer that could have influenced participant's risk perception. Additionally, increased risks were only observed in the variant group. If the increased

Table 6
Associations of cell phone use year on the risk of thyroid cancer in populations stratified by SNP variants.

Gene	SNP	Cell phone non-user			Cell phone use year						
					≤13 years			> 13 years			P value for trend
		Case	Control	OR[a] (95% CI)	Case	Control	OR[a] (95% CI)	Case	Control	OR[a] (95% CI)	
PAK6	rs11070256										
	AA	33	59	1.00	131	144	0.62 (0.38–1.01)	76	81	0.71 (0.42–1.21)	0.2982
	AC/CC	11	53	1.00	81	71	2.49 (1.32–4.71)	52	53	2.23 (1.12–4.43)	0.0975
MDM2	rs1695147										
	AA	31	69	1.00	131	154	0.73 (0.46–1.14)	80	90	0.81 (0.49–1.33)	0.4506
	AC/CC	13	43	1.00	81	60	2.77 (1.37–5.59)	47	44	2.19 (1.02–4.69)	0.0870
HDAC4	rs6732673										
	TT	20	33	1.00	69	77	0.56 (0.29–1.08)	44	48	0.70 (0.34–1.42)	0.3820
	TC/CC	24	80	1.00	142	137	1.60 (1.00–2.56)	82	86	1.57 (0.93–2.65)	0.1239
HDAC4	rs1063639										
	GG	13	14	1.00	47	52	0.30 (0.09–1.03)	33	34	0.44 (0.17–1.10)	0.1946
	GA/AA	31	98	1.00	165	162	1.48 (0.97–2.27)	95	99	1.41 (0.88–2.25)	0.1919
HDAC4	rs843458										
	AA	25	73	1.00	65	77	0.64 (0.35, 1.17)	40	53	0.67 (0.34, 1.33)	0.5375
	AC/CC	19	40	1.00	146	138	1.55 (0.95, 2.51)	88	81	1.70 (0.91, 3.18)	0.2004
GATA4	rs3757949										
	GG	19	78	1.00	79	95	0.55 (0.30, 1.01)	57	62	0.73 (0.38, 1.40)	0.4582
	GC/CC	24	35	1.00	132	117	1.64 (0.85, 3.16)	69	72	1.50 (0.87, 2.59)	0.3257
UBE2V1	rs6125888										
	TT	34	100	1.00	44	53	0.41 (0.15, 1.12)	24	32	0.39 (0.13, 1.17)	0.5208
	TG/GG	10	13	1.00	167	162	1.36 (0.90, 2.07)	104	101	1.48 (0.94, 2.34)	0.1856
LINC00336	rs396746										
	AA	35	82	1.00	156	166	0.88 (0.58–1.34)	92	106	0.86 (0.54–1.37)	0.5480
	AC/CC	9	31	1.00	56	49	2.33 (1.00–5.41)	36	28	2.85 (1.14–7.12)	0.0340
DACT2	rs12204529										
	CC	36	72	1.00	149	152	0.77 (0.49–1.21)	87	100	0.76 (0.46–1.24)	0.3040
	CG/GG	8	40	1.00	62	63	2.42 (1.18–4.95)	41	34	2.95 (1.33–6.54)	0.0099
DACT2	rs3800537										
	AA	38	75	1.00	154	154	0.81 (0.52–1.26)	91	100	0.81 (0.50–1.31)	0.4289
	AG/GG	6	38	1.00	58	61	2.48 (1.18–5.21)	37	34	2.86 (1.25–6.56)	0.0164

[a] Adjusted for age (continuous), sex (male, female), education (< college, college, > college), family history of thyroid cancer (yes, no), alcohol consumption (yes, no), body mass index (BMI, < 25, 25–29.9, ≥30), and previous benign thyroid diseases (yes, no).

risks had been due to bias or chance, they should have been observed in the common SNP group as well. Overall, though we cannot completely rule out recall bias and exposure misclassification, they were likely to be non-differential and resulted in an underestimation of the true association.

This study was conducted between 2010 and 2011, when it was still possible to recruit enough cell phone non-users, which is a strength of this study. Most of these non-users were nearly 10 years older than users (mean age: 59.2 vs. 50.5). Today with the popularity of cell phones, it is difficult to recruit enough non-users as in this study. It is also noteworthy that at that time, only a small proportion of people had smart phones. Therefore, if cell phone use increased the risk of thyroid cancer, it was possibly due to use of earlier generation of cell phones. The thyroid gland is exposed to more RFR emitted from smart phones compared to earlier generations of cell phone and thus smart phones may pose a greater risk. As a result, findings from this study warrant a further evaluation in future studies.

Given these findings in conjunction with the IARC classification and recent additional studies, we suggest a precautionary approach to cell phone use. Approaches for reducing cell phone radiation include the usage of hands-free devices, limited cell phone use among teenagers, and recommendation for low power cell phone mode. However, the associations observed in this study do not necessarily imply a complete restriction of cell phone use, especially given the important roles of cell phones in today's life. Further evaluation is needed.

In conclusion, this study found that cell phone use increased the risk of thyroid cancer when genetic variants were present within some genes. Our study suggests that pathways related to DNA repair may be involved in the cell phone-thyroid carcinogenesis. This study identifies potential susceptible subgroups. More studies are urgently needed to confirm our findings and explain the mechanisms behind the interactions between genetic variants and cell phone use.

Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2019.109013.

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Review Article

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Lost opportunities for cancer prevention: historical evidence on early warnings with emphasis on radiofrequency radiation

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Abstract: Some historical aspects on late lessons from early warnings on cancer risks with lost time for prevention are discussed. One current example is the cancer-causing effect from radiofrequency (RF) radiation. Studies since decades have shown increased human cancer risk. The fifth generation, 5G, for wireless communication is about to be implemented world-wide despite no comprehensive investigations of potential risks to human health and the environment. This has created debate on this technology among concerned people in many countries. In an appeal to EU in September 2017, currently endorsed by more than 400 scientists and medical doctors, a moratorium on the 5G deployment was required until proper scientific evaluation of negative consequences has been made (www.5Gappeal.eu). That request has not been taken seriously by EU. Lack of proper unbiased risk evaluation of the 5G technology makes adverse effects impossible to be foreseen. This disregard is exemplified by the recent report from the International Commission on non-ionizing radiation protection (ICNIRP) whereby only thermal (heating) effects from RF radiation are acknowledged despite a large number of reported non-thermal effects. Thus, no health effects are acknowledged by ICNIRP for non-thermal RF electromagnetic fields in the range of 100 kHz–300 GHz. Based on results in three case-control studies on use of wireless phones we present preventable fraction for brain tumors. Numbers of brain tumors of not defined type were found to increase in Sweden, especially in the age group 20–39 years in both genders, based on the Swedish Inpatient Register. This may be caused by the high prevalence of wireless phone use among children and in adolescence taking a reasonable latency period and the higher vulnerability to RF radiation among young persons.

Keywords: asbestos; cancer prevention; DDT; dioxins; early warnings; glyphosate; phenoxyacetic acids; radiofrequency radiation; tobacco.

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Introduction

The International Agency for Research on Cancer (IARC) at the World Health Organization (WHO) initiated in 1969 a program to evaluate human cancer risks of chemicals. It was later expanded to include chemical mixtures, radiation and viruses. So far, this program has resulted in 125 Monographs. Mostly, as the history shows, it has taken a long time between the first reports of increased cancer risk and cancer classification of the agent. Thereby preventive measures have not been taken in due time with high costs to society as a consequence in terms of increased numbers of cases with diseases leading to suffering and costs for treatment, loss of professional activity and eventually premature deaths [1–3]. Thus, early warnings should not be neglected. In fact, false positives on environmental risks are extremely rare [4]. In the following some historical examples are discussed, followed by a review of the current controversy on radiofrequency (RF) radiation and cancer. These examples serve as lessons for early warnings [5, 6].

No doubt the reports from the European Environment Agency on late lessons from early warnings may serve as important documents for the precautionary approach. Volume 1 was published in 2001 [5]. It dealt with 12 key lessons on health and environmental hazards. The 2013 volume on late lessons was grouped into five parts including e.g., health, ecosystems, justice, and governance [6]. Both volumes give examples on action that could have been taken to prevent harm. In the following some examples are discussed partly based on our own research experiences.

Examples of early warnings on cancer risks

The first history on occupational diseases was written by the Italian physician Bernardini Ramazzini in his book "De morbis artificum" (Diseases of Workers) printed in Modena, Italy 1700. He is regarded to be the 'father of occupational medicine'. A second extended version was printed in Padua 1713. In the book 53 chapters deal with different occupations and diseases occurring in these occupations [7].

Regarding specific occupational exposures the English physician Percival Pott was the first to describe that men working as chimneysweeps, and thereby exposed to soot, had an increased risk for scrotal cancer. He published his findings in 1775 [8]. This disease was known as chimney-sweepers' cancer. It is regarded to be the first report of an environmental factor causing cancer. It took a long time of campaigning to stop little boys being used to clean chimneys by climbing up them. More than 200 years later soot was classified as a human carcinogen Group 1 (carcinogenic) by IARC in 1985 [9].

Asbestos

Another both occupational and environmental toxic substance is asbestos. Already in 1899, a UK Factor Inspector observed the sharp glass-like jagged nature of asbestos particles [10]. The author noted asbestos dust in the air of the factory rooms and that "*the effects have been found to be injurious*". Numerous reports have since then described increased risks primarily of lung cancer and mesothelioma. Already in 1935, a man with asbestosis and lung cancer was reported [11]. In 1953 it was reported that a man who had worked with asbestos died of pleural mesothelioma [12]. South African researchers published in 1960 a report on increased risk for mesothelioma for both occupational and environmental exposure to asbestos [13]. The American physician Dr. Irving Selikoff gave to a broader public insight into a dramatic increased cancer mortality among American insulation workers exposed to asbestos. Also, that environmental exposure increased the risk of mesothelioma [14]. This started a long-standing battle between a multinational industry defending its product, and public health and regulatory bodies [15, 16]. Asbestos was in 1977 evaluated by IARC to be carcinogenic to humans, Group 1 [17]. This was almost 20 years since the clear evidence of cancer risks was published in the early 1960s. Years were lost for prevention and yielded increased numbers of deaths.

Tobacco

Tobacco has a long history of reported adverse health effects. When first introduced in Europe smoking was recommended for medical purposes, in fact as prophylaxis for many diseases. In 1604 King James I of United Kingdom wrote against the use of tobacco [18]. Sömmering stated in a thesis in 1795 that tobacco pipes induced an increased risk for lip cancer [19]. Cancer of the tongue was described some 100 years later in 1890 [20]. A high proportion of diseases including lung cancer among cigar makers and sellers, waiters, and innkeepers was reported in 1914 [21]. A clearly increased incidence of lung cancer was first reported by Müller in 1940 [22]. This evidence and other cancer studies in the 1940s in Germany [23] and in the Netherlands [24] were mainly disregarded thereby omitting the possibility of early prevention. It was not until the 1950s when more studies showed health risks from tobacco, primarily for diseases such as cancer of the lung, myocardial infarction, peripheral vascular diseases, and chronic obstructive lung disease. Tobacco was in 1986 classified by IARC as a human carcinogen, Group 1 [25]. No doubt the history of smoking shows that early warnings were mainly neglected. Greenwashing by industry and its allied experts has a history of counteracting preventive measurements [26].

DDT

The marine biologist Rachel Carson was the first to write a general picture of chemical damage to the environment, human and animal health in her book Silent Spring published in 1962 [27]. She gave the first comprehensive description of the bioaccumulation of the insecticide DDT (*para,para'*-DDT –1,1'-(2,2,2-trichloro-ethylidene)bis (4-chloro benzene)). DDT was discovered in 1939 by the Swiss researcher Paul Müller. For that he received the Nobel Prize in medicine in 1948. No doubt the book by Rachel Carson was opposed by the chemical industry that even tried to stop the publication. In fact, DDT was defended by the American Medical Association and the US Nutrition Foundation unified with 54 companies in the food, chemical and allied industries [28]. The main human studies on human carcinogenicity of DDT and its main metabolite DDE (1,1'-(2,2-dichloroethenylidene)- bis(4-chlorobenzene)) were performed from the 1990s and onward [29].

The Stockholm Convention on Persistent Organic Pollutants was adopted in 2001. It provided initially evidence for the elimination of 12 chemicals, one of which was DDT [30]. The use of DDT was banned in most countries in the 1970s [31]. In 1972, the US EPA issued a cancellation order for DDT [32]. DDT was evaluated by IARC in 2018 to be probably carcinogenic to humans, Group 2A [29]. It had previously been evaluated as a possibly human carcinogen, Group 2B [33]. One of the main toxic issues is the bioaccumulation of DDT and its metabolites with long half-time in the environment [27]. DDT is still used in some countries, e.g. for malaria control. Due to its chemical behavior its metabolites can be found in human tissue [34, 35].

Phenoxyacetic acids

In 1977, a report was published on a series of patients who had been spraying phenoxy herbicides for the Swedish Forestry and who subsequently developed soft-tissue sarcoma [36]. Herbicides of this type include 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). 2,4,5-T was contaminated by 2,3,7,8,tetrachlorodibenzo-p-dioxin (TCDD), one of the most toxic chemicals in the world. This clinical observation was the first to indicate a possible increased cancer risk for these chemicals. Based on that report an increased risk for soft-tissue sarcoma was found both for these phenoxy herbicides and the chemically related chlorophenols, mostly exposure to pentachlorophenol, in a following case-control study [37]. These results were corroborated in further studies by our research group and others, for an overview see [2].

Another set of studies included malignant lymphoma, also initiated by a clinical observation [38]. This clinical observation resulted in further studies. An increased risk was found for both non-Hodgkin lymphoma (NHL) and Hodgkin's disease for persons exposed to phenoxy herbicides or chlorophenols [39]. Also, the increased lymphoma risk was confirmed in other studies, for overview see [2, 40].

One of the main types of chlorophenols, pentachlorophenol, was classified by IARC in 2019 to be carcinogenic to humans, Group 1 [41]. The phenoxy herbicide 2,4-D was in 2018 classified by IARC as possibly carcinogenic to humans, Group 2B [29]. It was the same classification as in 1977 including also 2,4,5-T [42].

Dioxins

The phenoxy herbicides 2,4-D, 2,4,5-T and chlorophenols were contaminated with dioxins. Of large concern was TCDD that contaminated 2,4,5-T and trichlorophenol. The initial Swedish results on cancer risks from this group of chemicals were followed by studies in other countries that confirmed the findings, for overview see [2,40]. Vietnam veterans exposed to the defoliating agent Agent Orange, including 2,4-D and 2,4,5-T, with TCDD contamination suffering from soft-tissue sarcoma or malignant lymphoma were in 1991 judged to be eligible for service-related compensation [43].

In 1976 an accident occurred in a chemical plant at Seveso, Italy producing 2,4,5-trichlorophenol. Thereby the surrounding area was contaminated with dioxins and the general population was exposed to TCDD. In the aftermath an increased incidence in malignant diseases, notably soft-tissue sarcoma and hematolymphatic malignancies was found in the population [40, 44].

Various *ad hoc* explanations were postulated by the chemical industry and its allied experts to discredit the cancer risks [2]. However, in 1997 IARC classified TCDD as a human carcinogen, Group 1 [45]. It had previously been evaluated in 1977 by IARC to be a possibly human carcinogen, Group 2B [42]. This was about two decades after the first epidemiological publications on increased cancer risk for TCDD contaminated herbicides.

Glyphosate

In the case-control studies by the Hardell group on risk factors for NHL exposure to all types of herbicides was assessed. In addition to phenoxyacetic acids also glyphosate turned out to increase the risk [46, 47]. Hairy cell leukemia (HCL) is regarded to be a subtype of NHL. In a separate study on HCL glyphosate was a risk factor also for that malignancy [48]. Similar results were also found in other studies [49, 50].

Glyphosate was in 1970 tested as herbicide and was patented by Monsanto [51]. It was registered for use in USA in 1974 with the trade name 'Roundup'. Since the patent has expired it is produced nowadays by many manufactures. In 1996 genetically engineered glyphosate tolerant crops were introduced (Roundup Ready) and since then the global use has increased 15-fold. Glyphosate has in recent years been the most widely used pesticide [52].

IARC at WHO evaluated glyphosate in March 2015 and classified it as a Group 2A, a probable human carcinogen [53, 54]. This was based on "limited" evidence of cancer in humans (from real-world exposures that occurred) and "sufficient" evidence of cancer in experimental animals (from studies of "pure" glyphosate). IARC also concluded that there was "strong" evidence for genotoxicity, both for "pure" glyphosate and for glyphosate formulations.

The European Food Safety Authority (EFSA) is the EU agency for risk assessment regarding food safety. In October 2015, that is seven months after the IARC evaluation, EFSA published its own evaluation [55]. In summary EFSA dismissed without clear explanation any association of glyphosate with cancer. All findings on carcinogenesis in animal studies were incorrectly discarded as chance findings. Mechanistic evidence on genotoxicity was ignored. Oxidative stress was confirmed but dismissed as a ground for carcinogenesis [56]. It should be noted that EFSA did not reveal the names of the authors of the chapters and references were redacted.

Monsanto, the main glyphosate producer, hired a panel of scientists to defend glyphosate. Thus, in 2016 a 17-page article was published in Critical Reviews in Toxicology, known to be an industry friendly product defense journal [57]. It was concluded that "*In summary, the totality of the evidence, especially in light of the extensive testing that glyphosate has received, as judged by the Expert Panels, does not support the conclusion that glyphosate is a "probable human carcinogen" and, consistent with previous regulatory assessments, the Expert Panels conclude that glyphosate is unlikely to pose a carcinogenic risk to humans.*"

This review was made by four expert panels. In the initial publication no conflicts of interest were stated. All but six of the 16 authors appeared with their university or hospital affiliation. During lawsuits in USA on glyphosate exposure and NHL it was revealed that the authors were not independent, and that Monsanto was deeply involved in organizing, reviewing and editing the review. In fact, Monsanto paid the authors through a consulting firm, *Intertek* [58].

As a consequence Critical Reviews in Toxicology was forced to make a Corrigendum two years later: "*When this article was originally published on 28th September 2016, the contributions, contractual status and potential competing interests of all authors and non-author contributors were not fully disclosed to Critical Reviews in Toxicology. Specifically, the Acknowledgments and Declaration of Interest were not complete. After further clarification from the authors, these sections are corrected to reflect the full contributions, contractual status and, potential competing interests of all authors and non-author contributors and read as follows … This overview paper (paper) is part of a supplement, the preparation of which was coordinated by Intertek Scientific & Regulatory Consultancy (Intertek) under the leadership of Ashley Roberts. It was prepared subsequent to completion of the four manuscripts as an overview and presented the opinions and conclusions of four groups of the expert panel. The expert panels were organized and supported administratively by Intertek. Funding was provided to Intertek by Monsanto Company, which is a primary producer and marketer of glyphosate and related products. All the expert panelists other than John Acquavella and Larry D. Kier were compensated through a contract with Intertek. John Acquavella and Larry D. Kier were compensated through existing consulting contracts with Monsanto Company*" [59].

Product defense by downplaying risk seems to have been one of Monsanto's strategies [60].

The German chemical company Bayer purchased Monsanto in 2018. It is facing a magnitude of lawsuits on NHL and glyphosate exposure. So far in three lawsuits about 200 million USD have been awarded by the juries [58]. No doubt the use of glyphosate is of large economic importance both for the producers and the agriculture. In 2017 the EU Commission extended the use of glyphosate until 2022 [61].

Radiofrequency radiation

In 2011 radiofrequency electromagnetic fields (RF-EMF) in the frequency range 30 kHz–300 GHz were evaluated by IARC at WHO to be possibly carcinogenic to humans, Group 2B [62, 63]. This was based on evidence of increased risk for glioma and acoustic neuroma in human epidemiology studies on use of mobile and/or cordless phone (DECT) [64–69]. The increased cancer risk was supported by laboratory studies [70, 71].

Extremely low frequency (ELF)-EMF was in 2001 evaluated by IARC to be a possible human carcinogen, Group 2B [72]. This was the first time that non-ionizing radiation at low intensity levels can be a possible cause of cancer. It predated the IARC finding for RF-EMF by a decade.

Since then the evidence on RF-EMF carcinogenesis has strengthened based on further human studies on use of wireless phones, as reviewed [73, 74]. Also animal studies show increased cancer risk, both near field RF-EMF exposure [75–77] and far field exposure [78, 79]. Mechanistic studies show increase of reactive oxygen species (ROS) [80] as well as DNA damage [81]. These results give support to the increased cancer risk in humans and laboratory tested animals for RF radiation. In fact, RF-EMF may now be classified as a human carcinogen, Group 1 [82, 83]. However, such classification can only be made by IARC.

Of course, these well documented health hazards from RF-EMF are not well accepted by the telecom industry and its allied experts. Several methods are used to create doubt.

Studies are discredited, only partly cited, or even not cited at all [84–86]. Thereby the uniformed reader gets the wrong information on actual risks. This includes also regulatory agencies and policy makers. Even agencies aimed at setting exposure guidelines may include pro-industry and biased scientists that obscure the true risks [87, 88].

ICNIRP

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is a private non-governmental (NGO) organization registered in Munich, Germany. ICNIRP appoints its own members and is closed to transparency. It was started in 1992 with the biophysicist Michael Repacholi as the first chairman, now emeritus member. ICNIRP has published three articles with guidelines on RF-EMF exposure [86, 89, 90]. Only thermal (heating) effects from RF radiation are recognized, thereby excluding all studies showing harmful effects at lower non-thermal intensities. In contrast to ICNIRP, some other expert panels such as European Academy of Environmental Medicine [91], the Bioinitiative group [92], and the Russian Commission for Protection from Non-Ionizing Radiation [93], take into account non-thermal RF effects and suggest much lower guidelines for RF exposure.

ICNIRP has managed to get collaborative status with WHO, as discussed previously [88]. The aim is to harmonize the RF-radiation guidelines all over the world. For that purpose ICNIRP has been successful. The guidelines are set to allow very high exposure levels so that the deployment of this technology is not hampered, in favor for industry but at disadvantage to human health and environment. In fact, the ICNIRP guidelines have never been challenged by industry in peer-reviewed articles, which must be taken as a green card for acceptance by industry.

Attributable fraction

The attributable fraction (AF), sometimes also called the etiologic fraction, is the number of cases in which exposure played an etiologic role. This is the preventable fraction if exposure would not be present. In Belpomme et al. [73] we published meta-analyses for longest cumulative use of mobile phones with odds ratio (OR) and 95 % confidence interval (CI), both for total and for ipsilateral wireless phone use. Note that only the Hardell group assessed also use of cordless phones (DECT). We present here AF based on statistically significant increased risks in the meta-analyses. AF is the proportion of cases that can be attributed to the particular exposure. This is calculated as the exposed case fraction multiplied by [(OR-1)/OR].

As displayed in Table 1 the AF for glioma was calculated to 4.88%, 95% CI = 2.44–6.57%, corresponding to 211 preventable cases, 95% CI = 105–284 cases in the longest time for all cumulative use of wireless phones. Regarding ipsilateral use of the wireless phone AF was 6.03%, 95% CI = 4.51–7.12%, yielding 150 cases; 95% CI 112–177 to be preventable.

For meningioma AF = 1.75%, 95% CI = 0.39–2.73 corresponded to 39 cases, 95 % CI = 9–61 cases for ipsilateral use of the wireless phone was calculated. Calculation of AF for acoustic neuroma yielded 4.63%, 95% CI = 3.07–5.63% corresponding to 42 cases, 95% CI = 28–51 cases for ipsilateral use of the phone.

Table 1: Attributable fraction (AF) based on meta-analyses of case-controls studies on use of wireless phones with statistically significant increased risk. For details see Belpomme et al. [73]. Odds ratio (OR), 95% confidence interval (CI), and numbers (n) are given.

	Cases		Meta-analysis		AF		AF, corresponding cases	
	Total n	Exposed n	OR	95% CI	AF, %	95% CI (%)	N	95 % CI
Glioma[a]								
Longest[b] cumulative use ≥ 1640 h	4,319	445	1.90	1.31–2.76	4.88	2.44–6.57	211	105–284
Longest[b] cumulative use, ipsilateral ≥ 1640 h	2,484	247	2.54	1.83–3.52	6.03	4.51–7.12	150	112–177
Meningioma[a]								
Longest[b] cumulative use, ipsilateral ≥ 1640 h	2,241	119	1.49	1.08–2.06	1.75	0.39–2.73	39	9–61
Acoustic neuroma[c]								
Longest cumulative use, ipsilateral ≥ 1640 h	899	66	2.71	1.72–4.28	4.63	3.07–5.63	42	28–51

[a]Based on Interphone [67], Coureau et al. [101], Hardell and Carlberg [104], Carlberg and Hardell [102]. [b]Coureau et al. [101] ≥896 h. [c]Based on Interphone [68], Hardell et al. [108].

Rates of brain tumors in the Swedish National Inpatient Register ICD-code D43

Rates of brain tumors of unknown type, D43, were studied using the Swedish Inpatient Register (IPR) without any personal identification information [94]. It was established in 1964 and has complete national coverage since 1987 [95]. Register data on D43 are available from 1998. Currently more than 99% of hospital discharges are registered. For outpatients the data are less reliable due to missing information. The reporting of outpatients has increased during more recent years so these time trends may give spurious results, thus we omitted outpatients from the analysis.

Data were analyzed for the time period 1998–2019. Age-standardized rates are not available in the register. Instead numbers of patients per 100,000 inhabitants are reported. The Joinpoint Regression Analysis program version 4.1.1.1 was used to examine numbers of patients per 100,000 in inpatient care and incidence per 100,000 person-years in the Swedish Inpatient Register, by fitting a model of 0–3 joinpoints using permutation tests with Bonferroni correction for multiple testing to calculate the number of joinpoints that best fits the material [96]. When joinpoints were detected annual percentage changes (APC) and 95% CIs were calculated for each linear segment. Average annual percentage changes (AAPC) were also calculated for the whole time period using the average of the APCs weighted by the length of the segment. To be able to calculate APC and AAPC the data was log-transformed prior to analysis. Thus, it was not possible to perform joinpoint regression analysis when there were years with no cases during that time period. Since the data do not include any personal identification no ethical approval was needed.

In men AAPC increased during 1998–2019 with +1.77%, 95% confidence interval (CI) −0.02, +3.58%, Table 2; Figure 1. The increase was highest in the age group 20–39 years, +2.90%, 95% CI +1.66, +4.16 %, Figure 2. AAPC increased statistically significant in all age groups, except 0–19 years.

Similar results were found in women with AAPC +1.70%, 95% CI +0.38, +3.05% during 1998–2019, Table 3; Figure 3. Also in women the highest increase of AAPC was found in the age group 20–39 years, +2.89%, 95% CI + 1.54, +4.27%, Figure 4. AAPC increased statistically significant in all age groups except 0–19 years and 80+ years. Especially high increase of APC was seen in women aged 60–79 years during 2005–2019, and women aged 80+ years during 2010–2019.

Table 2: Joinpoint regression analysis of brain tumor rates (numbers per 100,000) in men in the Swedish Inpatient Register 1998–2019, ICD-10 code D43 (https://sdb.socialstyrelsen.se/if_par/val.aspx).

ICD-10	Joinpoint location	APC 1 (95% CI)	APC 2 (95% CI)	APC 3 (95% CI)	AAPC (95% CI)
D43					
All men (n=10,540)	2008; 2011	+0.13 (−0.85, +1.12)	+8.95 (−3.99, +23.64)	+1.22 (−0.16, +2.63)	+1.77 (−0.02, +3.58)
0–19 years (n=662)	No joinpoint detected	–	–	–	+1.83 (−0.13, +3.82
20–39 years (n=1,117)	No joinpoint detected	–	–	–	+2.90 (+1.66, +4.16)
40–59 years (n=2,799)	No joinpoint detected	–	–	–	+1.61 (+0.88, +2.36)
60–79 years (n=4,867)	No joinpoint detected	–	–	–	+1.67 (+0.99, +2.36)
80+ years (n=1,095)	No joinpoint detected	–	–	–	+1.40 (+0.11, +2.70)

APC, annual percentage change (APC 1, time from 1998 to first joinpoint; APC 2, time from first joinpoint to 2019 or to second joinpoint; APC 3, time from second joinpoint to 2019); AAPC, average annual percentage change

Discussion

No doubt there are historical examples of late lessons from early warnings on health risks whereby preventive measurements have been neglected. Some of the examples here clearly show that if the scientific evidence on cancer risks had been taken seriously lives could have been saved.

Tobacco is a good example of cancer risks that were disregarded for decades since clear evidence of increased risk. It was not until 1986 that IARC classified tobacco as a human carcinogen, Group 1 [25]. The strategies by the tobacco industry to sow doubt on the risks include e.g., to fund research that supports their position, to hide their involvement, to promote ‘no risk’ studies, to criticize research that shows risk, and to disseminate data and their interpretation of the results to the press and layman, for further details see Bero [98].

In fact, these strategies by the tobacco industry to obscure scientific facts seem to be textbook examples on product defense that may be used by different industries.

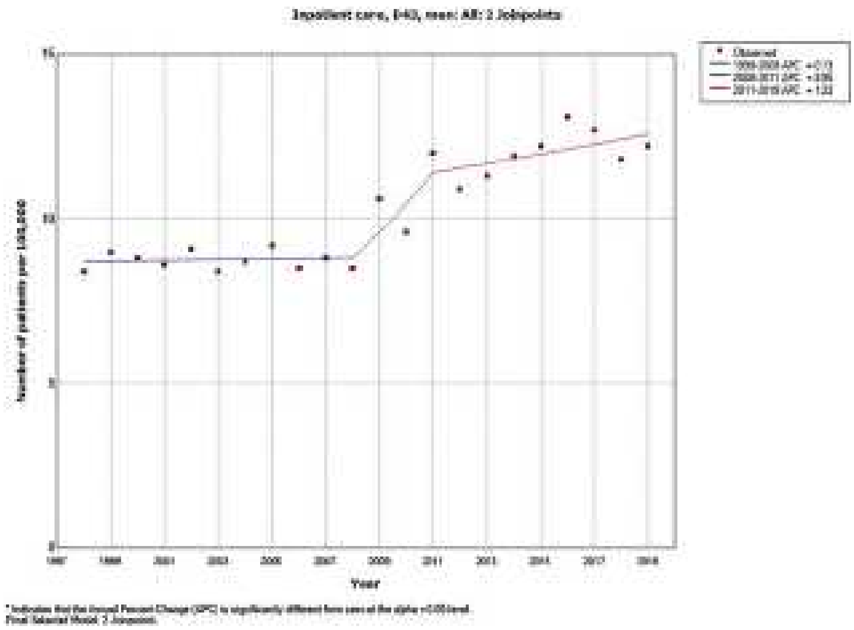

Figure 1: Joinpoint regression analysis of number of patients per 100,000 inhabitants. According to the Swedish National Inpatient Register for men, all ages during 1998–2019 diagnosed with D43 = tumour of unknown type in the brain or CNS. Note that in Sweden 1G (NMT, Nordic mobile telephone System) operated during 1981–2007. 2G (GSM) started 1991, 3G UMTS) started 2003, 4G started 2015, and DECT started 1988 [97].

One current controversy is cancer risks from RF radiation. No lessons on prevention of cancer risks seem to have been learned in spite of decades of publications on adverse health risks. In fact, early prevention is usually very cost effective [2, 99]. The issue on RF radiation risks is on-going and in fact increasing despite decades of research showing adverse effects on human health, plants, insects and birds. It seems as if the industry view of no risk dominates on national level [84], among many countries [85], also at EU level (www.5gappeal.eu), and even within WHO [88]. Notably such industry organizations and nations have the power and economic resources to suppress scientific evidence on risks and have access to mainstream media to propagate their views, may it be for political or economic reasons.

RF radiation is a current controversy regarding cancer risks. The 2011 IARC evaluation on carcinogenesis [62, 63] has been downplayed and detracted by industry and captured agencies from the very beginning in spite of increasing evidence on harmful effects. However, IARC has decided that a new evaluation of cancer risks is top priority within a few years [100].

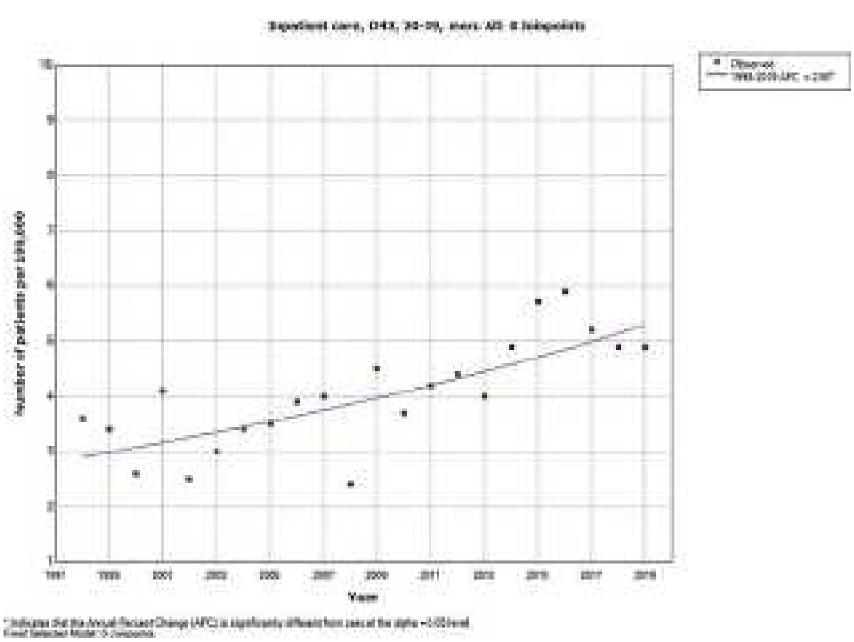

Figure 2: Joinpoint regression analysis of number of patients per 100,000 inhabitants. According to the Swedish National Inpatient Register for men aged 20–39 years during 1998–2019 diagnosed with D43 = tumour of unknown type in the brain or CNS.

Table 3: Joinpoint regression analysis of brain tumour rates (numbers per 100,000) in women in the Swedish Inpatient Register 1998–2019, ICD-10 code D43 (https://sdb.socialstyrelsen.se/if_par/val.aspx).

ICD-10	Joinpoint location	APC 1 (95% CI)	APC 2 (95% CI)	APC 3 (95 % CI)	AAPC (95% CI)
D43					
All women (n=9,611)	2008; 2017	+0.24 (−0.75, +1.24)	+4.77 (+3.32, +6.24)	−4.35 (−15.82, +8.68)	+1.70 (+0.38, +3.05)
0–19 years (n=570)	No joinpoint detected	–	–	–	+0.86 (−0.55, +2.28
20–39 years (n=907)	No joinpoint detected	–	–	–	+2.89 (+1.54, +4.27)
40–59 years (n=2,509)	No joinpoint detected	–	–	–	+1.91 (+0.80, +3.02)
60–79 years (n=4,307)	2005	−0.95 (−4.07, +2.27)	+3.45 (+2.30, +4.62)	–	+1.96 (+0,73, +3.21)
80+ years (n=1,318)	2010	−0.66 (−3.11, +1.84)	+5.49 (+1.51, +9.63)	–	+1.93 (−0.11, +4.02)

APC, annual percentage change (APC 1, time from 1998 to first joinpoint; APC 2, time from first joinpoint to 2019 or to second joinpoint; APC 3, time from second joinpoint to 2019); AAPC, average annual percentage change.

In this article we give some further data on the RF carcinogenesis. The attributable fraction gives the number of cases that could have been prevented if no risk exists for a specific exposure. Based on results in case-control studies from three study groups that have shown statistically significant increased risk for glioma and acoustic neuroma 211 glioma cases (all exposure) and 42 acoustic neuroma cases (ipsilateral exposure) would have been preventable in the longest cumulative exposure group. The preventable fraction was 4.88 and 4.63%, respectively. Highest preventable fraction was found for glioma with ipsilateral wireless phone use, 6.03% corresponding to 150 cases. Lower AF was calculated for meningioma, 1.75%, yielding 39 preventable cases (ipsilateral exposure). As displayed in Belpomme et al. [73] these results were based on Interphone [67], Coureau et al. [101], and Carlberg, Hardell [102], each without statistically significant increased risk. However, meta-analysis of these studies yielded, OR = 1.49, 95% CI = 1.08–2.06.

We have previously published results on increasing rates of tumors of unknown type in the brain or CNS both in the Swedish Inpatient Register and Causes of Death Register during 1998–2013 [103]. There was a clear increasing trend in both genders during that time period, especially during more recent years with AAPC +1.78 %, 95% CI + 0.76, 2.81% for both genders combined. A joinpoint was found in men in 2007; time period 2007–2013 APC +4.95%, 95% CI +1.59, +8.42%. Similarly, in women a joinpoint was detected in 2008; time period 2008–2013 APC +4.08%, 95% CI +1.80, +6.41%.

We have now extended the time period up to 2019. Thus, we report increasing AAPC in both genders during 1998–2019 of similar magnitude as previously. In men the result was of borderline significance although the AAPC

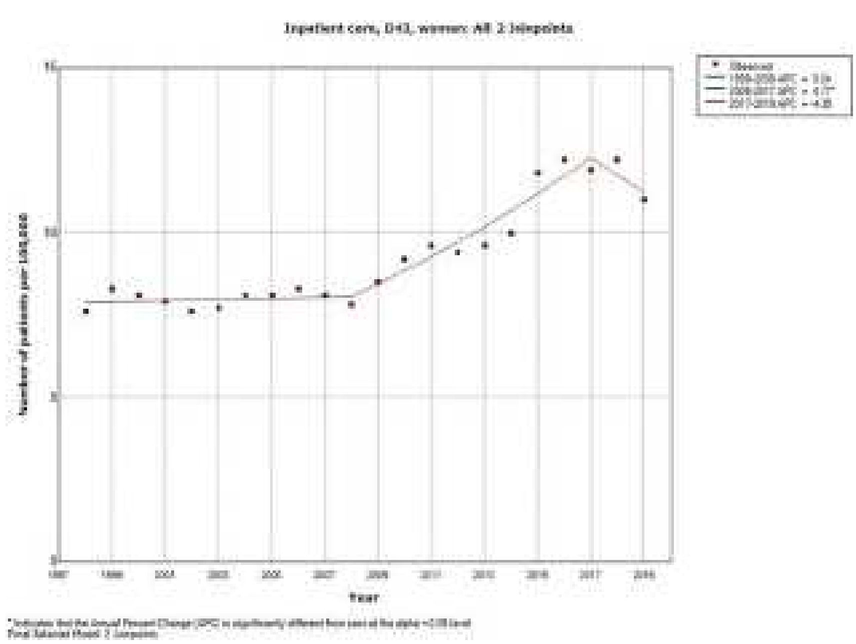

Figure 3: Joinpoint regression analysis of number of patients per 100,000 inhabitants. According to the Swedish National Inpatient Register for women, all ages during 1998–2019 diagnosed with D43 = tumour of unknown type in the brain or CNS. Note that in Sweden 1G (NMT; Nordic mobile telephone System) operated during 1981–2007. 2G (GSM) started 1991, 3G (UMTS) started 2003, 4G started 2015, and DECT started 1988 [97].

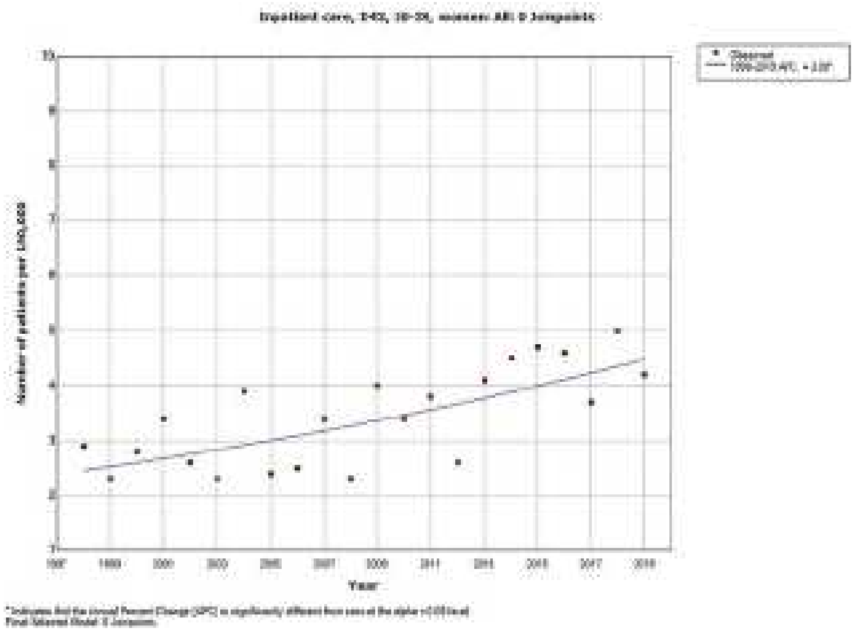

Figure 4: Joinpoint regression analysis of number of patients per 100,000 inhabitants. According to the Swedish National Inpatient Register for women aged 20–39 years during 1998–2019 diagnosed with D43 = tumour of unknown type in the brain or CNS.

overlapped previous findings. Lower APC was found during more recent years in both men and women, see Figures 1 and 3. This may reflect a better diagnostic procedure and thus decreasing numbers of unknown brain tumor type. A delay in reporting to the register during recent years may also have an impact on the results.

It is noteworthy that we found highest AAPC in the age group 20–39 years in both men and women, Tables 2 and 3. We found in our case-control study on glioma a median latency period for use of mobile phone of 9.0 years (mean 10.1 years). The corresponding results for cordless phones (DECT) were 7.0 and 8.0 years, respectively [104]. In a population-based study during 2005–2006 on use of mobile and cordless phones among Swedish children aged 7–14 years 79.1% reported access to mobile phone and use of cordless phone was reported by 83.8% [105]. Thus, our current findings with increasing numbers of brain tumors in the age group 20–39 years may be consistent with use of wireless phones taking a reasonable latency period. Moreover, our previous results showed highest risk for subjects that started the use of mobile or cordless phone before 20 years of age [104]. That age groups would also be more vulnerable to RF radiation [106]. In legends to Figures 1 and 3 we report the history for wireless phone use in Sweden. Figure 5 displays the number of out-going mobile phone minutes in millions during 2000–2019 in

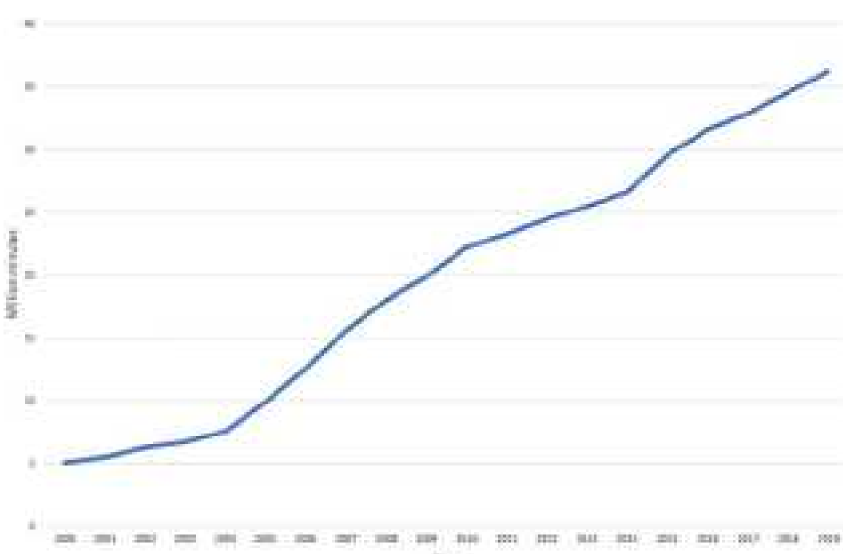

Figure 5: Number of out-going mobile phone minutes in millions during 2000–2019 in Sweden according to post-och Tele-styrelsen [The Swedish post and telecom Authority (PTS)]. Available from: https://statistik.pts.se/svensk-telekommarknad/tabeller/mobila-samtals-och-datatjanster/tabell-13-trafikminuter-utgaende/.

Sweden. The major increase is since early 21st century and may be associated with our findings of increasing numbers of brain tumors of unknown type considering a reasonable latency time.

As we have discussed elsewhere the Swedish Cancer Register is not reliable to study the incidence of brain tumors [103, 107]. The register is mainly based on reporting of cases with histopathological diagnosis. Now diagnosis may be based on CT and/or MRI without further investigations especially of patients with poor outcome. Biopsy or operation may be difficult to perform due to tumor location, age and co-morbidity. In the Swedish Cancer Register about 90% of the cases are diagnosed with cytology or histology, a number that has increased somewhat during recent years [107]. This fact indicates that brain tumors of unknown type are under-reported to the Cancer Register.

This review gives insight into missed opportunities for cancer prevention exemplified by asbestos, tobacco, certain pesticides and now RF radiation. No doubt economic considerations are favored instead of cancer prevention. The cancer victim is the loser in terms of suffering, life quality and shorter life expectancy. Also the life for the next-of-kin is affected. A strategy to sow doubt on cancer risks was established decades ago and is now adopted and implemented in more sophisticated way by the telecom industry regarding RF-EMF risks to human beings and the environment. Industry has the economic power, access to politicians and media whereas concerned people are unheard.

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OPINION REVIEW

Health Council of the Netherlands and evaluation of the fifth generation, 5G, for wireless communication and cancer risks

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Abstract

Currently the fifth generation, 5G, for wireless communication is about to be rolled out worldwide. Many persons are concerned about potential health risks from radiofrequency radiation. In September 2017, a letter was sent to the European Union asking for a moratorium on the deployment until scientific evaluation has been made on potential health risks (http://www.5Gappeal.eu). This appeal has had little success. The Health Council of the Netherlands released on September 2, 2020 their evaluation on 5G and health. It was largely based on a World Health Organization draft and report by the Swedish Radiation Safety Authority, both criticized for not being impartial. The guidelines by the International Commission on Non-Ionizing Radiation Protection were recommended to be used, although they have been considered to be insufficient to protect against health hazards (http://www.emfscientist.org). The Health Council Committee recommended not to use the 26 GHz frequency band until health risks have been studied. For lower frequencies, the International Commission on Non-Ionizing Radiation Protection guidelines were recommended. The conclusion that there is no reason to stop the use of lower frequencies for 5G is not justified by current evidence on cancer risks as commented in this article. A moratorium is urgently needed on the implementation of 5G for wireless communication.

Key Words: 5G; Cancer risk; Health Council Netherlands

Core Tip: In this comment, guidelines for radiofrequency radiation are discussed in

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relation to a recent evaluation by the Health Council of the Netherlands. The Committee recommends that for the deployment of 5G the frequency band 26 GHz should not be used. For lower frequencies, the International Commission on Non-Ionizing Radiation Protection guidelines are recommended. However, these guidelines are not based on an objective evaluation of health risks, which is discussed in this paper.

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INTRODUCTION

The fifth generation, 5G, for wireless communication is about to be rolled out worldwide in spite of health concerns. This has created debate among concerned people in many countries. In an appeal to the European Union (EU) in September 2017, currently endorsed by more than 400 scientists and medical doctors, a moratorium on the 5G deployment was required until proper scientific evaluation of negative consequences has been made (http://www.5Gappeal.eu). This has not had any impact on the progress of the deployment of 5G.

On September 2, 2020, the Health Council of the Netherlands released their evaluation of 5G and health (No. 2020/16/16e/16Ae). The Committee consists of 9 members, 2 scientific secretaries, 1 incidentally consulting expert, and 3 observers. (https://www.healthcouncil.nl/documents/advisory-reports/2020/09/02/5g-and-health).

Of large concern as to impartiality is that one member of the Committee, Huss A, is a member of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) since May 2020. ICNIRP is a private organization based in Germany that does not acknowledge health effects other than caused by heating from radiofrequency (RF) radiation. Thereby nonthermal biological effects are disregarded.

Furthermore, one of the two secretaries, van Rongen E, has been a long-time commission member of ICNIRP since 2010, chair 2016 to 2020, and vice chair since May 2020 (https://www.researchgate.net/profile/Eric_Rongen). A third former ICNIRP member, Sienkiewicz Z, participated as a consulting expert.

It should be added that Huss A receives research funding from a telecom industry sponsored Swiss Foundation, and she is also member of this foundation's Scientific Committee (https://www.emf.ethz.ch/en/foundation/organisation). Further, van Rongen E is a long-time member of the industry organizations, the Institute of Electrical and Electronics Engineers and the International Committee on Electromagnetic Safety (IEEE/ICES).

These facts give concern of conflicts of interest in the Health Council Committee. Members of ICNIRP tend to adhere also in other settings to the ICNIRP no-risk paradigm regarding nonthermal RF radiation. This may also be the case in the Health Council report. In fact it should be noted that the Ethical Board at the Karolinska Institute in Stockholm, Sweden concluded already in 2008 that being a member of ICNIRP may be a conflict of interest that should be stated officially whenever a member from ICNIRP makes opinions on health risks from electromagnetic fields (EMFs) on behalf of another organization, as in this case (Karolinska Institute Diary No. 3753-2008-609). This verdict is related to Prof. Ahlbom A, ICNIRP Commission Member from 1996 until 2008, and is a general statement. Those involved in the current Health Council report with ICNIRP affiliation (present or former) omitted to state that conflict of interest.

Recommendations by the Health Council of the Netherlands

The Committee has made four recommendations to the Parliament, cited in the following: (1) Because the lower frequency bands for 5G (up to 3.5 GHz) have already been used for telecommunication applications and Wi-Fi for years without resulting in any proven adverse health effects, the committee sees no reason to stop or restrict the use of these frequency bands. It does, however, recommend that the exposure should be monitored before, during and after the rollout of the 5G systems. This will make clear to what extent exposure to radiofrequency EMF changes as a result of the introduction of 5G, and any long-term health risks can then be estimated better. The World Health Organization (WHO) analysis can also be used in estimating the risks; (2) The committee recommends doing more research: epidemiological research into the relationship between exposure to the 5G frequencies used and the incidence of cancer, reduced male fertility, poor pregnancy outcomes and birth defects. An ongoing international study into the use of mobile telephones, in which the Netherlands is participating, can play a role in this: (a) experimental research into the health effects of exposure to EMFs in the 26 GHz frequency band; (b) scenario studies to get a picture of the exposure of individuals as a result of wireless communication systems (3G, 4G and 5G); (3) The committee recommends to not use the 26 GHz frequency band for 5G for as long as the potential health risks have not been investigated; and (4) Finally, the committee recommends using the latest guidelines from the ICNIRP as the basis for exposure policy in the Netherlands. Because it cannot be excluded that exposure under the latest ICNIRP standards also has the potential to affect health, the committee recommends taking a cautious approach and keep exposures as low as reasonably achievable.

Of these conclusions, number 3 is in agreement with an appeal to the EU asking for a moratorium on the roll-out of 5G until research has been done on potential health risks, although the appeal concerned all 5G frequencies (https://www.5gappeal.eu). The appeal has currently been signed by more than 400 international scientists and/or medical doctors.

The claim that "the lower frequency bands for 5G (up to 3.5 GHz) have already been used for telecommunications applications and Wi-Fi for years without resulting in any proven adverse health effects" is incorrect.

Evidence from research on cells, animals and humans shows that the frequencies used so far for telecommunications are harmful for humans and the environment. For overviews see[1-3].

There is no substantial research on health effects from the frequencies in the range between 3 and 4 GHz intended to be used for 5G as noted by the French authority ANSES in an expert report published in January 2020.

The Health Council Committee in Netherlands has mainly based its review on a 2014 draft report from the WHO and the reports from the Swedish Radiation Safety Authority (SSM). Huss A and van Rongen E have been coauthors of the Swedish SSM reports, and van Rongen E was furthermore a member of the WHO draft report's core group of members, see Table 1.

The Committee recommends using the latest ICNIRP 2020 guidelines, which in turn relies on the 2014 draft report from the WHO, the reports from the SSM and the 2015 report from the Scientific Committee on Emerging and Newly Identified Health Risk (SCENIHR).

There seems to be an "ICNIRP cartel" of experts that dominate different expert evaluations, *e.g.,* ICNIRP, WHO, SSM, SCENIHR. This seems also to be the case in this Health Council report, see Table 1.

As a general rule, scientists who are of the opposing opinion, *i.e.*, that there are health risks associated with exposure to RF radiation, have never been invited to take part of these expert groups. Thus, the opinions expressed in these reports are not representative of the opinions in the scientific community on effects from EMFs (https://www.emfscientist.org).

It is pertinent to evaluate the current ICNIRP 2020 conclusions on cancer risks from RF radiation because the Health Council of the Netherlands recommends using the ICNIRP 2020 guidelines. The recommendation to "take a cautious approach and keep exposures as low as reasonably achievable" is certainly difficult to achieve on a market with expanding wireless communication and may be of no practical use. It is assumed that the ICNIRP 2020 guidelines will be used in most countries. Thus, the influence by ICNIRP and its members on reports that form the basis for guidelines by different organizations is necessary to elucidate.

The ICNIRP

In the following, the evaluation of increased cancer risks according to ICNIRP 2020 is discussed in more detail. It should be mentioned that ICNIRP relies only on thermal (heating) effects from RF radiation. Nonthermal effects are dismissed thereby neglecting a large amount of scientific evidence on harmful nonthermal effects, for instance DNA damage[4], oxidative stress[5] and cancer[2]. It should be noted that the International Agency for Research on Cancer (IARC) at the WHO evaluation from 2011 is not included in the report. IARC concluded that RF radiation in the frequency range

Table 1 Members of World Health Organization monograph core group and their involvement in other groups, see Hardell[16], 2017

Name	WHO	ICNIRP	UK/AGNIR	SSM	SCENIHR
Simon Mann	X	X	X		
Maria Feychting	X	X	X	X[1]	
Gunnhild Oftedal	X	X			
Eric van Rongen	X	X		X	
Maria Rosaria Scarfi	X	X[1]		X	X
Denis Zmirou	X				

[1]Former. X: Describes that the person is a member of a specific group. WHO: World Health Organization; ICNIRP: International Commission on Non-Ionizing Radiation Protection; AGNIR: Advisory Group on Non-Ionizing Radiation; SSM: Strålsäkerhetsmyndigheten (Swedish Radiation Safety Authority); SCENIHR: Scientific Committee on Emerging and Newly Identified Health Risk.

30 kHz to 300 GHz is a possible human carcinogen, Group 2B after an evaluation by 30 international experts[6,7].

ICNIRP is a non-governmental organization based in Germany. It has obtained major influence worldwide on health risks from RF radiation through its recommended guidelines for limiting RF radiation exposure published in 1998, 2009 and 2020[8-10].

ICNIRP maintains the same attitude towards health effects from RF radiation as the IEEE and its standards setting Committee, the ICES. In fact, several members of ICNIRP are also members of these organizations, for instance van Rongen E, member of ICES since 2000. ICES is dominated by industry and military representatives[11]. ICES within IEEE also sets limits for RF exposure, which are in line with the ICNIRP's opinion that there are only immediate thermal effects, and no effects below those that cause immediate effects due to increased temperature.

As stated in an EU report[12], ICNIRP's chairman, van Rongen E, was invited in 2016 to the industry organization ICES to comment and thereby influence the upcoming ICNIRP 2020 guidelines. The report concluded that it is "clear from ICES minutes that ICNIRP worked very closely with IEEE/ICES on the creation of the new RF safety guidelines that were published in March 2020. And this implies that large telecom-companies such as Motorola and others, as well as United States military, had a direct influence on the ICNIRP guidelines, which are still the basis for EU- policies in this domain."

This adds to the evidence that van Rongen E, one of two secretaries of this Health Council, seems to have conflicts of interest.

In 2020, ICNIRP published new guidelines on health risks[10]. These updated guidelines were based on documents from the WHO, the SSM and the SCENIHR, as mentioned earlier, without any new thorough evaluation of its own.

Not one of these three reviews has been published after peer review in a scientific journal. In fact, substantial critique from the scientific community has been expressed against these reviews but has been ignored[13,14]. It should be noted that the most recent research is not covered in these older documents.

WHO

A draft of a monograph on health effects of EMF exposure was released by the WHO in 2014 but has never been published as a final version[15]. Public consultations were open until December 31, 2014.

It should be noted that the WHO in 2014 issued the following statement: "This is a draft document for public consultation. Please do not quote or cite"[15]. Nevertheless, this WHO draft from 2014, issued by a group dominated by ICNIRP members, among them van Rongen E, was used as a basis for the ICNIRP guidelines 2020 and this new report by the Health Council of the Netherlands. Five of six members of the WHO core group were members of ICNIRP, see Table 1[16]. The WHO group was nearly identical to ICNIRP.

The SCENIHR

The following quote is from the SCENIHR report 2015[17]: "Overall, the epidemiological studies on mobile phone RF EMF exposure do not show an increased risk of brain tumors. Furthermore, they do not indicate an increased risk for other cancers of the head and neck region…The results of cohort and incidence time trend studies do not support an increased risk for glioma while the possibility of an association with acoustic neuroma remains open."

The SCENIHR report was criticized for its biased presentation and conclusions[13,14]. Like the WHO draft report and the Swedish reports by SSM, it was written by a group of experts with no representation from the many scientists that report increasing evidence of harmful effects below the ICNIRP guidelines and demand better protection against health risks (https://www.emfscientist.org). SCENIHR included scientists with financial ties to industry or membership in ICNIRP or IEEE.

The SSM

Between 2003 and 2019, the SSM group has published reports in English on its webpage, three cited by ICNIRP 2020[18-20]. In line with ICNIRP, the SSM reports have ignored harmful effects from nonthermal RF exposure. Since the first report in 2003 until today, around half of the group's members have also been present or previous ICNIRP members. Both van Rongen E and Huss A have been part of this group of SSM experts. In consequence, the conclusions have generally been that there are no health risks below the limits recommended by themselves, *i.e.* in agreement with ICNIRP.

The 2018 annual report was the twelfth in this series and covered studies published from October 2015 up to and including March 2017. The conclusion was that "No new health risks have been identified"[20].

It should be noted that SSM in April 2020 published a new report from the SSM expert group that concluded: "The results of the research review give no reason to change any reference levels (ICNIRP's) or recommendations in the field." Of the ten members in the scientific group, five were present or past members of ICNIRP[21].

Current ICNIRP evaluation

van Rongen E, at that time chair of the ICNIRP Commission, claimed in a press release of the new ICNIRP 2020 guidelines that the 1998 version was "conservative in most cases" and "still provide adequate protection for current technologies." He also argued that "The most important thing for people to remember is that 5G technologies will not be able to cause harm when these new guidelines are adhered to"[22]. Because there is still no published peer-reviewed research showing no health effects from the new 5G technology, not even from short-term exposure, that is a statement without scientific foundation.

Many incorrect statements were made in the ICNIRP 2020 article[10]. In the following, the section on cancer is commented. That section starts at page 41 in the ICNIRP 2020 article with "There is a large body of literature concerning cellular and molecular processes that are of particular relevance to cancer. This includes studies of cell proliferation, differentiation and apoptosis-related processes, proto-oncogene expression, genotoxicity, increased oxidative stress, and DNA strand breaks. Although there are reports of effects of radiofrequency EMFs on a number of these endpoints, there is no substantiated evidence of health-relevant effects."

Regarding studies on cancer risks, no current evaluation is made. Several studies are not included, or references are not even given to the discussed studies. This is not easily understood by the reader that is not experienced in this area.

Regarding animal studies yielding a tumor promoting effect from RF radiation[23,24], ICNIRP states that "interpretation of these results and their applicability to human health (is) difficult, and, therefore, there is a need for further research to better understand these results." In the next paragraph, the recent animal National Toxicology Program (NTP) studies[25,26] and Ramazzini Institute results[27] on animal carcinogenesis from RF radiation are disregarded stating that "no consistency was seen across these two studies" and "within the context of other animal and human carcinogenicity research (HCN 2014, 2016), their findings do not provide evidence that radiofrequency EMFs are carcinogenic."

That is a remarkable statement with no risk by ICNIRP and is not based on what the science really showed. There is a pattern of increased cancer risk based on human epidemiology, animal research and experimental findings. The Hardell team concluded that "There is clear evidence that RF radiation causes cancer/tumor at multiple sites, primarily in the brain (glioma) and head (acoustic neuroma). There is also evidence of an increased risk of developing other tumor types. The results are similar in both the NTP studies and the Ramazzini Institute findings (Falcioni *et al* [27]). Based on the IARC preamble to the monographs, RF radiation should be classified as Group 1: The agent is carcinogenic to humans"[28].

In a note published by ICNIRP, it was claimed that the histopathological evaluation in the NTP study was not blinded as to exposure status[29]. This false accusation was rebutted by one of those responsible for the NTP study[30]. However, the rebuttal seems to have had no impact on the current ICNIRP evaluation[10].

Regarding the 13 country Interphone case-control study on glioma[31] and acoustic neuroma[32], ICNIRP concluded that the studies do "not provide evidence of an increased risk," which is not correct. However, regarding glioma cumulative call-time of mobile phone ≥ 1640 h yielded odds ratio (OR) = 1.40, 95% confidence interval (CI) = 1.03-1.89. The risk increased over time for exposure and was highest in the most exposed parts of the brain. These findings were of biological relevance.

RF radiation dose was estimated in parts of Interphone as total cumulative specific energy (J/kg) absorbed at the tumor's estimated center taking into account multiple RF exposure determinants[33]. The risk increased with increasing total cumulative specific energy 7+ years before diagnosis, OR = 1.91, 95%CI = 1.05-3.47 (*P* value = 0.01) in the highest quintile. Compared with glioma in other parts of the brain increased, ORs were found for tumors in the most exposed part of the brain in those with 10+ years of mobile phone use, OR = 2.80, 95%CI = 1.13-6.94.

Grell *et al*[34] published similar results for the Interphone study. "We found a statistically significant association between the intracranial distribution of gliomas and the self-reported location of the phone…Taken together, our results suggest that ever using a mobile phone regularly is associated with glioma localization in the sense that more gliomas occurred closer to the ear on the side of the head where the mobile phone was reported to have been used the most."

For glioma, when comparing those in the highest quartile of use (> 558 lifetime hours) to those who were not regular users, the OR was 2.0, 95%CI = 1.2-3.4 in the Canadian part of Interphone[35]. After adjustment for selection and recall biases, a somewhat higher OR was found, 2.2, 95%CI = 1.3-4.1.

The Interphone study gave for acoustic neuroma statistically significant increased risk. Thus, ipsilateral cumulative mobile phone use > 1640 h gave OR = 2.33, 95%CI = 1.23-4.40[32].

Regarding the Hardell team studies, ICNIRP writes: "a set of case-control studies from the Hardell group in Sweden report significantly increased risks of both acoustic neuroma and malignant brain tumors already after less than five years since the start of mobile phone use, and at quite low levels of cumulative call time." The studies are not carefully evaluated by ICNIRP and no references are given. On the contrary, overall there was no statistically increased risk in the shortest latency period > 1-5 years for glioma or acoustic neuroma[36,37]. Somewhat higher risk was seen for ipsilateral exposure; a promotor effect cannot be excluded in addition to initiation of cancer[36]. Also in the Hardell team studies the risk increased with latency and cumulative use and was highest in the most exposed areas of the brain that would be expected for carcinogenesis. Concepts of both promotion, initiation and biological relevance for RF radiation carcinogenesis must be considered when discussing results in different studies. That is obviously not the case for ICNIRP.

In addition, ICNIRP claims that the Hardell team results may be caused by recall bias. For meningioma, no statistically significant increased risk was found in the same study. Using meningioma cases as "controls" (the comparison entity) still yielded statistically significant increased risk for glioma and mobile phone use[36]. Similar results were found for acoustic neuroma using meningioma cases as the comparison group[37]. These results clearly show that the increased risks for glioma and acoustic neuroma were not caused by recall bias, *i.e.* cases tending to overestimate exposure. That would have applied to all cases regardless of tumor type.

ICNIRP omitted the CERENAT study by Coureau *et al*[38]. The study strengthened the evidence of increased risk for glioma associated with mobile phone use. Life-long cumulative duration ≥ 896 h gave OR = 2.89, 95%CI = 1.41-5.93 for glioma. Number of calls ≥ 18360 gave OR = 2.10, 95%CI = 1.03-4.31. Higher risks were obtained for the highest exposed area, the temporal brain lobe, as well as occupational and urban mobile phone use.

In spite of serious methodological limitations, the Danish cohort study on mobile phone use was included, adding to the ICNIRP no-risk conclusion. This study, partly funded by Danish telecom operators, first published in 2001[39] and updated in 2011 [40], reported no increased risks of tumors in the central nervous system. It was based on 420095 mobile phone private subscribers. This group's incidence of brain tumors was compared to the incidence within the rest of the Danish population (control group). However, there are several methodological limits in the study such as inclusion only of mobile phone private subscribers in Denmark between 1982 and 1995 in the exposure group. The most exposed group, corporate users, and subscription in

1996 or later were excluded. Use of cordless/DECT phones was disregarded although shown to be a risk factor for brain and head tumors[36,37].

The study has been called "The most severely biased study among all studies published so far"[41]. Certainly, there were severe methodological flaws. The Danish cohort study was regarded by IARC in the 2011 evaluation[7] to be uninformative regarding cancer risks due to serious exposure misclassification. However, it was included by SCENIHR[17], WHO[15], SSM (2013)[42], and ICNIRP[10] as evidence of no risk. The statement by SSM 2013[42] that "The Danish cohort studies make an important contribution to the total assessment in the field" is not correct. The shortcomings in the study should have been known to the SSM expert panel as discussed in a peer-reviewed article[43] concluding that "After reviewing the four publications on the Danish cohort study, one might rightly wonder whether this cohort was initially set up to show no increased risk."

The ICNIRP 2020[10] reference levels for RF radiation are based on time averaged exposure over 6 min or 30 min. However, pulses from different RF radiation sources may give much higher peak radiation from short time pulses than the power density average. Using time averaging in reference values may thus underestimate the risk. In addition, ICNIRP 2020 suggests higher guidelines for local exposure. According to the article, the reference level, *e.g.*, > 2 to 6 GHz local exposure, is suggested to increase to 40 W/m^2 time averaged over 6 min. This is contrary to the increasing scientific evidence on detrimental effects on human health and the environment from RF radiation. Previously 10 W/m^2 was used as reference level time averaged 6 min exposure[8,9]. Now the reference level for whole body exposure, time averaged 30 min, is suggested to be 10 W/m^2.

The evidence for cancer

Several meta-analyses have during the last years reached the conclusions that all together the available evidence shows increased risk of cancer from mobile phone use [2]. One additional method is to use Sir Bradford Hill's viewpoints from 1965 on association or causation written at the height of the tobacco and lung cancer controversy[44]. In an article published in 2017, these viewpoints were used to evaluate RF radiation carcinogenesis based on epidemiology and laboratory studies [45]. It was concluded that based on these Hill "criteria" RF radiation should be regarded as a human carcinogen causing glioma. Since then the evidence has strengthened.

As discussed above, studies have shown an association between glioma and acoustic neuroma and mobile phone use especially in: (1) people with longest latency (time from first use until tumor diagnosis); (2) people with highest cumulative use of mobile phones; (3) people who had used mobile phones on the same side of the head as that on which their tumor developed; and (4) in people whose tumor was in the temporal lobe of the brain, *i.e.* the highest exposed lobe during use of the handheld wireless phone.

In addition, the Hardell team studies from Sweden found similar results for use of cordless phones. Thus, based on these findings that are of biological relevance and supported by the Hill viewpoints, a causal interpretation is possible. Thus, RF radiation should be classified as a human carcinogen, Group 1 according to the IARC criteria[45,46]. However, only IARC can make that classification.

DISCUSSION

In order to achieve sustainable development, policies must be based on the precautionary principle. No doubt there are threats of serious or irreversible damage by exposure to RF radiation, not the least the increased risk for glioblastoma with short survival for those affected[47]. Lack of full scientific certainty, as proposed by certain public health organizations, should not be used as a reason for postponing measures to prevent environmental degradation. Thus, a moratorium on the deployment of 5G and considerable reduction of RF radiation from existing systems is urgently needed. In short, "The precautionary principle provides justification for public policy actions in situations of scientific complexity, uncertainty and ignorance, where there may be a need to act in order to avoid, or reduce, potentially serious or irreversible threats to health or the environment, using appropriate strengths of scientific evidence, and taking into account the likely pros and cons of proportionate actions and inactions" [48].

In contrast to that as a general rule, ICNIRP, WHO, SSM, and SCENIHR have for many years dismissed available studies showing harmful effects from nonthermal RF radiation exposure and have based their conclusions mainly on studies showing no effects. Thereby results showing health hazards are criticized or not even cited in contrast to studies showing no risks that are accepted as evidence of no risk in spite of severe methodological problems. Many of the statements by these agencies are misleading and not correct. They are easily rebutted by reading the relevant publications. In fact, an Italian court ruling linked mobile phone use to tumors already in 2012. Also, later court rulings in Italy have come to the same conclusion.

These ICNIRP cartel dominated expert groups consequently reach similar conclusions that there are no health effects below ICNIRP guidelines. Scientists with opinions that there is increasing evidence of health risks below the ICNIRP guidelines, *e.g.,* as expressed in the EMF Scientists Appeal, are not invited to expert groups at the WHO, the EU (SCENIHR), the SSM, or ICNIRP. Table 1 clearly illustrates that few persons constitute different groups aimed at preventing hazards and risks to the health and the environment. The ICNIRP view is thereby influencing these expert reports, which also formed the basis for this Health Council report in the Netherlands.

There is growing scientific evidence on health risks from the RF radiation emitted by existing telecommunications systems prior to 5G. In addition, 5G will lead to an increase of radiation, including new techniques, which leads to the conclusion that hazardous exposure will increase. However, it is unacceptable that there is scanty research being performed on the risks or hazards from the new 5G technology and the new frequencies that will be used. This means an experiment on human health and the environment that should not be accepted. Thus informed consent would be needed from each involuntary exposed person. The exposure guidelines in ICNIRP 2020[10] constitute a hazard to public health and the environment because evidence is abundant on harmful effects including DNA damage, oxidative stress, and cancer.

The Health Council Committee argues that "epidemiological research into the relation between exposure to the 5G frequencies used and the incidence of cancer, reduced male fertility, poor pregnancy outcomes and birth defects" should be performed after the roll-out of the 5G and its increase in radiation. However, the same Committee in the same report claims that "The committee has however classified relations as "possible" for cancer, male fertility, pregnancy outcomes and birth defects."

Further the Committee states that "The conclusions from those earlier reports are also relevant for 5G as far as the frequency bands around 700, 1400, 1800 and 2100 MHz are concerned. The committee sees no reason to limit or stop the use of the lower frequency bands for 5G. Frequencies near 700 MHz and 3.5 GHz have been in use for current telecommunication systems or other applications such as Wi-Fi for years, without any demonstrable health damage as a result."

Thus, this report states that 5G at the lower frequencies has no "demonstrable health damage, although relations (are), "possible" for cancer, male fertility, pregnancy outcomes and birth defects".

The least to say is that the Committee is not transparent regarding health risks; they are "possible" but for the roll-out of 5G they are not "demonstrable." Research on health hazards must be done before exposure, not after, something that is suggested for the higher frequencies. "The committee recommends not to use the 26 GHz frequency band for 5G for as long as the potential health risks have not been investigated."

For implementation of 5G, regardless of frequency, ethics in medicine should be applied. In medicine the patient must be informed about the risks but also benefits in experimental studies and give written consent for the participation. That should also apply to the deployment of 5G. However, it has not been done so far. The participation is forced upon everybody, which is of course unacceptable from a human rights perspective.

CONCLUSION

In conclusion regarding cancer, current scientific evidence clearly demonstrates an increased risk for glioma and acoustic neuroma for use of mobile and/or cordless phones. In this review other tumor types and health endpoints are not discussed. The increased risk for brain and head tumors is based on human cancer epidemiology studies and is supported by similar tumor types found in animal studies. In fact, these animal studies confirmed the earlier results in case-control studies on increased tumor risk for use of wireless phones (both mobile and cordless phones). Mechanistic aspects on carcinogenesis come from laboratory findings on, *e.g.*, the increase of reactive oxygen species[5] and DNA damage[4].

The current evaluation by the Health Council of the Netherlands is based on a WHO draft and SSM report. It also recommends using ICNIRP guidelines, considered to be insufficient to protect against health hazards, such as cancer, by the majority of the scientists in this field (https://www.emfscientist.org). The report does not represent a thorough, balanced, objective, and up-to-date evaluation of cancer risks and other hazardous effects from RF radiation. It is also strikingly contradictory as it concludes that serious health effects such as cancer and birth defects are "possible." Yet it has no objection to the roll-out of 5G and recommends that later studies are performed to study health outcomes such as cancer and birth defects. Thus, no lessons are learned from existing observations on increased cancer risks[49].

The conclusion by the Commission that there is no reason to stop the use of lower frequencies for 5G up to 3.5 GHz because of no "proven adverse health effects," merely reflects the biased conclusions by ICNIRP dominated groups. Thus that conclusion must be dismissed, and new guidelines for previous and new frequencies must be established considering the new technology, the different propagation pattern for 5G, and increased RF radiation.

A moratorium is urgently required on the implementation of 5G for wireless communication[13]. Ultimately, wired solutions are preferred.

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COMMENT

Appeals that matter or not on a moratorium on the deployment of the fifth generation, 5G, for microwave radiation

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Abstract. Radiofrequency (RF) radiation in the frequency range of 30 kHz-300 GHz is classified as a 'possible' human carcinogen, Group 2B, by the International Agency for Research on Cancer (IARC) since 2011. The evidence has since then been strengthened by further research; thus, RF radiation may now be classified as a human carcinogen, Group 1. In spite of this, microwave radiations are expanding with increasing personal and ambient exposure. One contributing factor is that the majority of countries rely on guidelines formulated by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), a private German non-governmental organization. ICNIRP relies on the evaluation only of thermal (heating) effects from RF radiation, thereby excluding a large body of published science demonstrating the detrimental effects caused by non-thermal radiation. The fifth generation, 5G, for microwave radiation is about to be implemented worldwide in spite of no comprehensive investigations of the potential risks to human health and the environment. In an appeal sent to the EU in September, 2017 currently >260 scientists and medical doctors requested for a moratorium on the deployment of 5G until the health risks associated with this new technology have been fully investigated by industry-independent scientists. The appeal and four rebuttals to the EU over a period of >2 years, have not achieved any positive response from the EU to date. Unfortunately, decision makers seem to be uninformed or even misinformed about the risks. EU officials rely on the opinions of individuals within the ICNIRP and the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), most of whom have ties to the industry. They seem to dominate evaluating bodies and refute risks. It is important that these circumstances are described. In this article, the warnings on the health risks associated with RF presented in the 5G appeal and the letters to the EU Health Commissioner since September, 2017 and the authors' rebuttals are summarized. The responses from the EU seem to have thus far prioritized industry profits to the detriment of human health and the environment.

Introduction

Over the years, numerous international appeals on radiofrequency (RF) radiation and health and the environment have been published (e.g., www.emfscientist.org). These seem to have had little or no impact on those proposing limits on RF radiation and on the deployment of this technology. On the contrary, ambient RF radiation exposure has increased and is a potential health risk based on the current knowledge of the biological effects of RF radiation (1-8). There seems to be an 'unholy' alliance between the telecom industry and certain scientists, organizations (even WHO), and some politicians, thus reducing the potential for precautionary actions (9,10).

The International Agency for Research on Cancer (IARC) of WHO in 2011 classified RF radiation in the frequency range of 30 kHz-300 GHz as a 'possible' human carcinogen, Group 2B (11,12). Since then, the evidence of the adverse effects of RF radiation has strengthened based on human epidemiological (7,8,13) and animal studies (14-16). These results add scientific evidence to a previous evaluation (17). Thus, RF radiation may now be classified as a human carcinogen, Group 1. That is the strongest classification, which is the same as that for e.g., asbestos and smoking.

The IARC cancer classification seems to have had little or no impact on protecting the public against risks associated with RF exposure. A major hampering factor has been the exposure guidelines by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) based only on the acute and very short-term thermal (heating) effects of RF radiation. These guidelines are used by the majority of countries worldwide. These guidelines were initially published approximately 20 years ago (18) and were updated in 2009 (19); however, no changes were made to adapt to the

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rapidly increasing evidence of the harmful effects of RF and new RF signal characteristics and exposure from new technologies. ICNIRP, with the support of the WHO (10) and the major telecom companies, has made considerable efforts to convince countries worldwide to follow their guidelines. However, with the deployment of the 5th generation of microwave radiation, 5G, even the obsolete ICNIRP guidelines may be exceeded and may become an obstacle for the deployment of 5G (20). Thus, ICNIRP is preparing new guidelines that are briefly commented on below. However, as already published (9,10), the ICNIRP guidelines may be contradictory to a vast number of existing scientific reports demonstrating the harmful effects of RF radiation (21). Furthermore, there may perhaps also be conflicts of interests in terms of ties to the industry.

ICNIRP

On July 11, 2018, the ICNIRP released a draft of the guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (100 kHz-300 GHz). It was open for public consultations until October 9, 2018. Appendix B was based on the assessment of the health risks based on a literature survey (https://www.icnirp.org/en/activities/public-consultation/index.html).

Of note, in the background material to the new ICNIRP guidelines, the IARC classification from 2011 of RF exposure as class 2B, 'possibly' carcinogenic to humans (11,12) was not included. Notably, one of the ICNIRP commission members, Martin Röösli (https://www.icnirp.org/en/about-icnirp/commission/index.html), was also one of the IARC experts evaluating the scientific RF carcinogenicity in May, 2011 (https://monographs.iarc.fr/wp-content/uploads/2018/06/mono102-F05.pdf), which classified RF exposure as a class 2B 'possible' carcinogen. Thus, he should be aware of the IARC classification. Of note, one of the authors of this article (L.H.) was a member of the IARC expert group.

Below, eight excerpts/quotes from the 2018 ICNIRP draft guidelines are presented (https://www.icnirp.org/cms/upload/consultation_upload/ICNIRP_RF_Guidelines_PCD_2018_07_11.pdf). These assertions in the ICNIRP evaluation do not seem to represent the valid evaluation of the published literature on the health risks associated with RF:

i) ***Brain physiology and function.*** *'In summary, there is no evidence of effects of radiofrequency EMF [electromagnetic field] on physiological processes or eye pathology that impair health in humans. Some evidence of superficial eye damage has been shown in rabbits at exposures of at least 1.4 kW m-2, although the relevance of this to humans has not been demonstrated'.*

ii) ***Auditory, vestibular, and ocular function.*** *'In summary, no effects on auditory, vestibular, or ocular function relevant to human health have been substantiated'.*

iii) ***Neuroendocrine system.*** *'In summary, the lowest level at which an effect of radiofrequency EMF on the neuroendocrine system has been observed is 4 W kg-1 (in rodents and primates), but there is no evidence that this translates to humans or is relevant to human health. No other effects have been substantiated'.*

iv) ***Neurodegenerative diseases.*** *'In summary, no adverse effects on neurodegenerative diseases have been substantiated'.*

v) ***Cardiovascular system, autonomic nervous system and thermoregulation.*** *'In summary, no effects on the cardiovascular system, autonomic nervous system, or thermoregulation that compromise health have been substantiated for exposures with whole body average SARs below approximately 1 W kg-1, and there is some evidence that 4 W kg-1 is not sufficient to alter body core temperature in hamsters. However, there is strong evidence that whole body exposures in rats that are sufficient to increase body core temperature by several degrees centigrade can cause serious adverse health effects in rats'.*

vi) ***Immune system and hematology.*** *'The few human studies have not indicated any evidence that radiofrequency EMF affects health in humans via the immune system or haematology'.*

vii) ***Fertility, reproduction and childhood development.*** *'In summary, no adverse effects of radiofrequency EMF exposure on fertility, reproduction or development relevant to human health have been substantiated'.*

viii) ***Cancer.*** *'In summary, no effects of radiofrequency EMF on cancer have been substantiated'.*

Since the ICNIRP 2018 draft guidelines excluded a large number of science-based evidence of health hazards from RF radiation, numerous rebuttals have been sent to the ICNIRP. However, it remains unknown as to whether these rebuttals have been taken into account or not.

Thus, the ICNIRP does not acknowledge the health effects caused by RF radiation. This has been rebutted by several scientists (21-24).

Details and proofs of scientific misinterpretation were outlined in a comprehensive response by Dr Martin Pall (21). He demonstrated that the denials of scientific facts concerning health risks seem to be the rule in the Health Risk Assessments of the ICNIRP 2018 Draft Guidelines. ICNIRP confirmed that Pall's response was received on October 8, 2018 (tinyurl.se/pall). As outlined above in all eight summarizing statements, the ICNIRP denies that any scientific reports exist which demonstrate harmful effects below the ICNIRP guidelines. However, as Dr Pall demonstrated, a large number of peer-reviewed studies have been published over a period of >20 years contradicting the ICNIRP evaluations. Independent peer-reviewed scientific articles (1,7,8) have demonstrated the harmful effects even far below the current public safety limits based on ICNIRP 1998 reference levels 10 W/m^2 for 2-300 GHz and 2-10 W/m^2 for 400 to 2,000 MHz (18).

The ICNIRP also seems to have disregarded previously published animal studies (14-16) on carcinogenesis. The NTP results have been discussed in a commentary (25) and clarified to that degree that they should have been considered in full. These findings supported human epidemiology results on cancer risks from RF radiation (6,26). The final new ICNIRP guidelines have yet to be published.

In fact, a hint of the ICNIRP final document may be found in a presentation by the ICNIRP chairman Eric van Rongen at a meeting held on April 17, 2019 https://www.anfr.fr/fileadmin/mediatheque/documents/expace/workshop-5G/20190417-Workshop-ANFR-ICNIRP-presentation.pdf.

van Rongen stated that there is no evidence that RF EMF causes diseases, such as cancer and that the US NTP (14-15) and Ramazzini Institute (16) studies are not convincing for carcinogenesis. ICNIRP seems still to hold the view, which is clearly beneficial to the industry, that only thermal effects exist for RF radiation and not any non-thermal effects, which have been proven in research by the majority of scientists in this field.

ICNIRP recently published a note on the NTP and Ramazzini Institute animal studies (27). Some of their incorrect statements are commented on below. The ICNIRP claims that there is no verified mechanism for RF radiation carcinogenesis, in spite of well-designed studies showing the contrary, e.g., oxidative stress (25,28) and DNA damage (25,29). The ICNIRP claims that the histopathological evaluation was not blinded in these studies; however, this is not true, as supported by the methods described in these studies. Furthermore, the ICNIRP claims that the body core temperature was increased in the NTP study (15) and suggested it to be a factor increasing cancer risk, although heat is not a known carcinogen. The ICNIRP also claims that only the Hardell group found an increased risk for acoustic neuroma although the Interphone study had similar findings (7). ICNIRP does not seem to take into account the concordance between the tumor types found in human epidemiological and animal studies. These are just a few examples.

It is noteworthy that ICNIRP repeats certain debatable statements in spite of being rebutted by Melnick (25) and should have been known to the 13 ICNIRP Commission members (https://www.icnirp.org/en/about-icnirp/commission/index.html) with their names listed at the end of the article (27). Perhaps this ICNIRP article lacks scientific authorization. As previously suggested, they seem to create doubt (30,31). Thus, one must be cautious when also interpreting other publications by the 13 Commission members.

The ICNIRP points out an important scientific problem: How incorrect data can achieve lives of their own and gain respectability and credence with inappropriate repetition. Corrections and clarifications (25), seem to have difficult time to counteract any possible errors, which is to the disadvantage of both good science and public health. Of note, President Franklin D. Roosevelt stated that *'Repetition does not transform a lie into a truth'* (https://www.azquotes.com/quote/377323).

Finland, in a new regulation, 1045/2018, dated December 15, 2018, allowed higher average radiation, 200 W, in narrow areas of 1x1 cm (1 cm^2) (please see Table 1.5, Note 3 (in Swedish): (https://www.finlex.fi/data/sdliite/liite/6943.pdf). This was probably decided in order to accommodate the steerable, beam-formed, narrow 5G fields, which will be used by most 5G equipment. The Director of the Radiation Safety Agency in Finland claims that this is no problem, as if you disperse the effect of 200 W (on 1 cm^2) upon a whole square meter it will still be within the ICNIRP guideline of 10 W/m^2 (private communication from Petteri Tiippana, 2018, please see https://www.dropbox.com/s/89cm7bmb410em8w/200W%3Am2-STUK.pdf?dl=0).

On top of the other flaws which ICNIRP members are presenting, they also suggest that only the 'mean values' of RF radiation should be measured. However, the interferences and the supra-additive effects between pulses from different RF radiation sources can lead to 'hundreds of thousands higher density' short-time pulses than the power density mean values with the guideline of 10 W/m^2. This has been well-documented in a report from the Finnish Radiation Safety Agency (32). Panagopoulos (29) has clearly demonstrated that using mean values for RF radiation may underestimate the risk. Intensity, frequency, exposure duration, polarization, pulsing and modulation are crucial parameters for the bioactivity. Puranen (32) states that the instant effect density can be much stronger than the mean values. However, the guidelines only consider the mean values.

Appeals to the EU and responses from the EU

The impact of the many international appeals on RF radiation safety, if any, is unclear. However, they will be historical documents on warnings that have been thus far ignored by the EU and the WHO. This is exemplified below.

The deployment of 5G for microwave radiation has given increasing awareness and concern among individuals regarding the risks to human health and the environment resulting in massive protests and even a moratorium in certain EU countries and US cities (https://tinyurl.se/5gstoppers). 5G uses a different technology compared with previous generations, such as 2G, 3G and 4G. In the following, our 5G appeal to EU is discussed (www.5Gappeal.eu). This has currently been signed by >260 scientists and medical doctors from a number of countries. It is still open for endorsement.

a) The 5G Appeal, September 13, 2017 and response. Below, the full text, with included links to references, is presented although it can also be found online (www.5gappeal.eu), and also at (https://www.environmentandcancer.com/5g-appeal/).

Scientists and doctors warn of potential severe health effects of 5G. *'We the undersigned scientists and doctors recommend a moratorium on the roll-out of the fifth generation, 5G, for telecommunication until potential hazards for human health and the environment have been fully investigated by scientists independent from industry. 5G will substantially increase exposure to radiofrequency electromagnetic fields (RF-EMF)* *on top of the 2G, 3G, 4G, Wi-Fi, etc. for telecommunications already in place. RF-EMF has been proven to be harmful for humans and the environment'.*

5G leads to the marked increase of mandatory exposure to wireless radiation. *'5G technology is effective only over short distance. [The range of 5G radiation is decreased due to its increased carrier frequency (up to ~100 GHz) compared to previous mobile telephony generations and other existing microwave telecommunications radiations such as Wi-Fi (up to 2.6 GHz), and according to Rayleigh's law which explains that the intensity of scattered electromagnetic radiation (Jscat) is proportional to f 4 (where f is the frequency of the radiation) when the dimensions of the scattering particles - such as the molecules of the air, of the building materials, etc. - are smaller than the wavelength (which is the case for all mobile telephony radiations): Jscat ∝ f 4 (33)]. It is poorly transmitted through solid material. Many new [base] antennas will be required and full-scale implementation will result in antennas every 10 to 12 houses in urban areas,* ***thus massively increasing mandatory exposure****'.*

'[Moreover, apart from the increase in background exposure, 5G is likely to induce significant thermal effects in addition to the already non-thermal ones, again due to its significantly higher frequency (34)]'.

'With "the ever more extensive use of wireless technologies," (35) nobody can avoid to be exposed. Because on top of the increased number of 5G-transmitters (even within housing, shops and in hospitals) according to estimates, "10 to 20 billion connections" (36) (to refrigerators, washing machines, surveillance cameras, self-driving cars and buses, etc.) will be parts of the Internet of Things. All these together can cause a substantial increase in the total, long term RF-EMF exposure to all EU citizens'.

Harmful effects of RF-EMF exposure have already been proven. *'Over 230 scientists from >40 countries [now 252 scientists from 43 nations] (37) have expressed their "serious concerns" regarding the ubiquitous and increasing exposure to EMF generated by electric and wireless devices already before the additional 5G roll-out. They refer to the fact that "numerous recent scientific publications have shown that EMFs affect living organisms at levels well below most international and national guidelines". Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects (38) to both plants (39) and animals (40)'.*

'After the scientists' appeal was written in 2015 additional research has convincingly confirmed serious health risks from RF-EMF fields from wireless technology. The world's largest study (25 million US dollar) National Toxicology Program (NTP) (41), shows statistically significant increase in the incidence of brain and heart cancer in animals exposed to EMF [intensities] below the ICNIRP (International Commission on Non-Ionizing Radiation Protection) guidelines followed by most countries. These results support results in human epidemiological studies (17) on RF radiation and brain tumour risk. A large number of peer-reviewed scientific reports (2) demonstrate harm to human health from EMFs'.

'The International Agency for Research on Cancer (IARC), the cancer agency of the World Health Organization (WHO), in 2011 concluded that EMFs of frequencies 30 KHz - 300 GHz are possibly carcinogenic to humans (Group 2B) (12,42). However, new studies like the NTP study mentioned above and several epidemiological investigations including the latest studies on mobile phone use and brain cancer risks confirm that RF-EMF radiation is carcinogenic to humans (17)'.

'The EUROPA EM-EMF Guideline 2016 (1) states that "there is strong evidence that long-term exposure to certain EMFs is a risk factor for diseases such as certain cancers, Alzheimer's disease, and male infertility…Common EHS (electromagnetic hypersensitivity) symptoms include headaches, concentration difficulties, sleep problems, depression, lack of energy, fatigue, and flu-like symptoms"'.

'An increasing part of the European population is affected by ill health symptoms that have for many years been linked to exposure to EMF and wireless radiation in the scientific literature. The International Scientific Declaration on EHS & multiple chemical sensitivity (MCS), Brussels (43), declares that: "In view of our present scientific knowledge, we thereby stress all national and international bodies and institutions… to recognize EHS and MCS as true medical conditions which acting as sentinel diseases may create a major public health concern in years to come worldwide i.e. in all the countries implementing unrestricted use of electromagnetic field-based wireless technologies and marketed chemical substances… ***Inaction is a cost to society*** *and is not an option anymore… we unanimously acknowledge this serious hazard to public health…that major primary prevention measures are adopted and prioritized, to face this* ***worldwide pan-epidemic*** *in perspective"'.*

Precautions. *'The Precautionary Principle (44) was adopted by EU 2005 (45): "When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm"'.*

'The Council of Europe Resolution 1815 (46): "Take all reasonable measures to reduce exposure to electromagnetic fields, especially to radio frequencies from mobile phones, and particularly the exposure to children and young people who seem to be most at risk from head tumours…Assembly strongly recommends that the ALARA (as low as reasonably achievable) principle is applied, covering both the so-called thermal effects and the athermic [non-thermal] or biological effects of electromagnetic emissions or radiation" and to "improve risk-assessment standards and quality"'.

'The Nuremberg code (47) applies to all experiments on humans, thus including the roll-out of 5G with new, higher

RF-EMF exposure. All such experiments: "should be based on previous knowledge (e.g., an expectation derived from animal experiments) that justifies the experiment. No experiment should be conducted, where there is an a priori reason to believe that death or disabling injury will occur; except, perhaps, in those experiments where the experimental physicians also serve as subjects," Nuremberg code pts 3-5 (47). Already published scientific studies show that there is "a priori reason to believe" in real health hazards'.

'The European Environment Agency (48) is warning for "Radiation risk from everyday devices" in spite of the radiation being below the WHO/ICNIRP standards (49). EEA also concludes: "There are many examples of the failure to use the precautionary principle in the past, which have resulted in serious and often irreversible damage to health and environments…harmful exposures can be widespread before there is both 'convincing' evidence of harm from long-term exposures, and biological understanding [mechanism] (50) of how that harm is caused"'.

'Safety guidelines' protect the industry, not health. *'The current ICNIRP "safety guidelines" are obsolete. All proofs of harm mentioned above arise although the radiation is below the ICNIRP "safety guidelines" (49). Therefore new safety standards are necessary. The reason for the misleading guidelines is that "conflict of interest of ICNIRP members (10) due to their relationships with telecommunications or electric companies undermine the impartiality that should govern the regulation of Public Exposure Standards for non-ionizing radiation…To evaluate cancer risks it is necessary to include scientists with competence in medicine, especially oncology'.*

'The current ICNIRP/WHO guidelines for EMF are based on the obsolete hypothesis that "The critical effect of RF-EMF exposure relevant to human health and safety is heating of exposed tissue" (51). However, scientists have proven that many different kinds of illnesses and harms are caused without heating ("non-thermal effect") (52) at radiation levels well below ICNIRP guidelines'.

The authors thus urge the EU to carry out the following. *i) 'To take all reasonable measures to halt the 5G RF-EMF expansion until independent scientists can assure that 5G and the total radiation levels caused by RF-EMF (5G together with 2G, 3G, 4G, and WiFi) will not be harmful for EU-citizens, especially infants, children and pregnant women, as well as the environment'. ii) 'To recommend that all EU countries, especially their radiation safety agencies, follow Resolution 1815 and inform citizens, including, teachers and physicians, about health risks from RF-EMF radiation, how and why to avoid microwave radiation, particularly in/near e.g., daycare centers, schools, homes, workplaces, hospitals and elderly care'. iii) 'To appoint immediately, without industry influence, an EU task force of independent, truly impartial EMF-and-health scientists with no conflicts of interest (to re-evaluate the health risks and: a) To decide about new, safe "maximum total exposure standards" for all microwave radiation within EU. b) To study the total and cumulative exposure affecting EU-citizens. c) To create rules that will be prescribed/enforced within the EU about how to avoid exposure exceeding new EU "maximum total exposure standards" concerning all kinds of EMFs in order to protect citizens, especially infants, children and pregnant women'. iv) 'To prevent the wireless/telecom industry through its lobbying organizations from persuading EU-officials to make decisions about further propagation of RF radiation including 5G in Europe'. v) 'To favor and implement wired digital telecommunication instead of wireless'.*

First reply from the EU. A reply from the EU was sent on October 13, 2017 by the Directorate-General Health and Food Safety (Public health, country knowledge, crisis management) in Luxembourg. It was not replied to by the Commissioner Andriukaitis, but instead by Mr. John F. Ryan, Director (for the full text please see: http://www.5gappeal.eu/wp-content/uploads/2018/06/reply_ryan.pdf). Some paragraphs are presented below:

'It is worth underlining that for the Commission health protection is always taken into account in all of its proposals. There is consistent evidence presented by national and international bodies (International Commission on Non Ionising Radiation Protection - ICNIRP, Scientific Committee on Emerging and Newly Identified Health Risks - SCENIHR) that exposure to electromagnetic fields does not represent a health risk, if it remains below the limits set by Council Recommendation 1999/519/EC (https://ec.europa.eu/health//sites/health/files/electromagnetic_fields/docs/emf_rec519_en.pdf)'.

'The Scientific Committee on Emerging and Newly Identified Health Risks, which is independent of the Commission, has a standing mandate to provide this update'.

'It has already produced five opinions. The last opinion was adopted in January 2015 on "Potential health effects of exposure to electromagnetic fields". (https://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_041.pdf)'.

'These scientific opinions have not provided any scientific justification for revising the exposure limits (basic restrictions and reference levels) under Council Recommendation 1999/519/EC'.

'Digital technologies and mobile communication technologies, including high speed internet, will be the backbone of Europe's future economy, allowing all citizens to be connected. At the same time, all citizens deserve appropriate protection against electromagnetic fields from all types of sources including from wireless devices'.

'Most 5G networks are expected to use smaller cells than previous generations with lower electromagnetic fields exposure levels. This is confirmed by the experience so far gained. The introduction of 3G and 4G has not increased exposure from environmental fields and this has been published also in peer-reviewed journals. In particular, the introduction of 3G has lowered exposure of mobile phone users for calls, compared to 2G'.

'Related to the issue of the alleged conflicts of interests, the Commission is not aware of any conflicts of interests of members of international bodies such as ICNIRP or the members of SCENIHR. Please be informed that the Ombudsman conclusion in case 208/2015/P concerning conflicts of interests in a Commission expert group on electromagnetic fields is that there was no maladministration by the European Commission (https://www.ombudsman.europa.eu/en/cases/decision.faces/en/78175/html.bookmark)'.

'Please be assured that the Commission will pursue scrutiny of the independent scientific evidence available to ensure the highest health protection of our citizens'.

Comment: There are obvious misconceptions in this reply such as: *'The introduction of 3G and 4G has not increased exposure from environmental fields and this has been published also in peer-reviewed journals'.* On the contrary, numerous peer-reviewed articles have demonstrated that exposure to ambient RF radiation has increased substantially, as discussed (3-6).

In addition, the statement that: *'the Commission is not aware of any conflicts of interests of members of international bodies such as ICNIRP or the members of SCENIHR'* does not represent the scientific evidence of inherent conflicts of interest both in ICNIRP and SCENIHR (9,10). The very Commission seems to be ill-informed or even misinformed, as the EU seems to take information mainly from these two fraudulent organizations, but not from independent researchers. The EU does not seem to rely on sound science and thereby downplays the RF-related risks (7-12,53,54).

b) First rebuttal to the EU and the response. On November 13, 2017, a rebuttal was sent to the EU Commissioner of Health, Dr Andriukaitis. The whole letter can be found at: https://www.environmentandcancer.com/letter-to-vytenis-andriukaitis-13-11-2017/.

*'We suppose that you know that Director John F. Ryan, October 13, 2017 replied (Ares 2017 5015409 - Reply to the EU 5G-appeal, and that he said: "There is **consistent evidence** that exposure to electromagnetic fields **does not represent a health risk… if below the limits** …" His conclusion is based on the opinions of ICNIRP and SCENIHR'.*

'As early as February 1, 2016, in a Comment on SCENIHR to Mr. Ryan it was shown in article and letter by Drs. *[Sage], Carpenter and Hardell, representing BioInitiative and ECERI, that: "The evidence in the SCENIHR Final Opinion on EMF **clearly and convincingly establishes the potential for health effects of exposure to electromagnetic fields** [EMF]. Based on the evidence provided in this Opinion, the Committee is obligated to draw to the attention of the [EU] Commission that EMF is a new and emerging problem that may pose an actual or potential threat"' (55).*

'In spite of all this, Mr Ryan in his reply to us still continues to claim that EMF 'does not represent a health risk' and - without any other references than ICNIRP and SCENIHR - defends industry's standpoint that EMFs are harmless if below the ICNIRP "safety guidelines". In addition he ignores the IARC evaluations on both ELF-EMF and RF-EMF to be 'possible' human carcinogens, Group 2B'.

*'In the 5G-Appeal we urge EU to appoint a truly independent expert group of EMF-and-health researchers (contrary to ICNIRP and SCENIHR) to decide about new safe guidelines for EMF exposure. It is imperative to **immediately apply EU:s Precautionary Principle (and ALARA)** enabling rapid response to stop distribution of 5G products in order to diminish the harm that has already been proven by scientists. A **European pan-epidemic** may follow if you don't do so'.*

Second reply from EU on 29 November, 2017. This was sent from the European Commission, Cabinet of Commissioner Vytenis Andriukaitis, Head of Cabinet Brussels, written by Arūnas Vinciunas. The full reply can be found at: http://www.5gappeal.eu/wp-content/uploads/2018/06/reply_vinciunas.pdf).

'When Mr Ryan answered your email, in which you stated your disagreement with the Commission's stance on the 5G appeal, he presented the conclusions of roughly two decades of research on the potential health effects of EMF, and the views expressed in the Scientific Opinions produced by the independent Scientific Committees. [ICNIRP - International Commission on Non-Ionizing Radiation Protection and SCENIHR - Scientific Committee on Emerging and Newly Identified Health Risks]. The Committee's last Opinion on EMF, published in 2015, is based on hundreds of peer-reviewed studies published worldwide and is the fourth Opinion on EMF published since EMF legislation was adopted in 1999. The Committee's conclusion in this latest Opinion was based on exposure studies, epidemiological studies and in vivo and in vitro studies, and studies on any suggestions of causality were considered for the weighting'.

'The Commission services are confident that the advice provided by the Scientific Committees is unbiased, accurate and scientifically sound and therefore do not feel it necessary to appoint an independent expert group of EMF-and-health researchers to discuss new safe guidelines for EMF exposure'.

'The recourse to the EU's Precautionary Principle to stop the distribution of 5G products appears too drastic a measure. We first need to see how this new technology will be applied and how the scientific evidence will evolve. Please rest assured that the Commission will keep abreast of future developments in view of safeguarding the health of the European citizens at the highest level possible and in line with its mandate'.

Comment: This reply from EU is far from adequate. It does not represent a sound evaluation of the RF-related radiation risks based on published peer-reviewed studies. This is again outlined in our response to the EU.

c) Second rebuttal to the EU and the response. On January 17, 2018, a letter was sent to Dr. Vytenis Andriukaitis, EU Commissioner of Health. Sections of this letter are presented below and the full text can be found at: https://www.environmentandcancer.com/letter-to-vytenis-andriukaitis-and-donald-tusk-17-01-18/.

'Following the letter and the Scientist Appeal calling for a moratorium on 5G ("The 5G Appeal"), which we sent to your office, we received a response from Director John F. Ryan on October 13, 2017 and then, upon our reply, a letter from Mr. Arūnas Vinciūnas dated 29.11.2017'.

'Despite the conclusive evidence presented in our letters, both Director Ryan and Mr. Vinciūnas gave generic responses and continued to claim that EMF "does not represent a health risk". In doing so they only refer to ICNIRP and SCENIHR opinions without explaining why they disregarded the compelling evidence and references under the 5G-Appeal headline: "Harmful effects of RF-EMF exposure are already proven"'.

'The ICNIRP exposure limits are dependent on an unproven hypothesis that "only heat from EMF can cause health hazards". This hypothesis has clearly been rejected in a large number of scientific studies'.

'Both EU officials defend the industry-supportive standpoint that EMFs are harmless if below the ICNIRP "guidelines". However, many of the scientists on both ICNIRP's and SCENIHR's committees are connected to the telecom industry with obvious conflicts of interest'.

'Mr Vinciūnas stated in his letter: "The recourse to the EU's Precautionary Principle to stop the distribution of 5G products appears ***too drastic a measure****." Mr Vinciūnas finishes his letter: "we need to see … how the scientific* ***evidence will evolve****"'.*

'According to Communication from the Commission on the precautionary principle: "Whether or not to invoke the Precautionary Principle is a decision exercised where scientific information is insufficient, inconclusive, or uncertain and where there are indications that the possible effects on the environment, or human, animal or plant health may be potentially dangerous and inconsistent with the chosen level of protection." That describes the situation with 5G perfectly. Existing data shows that 5G frequencies [radiations] are hazardous. However, additional studies will be necessary to fully determine the extent of the risk'.

Third reply from the EU. This letter was replied to on April 27, 2018 by Mr. Arūnas Vinčiūnas from the Cabinet of Commissioner Vytenis Andriukaitis. For the full third reply to our appeals please see: https://www.environmentandcancer.com/answer-from-arunas-vinciunas-27-04-2018/.

'Thank you very much for your letter of 15 March 2018 which was also transmitted by email on 19 March. Commissioner Andriukaitis has asked me to reply to you on his behalf'.

'Finally, let me refer to the previous correspondence you have had with John F. Ryan, Director of Public Health and me (29 November 2017, 13 October 2017 and 19 February 2018) where we have comprehensively explained our position with regard to the arguments you have raised. It is my view that we have now extensively deliberated on the matter and that we should refrain from further repetition'.

'Please rest assured that the Commission will remain committed to safeguarding the health of the European citizens, at the highest level possible and in line with his mandate'.

d) Third rebuttal to the EU and the response. This rebuttal had the title *"Request for a moratorium on the 5G rollout. Request for guidelines based on independent research. Request for documents showing that 5G is safe".* On May 20, 2019 a letter with these requests was sent to Dr Karmenu Vella, EU Commissioner of Environment and Dr Vytenis Andriukaitis, EU Commissioner of Health. For the full text please see: https://www.environmentandcancer.com/letter-to-vytenis-andriukaitis-20-05-2019/.

'We make reference to the Precautionary Principle (PP) (56) It "enables a rapid response to be given in the face of a possible danger to human health…institutions may take protective measures without having to wait until the reality… of risks become apparent … preventive action should be taken" (57). Research confirms 5G to be a risk to all life on earth'.

'With this communication we touch upon three points:' i) 'Firstly, we request in the 5G Appeal to EU (www.5gappeal.eu), of which you are a public servant and representative, to declare an immediate ***moratorium*** *on 5G deployment. The 5G appeal to EU is now confirmed by 230+ truly independent scientists and physicians from 36 countries. The Space 5G appeal (58) has more than 83,000 affirmations from 168 countries. According to PP (56) and EU IP/00/96 (59) "protection of health takes precedence over economic considerations."' ii) 'Secondly, we ask for groups of truly industry-independent researchers to establish* ***new guidelines for exposure****. An "In-depth analysis" of the deployment of 5G (60), published by EU in April 2019, needs to be seriously considered. It stated that" One aspect, for example, that is not well understood today is the unpredictable propagation patterns that could result in unacceptable levels of human exposure to electromagnetic radiation."(p. 6)'. iii) 'Thirdly, with this letter we are formally requesting, in accordance with Art. 42 (61) on EU Fundamental Rights,* ***access to all documents*** *in your possession, either created by you or at your disposal, related to the effects of EMF to human health and the environment. Once in possession of such a list, we will decide which of those documents, if any, are of interest and show that 5G is safe. The list of the documents, and the ways to access them, should be sent to the email addresses below'.*

'We note that, while the EU is eagerly promoting the rollout of 5G, a new EU report admits (60) "the problem is that currently it is not possible to accurately simulate or measure 5G emissions in the real world" (p. 12). "Significant concern is emerging over the possible impact on health and safety arising from potentially much higher exposure to radiofrequency electromagnetic radiation arising from 5G" (p. 4). The EU report also stresses dangers: "Increased exposure

may result not only from the use of much higher frequencies in 5G but also from the potential for the aggregation of different signals, their dynamic nature, and the complex interference effects that may result, especially in dense urban areas." (p. 11)'.

Fourth reply from the EU. Finally, a response was delivered by the EU on September 5, 2019, although with reference to the wrong date of our letter. It was sent by Arunas Vinciunas from the Cabinet of Commissioner Vytenis Andriukaitis. The full response can be read at: https://www.environmentandcancer.com/answer-from-arunas-vinciunas-05-09-2019/.

'Thank you for your email of 7 July 2019 to Commissioner Andriukaitis in which you request to halt the 5G expansion in the EU immediately in order to allow a moratorium for industry independent research. Commissioner Andriukaitis has asked me to reply to you on his behalf'.

'In my latter note to you I already expressed my view that we had extensively deliberated on the matter and that we should refrain from further repetition'.

'As regards your request to halt the launch of the new 5G technology, I would like to confirm the view already expressed in my note of 29 November 2017 to you that stopping the distribution of 5G products appears too drastic a measure. I repeat that first there is a need to see how this new technology will be applied and how the scientific evidence will evolve'.

'Concerning your call for a scientific evaluation and new guidelines for exposure, the second point you have raised, let me stress that the Commission will review the situation once the review of the guidelines issued by the International Commission on Non-Ionizing Protection (ICNIRP) will be finalised which is expected in due course'.

'As regards your third point, documents related to the effects of electromagnetic fields to human health and the environment, please be referred to the opinion of the Commission's Scientific Committee on Emerging and Newly Identified Health Risks of 20 January 2015 on potential health effects of exposure to electromagnetic fields (EMF) (https://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_041.pdf) that provides an extensive list of references to scientific literature on this issue'.

Comment on the fourth reply from the EU appeal: There is no new evidence of the safety in this letter from EU compared with the earlier replies. Of note, the EU relies on documentation of risk only on old and biased selection of references in one single report from SCENIHR (https://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_041.pdf). Thus, EU officials still seem to base the evaluation of the health risks on reports from the ICNIRP and SCENIHR that have been seriously criticized. Of note, the EU relies on a report from 2015 as to scientific publications on the safety of 5G, a technology that was not developed during that time. This suggests that perhaps the EU is reluctant to deal with the safety issues associated with 5G technology.

e) Fourth rebuttal to the EU. On October 24, 2019 a fourth rebuttal was sent to the EU (https://www.environmentandcancer.com/letter-to-arunas-vinciunas-24-10-2019). We wrote that *'Specifically now, as we wish to assist the Commissioner in giving due response, it can be further specified from this side that we need the **list of documents** related to EMFs created by RF/Radiofrequencies (so: not by ELF) and even more specifically, to the list of those documents based on which the Commission is basing its current position that 5G should not be stopped nor subject to a moratorium (see the statement of your letter that "first there is a need to see how this new technology will be applied and how the scien6fic evidence will evolve"). We leave aside our total disagreement on the merits of such position at this time: formally, we are entitled to receive from you such a list of documents based on which the Commissioner determined that 5G is safe. Based on that list we will decide which of those documents, are of interest. Please provide such list by email no later than October 31, 2019. This is urgent'.*

Fifth reply from the EU. In this response, dated December 19, 2019, it was stated that new ICNIRP guidelines are expected. Thus, the same approach to this issue as previously and no new commitment (https://www.environmentandcancer.com/answer-from-martin-seychell-19-12-2019).

Appeals to the Nordic Prime Ministers

The 5G Appeal was also sent to the Nordic Prime Ministers (https://www.environmentandcancer.com/letter-to-nordic-ministers-27-6-2018/); (https://www.environmentandcancer.com/letter-to-nordic-ministers-5-3-2019/). The only reply, dated March 29, 2019, was sent from the Swedish government (Ministry of Enterprise and Innovation, Mari Mild). It was stated that the government relies on Swedish Radiation Safety Authority (SSM) and their yearly update of health risks and that no new health risks have been reported. According to the letter there is no reason for a moratorium on the deployment of 5G, see (in Swedish) (https://www.miljoochcancer.com/svar-fran-naringsdepartementet-29-3-2019/). SSM relies on ICNIRP.

Discussion

Our experience with the EU and the Governments of the Nordic countries suggests that the majority of decision makers are scientifically uninformed on health risks from RF radiation (62). In addition, they seem to be uninterested to being informed by scientists representing the majority of the scientific community, i.e., those scientists who are concerned about the increasing evidence or even proof of harmful health effects below the ICNIRP guidelines (www.emfscientist.org). Instead, they rely on evaluations with inborn errors of conflicts, such as ICNIRP. In fact, the ICNIRP, with the support of WHO and major telecommunications companies, has been rather successful in implementing their views in the EU and worldwide. Their guidelines seem to be based on the omission of scientific facts. Thus, their possible ignorance of the health risks is of concern, as well as their reluctance to adhere to warnings from large numbers of scientists around the world.

It is striking that 5G is deployed without previous scientific evaluation of health risks. Not only cancer risks, but also other health effects such as fertility, cognitive and neurobehavioral effects, oxidative stress and electromagnetic hypersensitivity (EHS) have been associated with RF exposure [for a more detailed discussion on this tope, please see previous publications (1,7,8,28,35)]. It is thus noteworthy that the ICNIRP thermal paradigm is still used for the evaluation of the health risks associated with RF radiation. One issue of major concern is that there seems to be conflicts of interest among persons in the evaluating groups. Furthermore the same persons may often be found in different bodies, thereby in fact citing themselves representing a cartel (https://www.saferemr.com/2018/07/icnirps-exposure-guidelines-for-radio.html). This has been outlined in peer-reviewed publications (9,10).

This is also an ethical question. Thus, it would not be possible to test a new drug on individuals without information and signed permission by each individual. Certainly, this principle should apply to 5G that is furthermore, mandatory. Exposure to RF radiation from 5G must be regarded as a medical experiment with potential health risks, some known and expected based on current knowledge, some unknown since this is a new untested technology. A letter of information to those exposed must be sent for informed consent. However, it must be concluded that such a letter, affirming no risk, cannot be formulated based on the limited number of studies on 5G, in fact most of them with no assurance of no risks.

This is also a moral question for all the individuals involved in the propagation of 5G. It is to be noted that individuals within e.g., ICNIRP, national governmental bodies and the EU, partly a cartel, seem to neglect scientific warnings. They instead seem to follow the no-risk paradigm. It is thus questionable as to how it is possible to thereby disregard the diseases caused by this technology and to not consider the affected persons.

Taking the history of e.g., tobacco and smoking and the long period of time it took for cancer classification into account, it is fully understandable that RF radiation is still in the beginning of that history. However, if no action is currently taken, the costs to society will most likely be very high in terms of premature deaths, deteriorated public health and damage to the ecological system. It is however, important to publish the history of neglected RF radiation warnings. The EU seems to perhaps lacking in that respect. It must be concluded that the polluter has to pay the full cost of harm from this technology (63). Those in responsible positions in governments and organizations intended to protect the public and the environment from harm (WHO and ICNIRP), but who fail to do so by ignoring the increasing warnings from scientists worldwide about the dangers of 5G, should also be held responsible for the harm to the public that they thereby induce (64). No doubt damage to the environment by the business sector may be substantial (https://www.theguardian.com/environment/2010/feb/18/worlds-top-firms-environmental-damage).

The EU principle that the Polluter Pays (Article 191, pt 2) states: *'Union policy on the environment shall aim at* ***a high level of protection taking*** *into account the diversity of situations in the various regions of the Union.* ***It shall be based on the precautionary principle*** *and on the principles that* ***preventive action should be taken****, that environmental damage should as a priority be rectified at source and that* ***the polluter should pay****'*. (https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:12008E191:EN:HTML).

'The fundamental principle of this Directive should therefore be that an operator whose activity has caused the environmental damage or the imminent threat of such damage is to be held financially liable, in order to induce operators to adopt measures and develop practices to minimise the risks of environmental damage so that their exposure to financial liabilities is reduced' (65) (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32004L0035&from=EN).

The industry tries to convince us that the super high frequencies of 5G are so weak and its millimeter waves will penetrate only the outer surface of the skin. The opposite was proven in USSR research already in 1977 (https://www.cia.gov/library/readingroom/docs/CIA-RDP88B01125R000300120005-6.pdf). High frequencies (37-60 GHz), which will be used in 5G, caused several kinds of detrimental effects in experimental rats. The high frequencies seem to be worse than the lower frequencies. The USSR experiments were made more than 40 years ago - when we had no digital pulsed radiation - with a generator producing sinus curves. Peaks of pulsed radiation used in 5G with unpredictable intensity changes seem to be an important parameter for the bioactivity of RF radiation (29).

In conclusion, this article demonstrates that the EU has given mandate to a 13-member, non-governmental private group, the ICNIRP, to decide upon the RF radiation guidelines. The ICNIRP, as well as SCENIHR, are well shown not to use the sound evaluation of science on the detrimental effects of RF radiation, which is documented in the research which is discussed above (9,10,21-24,54,55). These two small organizations are producing reports which seem to deny the existence of scientific published reports on the related risks. It should perhaps be questioned whether it is in the realm of protecting human health and the environment by EU and whether the safety of EU citizens and the environment can be protected by not fully understanding the health-related risks.

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Availability of data and materials

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Authors' contributions

Both authors (LH and RN) participated in the conception, design and writing of the manuscript, and have read and approved the final version.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Review article

Health effects of electromagnetic fields on children

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In today's world, most children are exposed to various manmade electromagnetic fields (EMFs). EMFs are electromagnetic waves less than 300 GHz. A developing child's brain is vulnerable to electromagnetic radiation; thus, their caregivers' concerns about the health effects of EMFs are increasing. EMF exposure is divided into 2 categories: extremely low frequencies (ELFs; 3–3,000 Hz), involving high-voltage transmission lines and in-house wiring; and radiofrequencies (RFs; 30 kHz to 300 GHz), involving mobile phones, smart devices, base stations, WiFi, and 5G technologies. The biological effects of EMFs on humans include stimulation, thermal, and nonthermal, the latter of which is the least known. Among the various health issues related to EMFs, the most important issue is human carcinogenicity. According to the International Agency for Research on Cancer's (IARC's) evaluation of carcinogenic risks to humans, ELFs and RFs were evaluated as possible human carcinogens (Group 2B). However, the World Health Organization's (WHO's) view of EMFs remains undetermined. This article reviews the current knowledge of EMF exposure on humans, specifically children. EMF exposure sources, biological effects, current WHO and IARC opinions on carcinogenicity, and effects of EMF exposures on children will be discussed. As well-controlled EMF experiments in children are nearly impossible, scientific knowledge should be interpreted objectively. Precautionary approaches are recommended for children until the potential health effects of EMF are confirmed.

Key words: Electromagnetic field, Extremely low frequency, Radiofrequency, Smart device, Child

Key message

- The nervous systems of children are more vulnerable to the effects of electromagnetic waves than adults.
- The exposure to electromagnetic fields (EMFs) among children should be minimized.
- According to International Agency for Research on Cancer EMFs are possibly carcinogenic, it should not be overlooked or interpreted with bias.

Introduction

Electromagnetic radiation is generated from natural environments such as the solar energy and geomagnetic field or from manmade sources. With scientific and technological advancements, our everyday environments are filled with various manmade electromagnetic fields (EMFs). EMFs are invisible and generated from electrical lines, transmission towers, telecommunications, home appliances, mobile phones, WiFi, and base stations. An increasing number of children use computers and iPads for school, entertainment, and social activities. Even infants can be exposed to EMFs in the residential environment or by the direct use of electronic devices (Fig. 1).

There are 2 main categories of EMFs: extremely low frequency (ELF) and radiofrequency (RF) waves.[1-3] ELFs can be generated from electrical lines or transmission towers, issues of which have been investigated for the last several decades. RFs can be generated from mobile phones and smart devices and the recent 5th-generation (5G) technologies. The human effects of RFs are less evident and more difficult to study than those of ELFs.

In Korea, general measures have been recommended to reduce EMF exposure such as reducing the use of electronic devices or using them away from the body. However, little is known about the exact amount of daily EMF exposure that can affect a child's health and whether the effects of EMF exposure are similar to those of adults. The developing nervous system is more conductive and absorbs more electromagnetic energies than those of adults.[4] Therefore, different standards are required to protect children.

In recent years, pediatricians have become increasingly asked about children's use of electromagnetic devices and the risks of EMF exposure. Thus, more knowledge about pediatric exposure to electromagnetic radiation is required than any other time before. Thus, this article reviews the current knowledge about the health effects of EMF exposure on children. The World Health Organization's (WHO's) opinions and other scientific researches will be critically reviewed, and the precautionary principle to reduce the negative effects of EMF on children will be emphasized.

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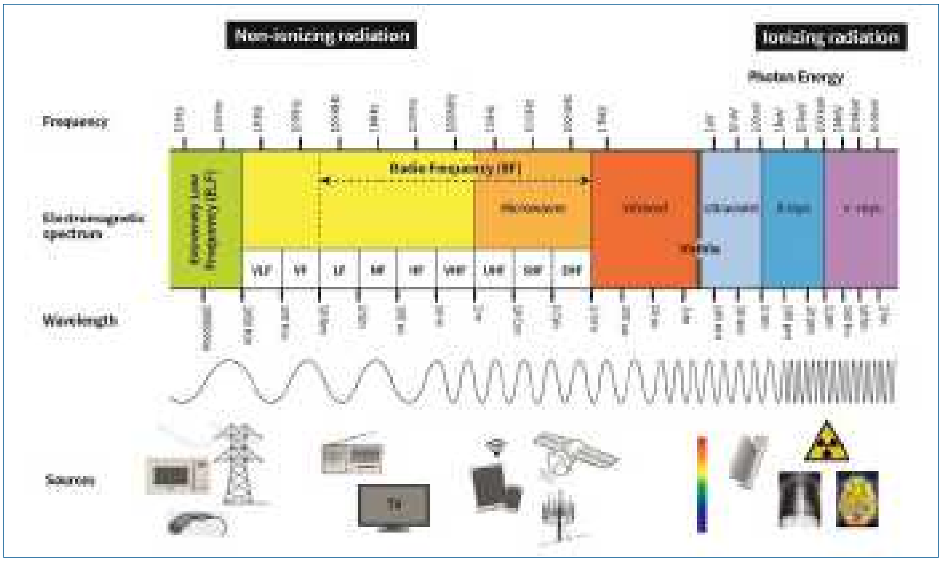

Fig. 1. The electromagnetic spectrum. Frequencies (expressed by hertz, Hz) increase from left to right, while wavelengths decrease from right to left. Ionizing radiations are x-rays and γ-rays. EHF, extremely high frequency; HF, high frequency; LF, low frequency; MF, medium frequency; SHF, super-high frequency; VF, voice frequency; VHF, very high frequency; VLF, very low frequency; UHF, ultra-high frequency.

Sources of EMF exposure

Whenever electrical current flows, both electrical and magnetic fields are generated, known as EMFs. Electric field strength is measured as volts per meter (V/m), while magnetic field strength is measured as amperes per meter (A/m). A magnetic field can be measured as magnetic flux density (Tesla).

The electromagnetic spectrum is categorized into a frequency range: ELF, RF, infrared, visible, ultraviolet, and ionizing radiations (x- and γ-radiation).[1,3] EMF refers to waves less than 300 GHz, which includes most of the frequencies in everyday exposure. The lowest frequencies (3–3,000 Hz) are referred to as ELF-EMF, while the higher frequencies (30 kHz to 300 GHz, under infrared) are referred to as RF-EMF (Fig. 2).

1. Extremely low-frequency EMFs

ELF-EMFs are generated from electricity, electrical machines, transmission towers, and high-voltage lines. In Korea, electric power is operated at 60 Hz. More EMFs are absorbed with the use of appliances that are close to the body (e.g., hair dryers, bidets, massagers, and electric blankets). The general recommendation is that electrical appliances should be used at least 30 cm away from the body (http://www.emf.or.kr/general/html/life/guideline.pdf).

2. Radiofrequency EMFs

RF-EMFs are generated from mobile phones, smart devices, WiFi, base stations, and radars. Radio or television transmitters and base stations can be large sources of RF exposure. Mobile phones generate more electromagnetic waves when used in a fast-moving subway or train or when searching for a base station before the ring back tone.[5]

Biological effects of EMFs

The main effects of EMFs on the human body are stimulation, thermal, and nonthermal. Stimulation effects involve the nerves and muscles at a high EMF, can be used for medical devices, and can cause electrical shock at very high stimulation levels. Thermal effects involve an increase in body temperature. Hot senses of the ear or body during mobile phone or laptop use are some examples. Nonthermal effects result from recurrent long-term exposure and may be related to the so-called electromagnetic hypersensitivity syndrome or neurodevelopmental disorders. However, the nonthermal effect is the least well investigated.[6]

The effects of EMF exposure differ with respect to frequencies and strength. For frequencies less than 300 GHz, limitation levels for human protection have been well established for public and occupational workers.[7,8] From 100 kHz to 10 GHz, which includes the use of mobile phones, limitation level is expressed as a specific absorption rate (SAR, W/kg).[2,8]

One of the major issues of EMF involves human carcinogenesis. Since the first report on residential ELF-EMF and childhood leukemia in 1979, several studies have investigated this association.[1,2,7] However, because of the nature of electromagnetic radiation, most studies were based on epidemiological data or animal experiments.

Animal studies on prenatal RF exposure demonstrated the deleterious effects of RF-EMF on the brain. Prenatal exposure to 900 MHz resulted in substantial loss of granule cells[9] or a significant reduction in pyramidal neurons.[10] Mice exposed to in utero RF from cellular telephones were hyperactive and demonstrated memory impairment after birth.[11] EMFs from mobile phones changed the blood-brain barrier's permeability and damaged neurons in the brains of exposed rats.[12-14]

Brain oxidative stress and epigenetics are considered biological

Fig. 2. Various sources of electromagnetic fields (EMFs). Extremely low-frequency EMFs are generated by electricity, various home appliances, in-house wiring, and outside high-voltage lines. Radio frequency EMFs waves are generated by mobile phones, smart devices, WiFi, base stations, and other devices.

mechanisms of RF-EMF effects. Several theories suggest that EMF exposure results in oxidative stress and reactive oxygen species and loss of cells and blocks their production.[15] Oxidative stress parameters increase lipid hydroperoxide and myeloperoxidase activity in immature rats.[16] RF-EMF exposure may change deoxyribonucleic acid methylation, histone modification, chromatin remodeling, and microribonucleic acid.[16-18] However, the results of studies on brain oxidative stress induced by EMF are inconsistent.

In Korea, many websites for public and nonpublic institutions provide information aiming to improve public awareness and EMF knowledge.[19-22] This information includes large amounts of data on human limitation levels, EMF measurements of electronic products, base station information, general safety guidelines, and false beliefs. Although the websites provide general information for public awareness, they sometimes conclude that the public concerns regarding carcinogenicity and nonthermal effects are exaggerated and have insufficient evidence. However, such conclusions may be hasty. Because evidence of the relevant websites is often based on WHO fact sheets, it is necessary for clinicians to review the WHO opinion and evaluate other scientific evidence objectively.

On the other hand, some individual websites or personal blogs deliver scientifically unreasonable negative information to users. Such messages exaggerate claims and interfere with reasonable discussions about EMF health effects.

Different tones for human carcinogenicity

1. Carcinogenicity of ELF-EMF

In 1996, the WHO organized an international EMF project task group to investigate the potential health risks of EMF-associated technologies. In the resulting fact sheet in 2007, the WHO concluded that there were no substantive health issues related to ELF electric fields at levels generally encountered by the public.[7] This position was based on findings and reviews of the WHO task group as well as the International Agency for Research on Cancer (IARC, 2002) and International Commission on Non-Ionizing Radiation Protection (2003).[2,7,23] The WHO task group referenced the IARC monograph evaluating the carcinogenic risks in humans in 2002 that classified ELF as a possible carcinogen.[2] However, the task group commented that the epidemiological evidence of carcinogenicity was weakened by methodological problems such as potential selection bias.[7]

In fact, the IARC's 2002 monograph evaluated a number of scientific studies on ELF electronic and magnetic fields and childhood and adult cancers.[2] In the part about the effects on children, it stated that "pooled analyses showed 2-fold excess risk for exposure to ELF magnetic fields above 0.4 μT and a relative risk of 1.7 for exposure above 0.3 μT.".[2] The IARC concluded that ELF magnetic fields were possibly carcinogenic to humans (Group 2B) and that the association between child leukemia and a high magnetic field was unlikely to be due to chance.[2] In contrast to ELF magnetic fields, evidence on the association between ELF electric fields and leukemia was inadequate, and the associations between other childhood brain tumors or cancers and ELF were inconsistent.[2]

The IARC is a working group under the auspices of WHO. Despite this, the different views between the WHO and the IARC may have originated from the differences in their respective members. Many committee members of the WHO's EMF project were involved with electricity-associated industries, whereas the IARC membership included more epidemiologists and health specialists.[24] In Korea, several public websites on EMF safety frequently cite the WHO EMF opinion. Some citations seem to have been changed through self-citation, which may cause the misleading interpretation that there is no scientific evidence of carcinogenicity.

2. Carcinogenicity of RF-EMF

A large international case-control study (INTERPHONE study, 2000) that aimed to determine the association between adult brain tumor risk and mobile telephone use reported no overall increase in brain tumor risk with the use of mobile phones.[25] However, in the 10th highest decile of cumulative call time (≥1,640 hours), the odd ratios were 1.4 for glioma and 1.15 for meningioma.[25] Glioma tended to occur more commonly in the temporal lobe on the side of usual phone use.[25] After the INTERPHONE study, in 2013, the IARC published another monograph evaluating the carcinogenic risks of RF-EMF on humans.[3] Similar to ELF magnetic fields, the IARC classified RF-EMFs as "possibly carcinogenic to humans (Group 2B)."[3]

In 2014, the WHO also published the following fact sheet on mobile phone EMF and public health.[26] Similar to ELF, the WHO opinion was undetermined. It referenced the IARC's classification of mobile phone use as possibly carcinogenic to humans. However, the WHO group repeated the comment that the "biases and errors limit the strength of these conclusions and prevent a causal interpretation."[26] Such undetermined views of the WHO on the adverse effects of RF or ELF-EMF have been criticized by several scientist groups, which have requested that the WHO should reevaluate all health effects of EMF and include experts from all related fields such as health, medicine, and engineering to reassess the effects of EMFs.[24,27,28]

Other EMF effects on children's health

In everyday life, children are exposed to indoor and outdoor EMFs. Although well-designed case-control studies are lacking, we can consider the available data in hypothesizing about the effects of EMF on children.

1. ELF effects on and children

ELF from high-voltage power lines can affect children living near them; in fact, children can be continuously affected by low-level in-house wiring. Much of the results regarding ELF and children's health are based on epidemiologic studies with childhood leukemia as described in the previous section.

While conducting the international EMF project, the WHO conducted an international workshop on "Sensitivity of children to EMF exposure" (Istanbul, Turkey, June 2004) of both ELF and RF-EMF exposure. They concluded that there was no direct evidence that children were more vulnerable to EMF because very few studies assessed this topic.[29] However, considering the uncertain effects of EMF on children, the WHO recommended general measures such as reducing personal EMF exposure. They also recommended minimizing EMF exposure in schools, kindergartens, and any locations where children remain for a substantial part of the day.[1,29]

2. RF effects on children

Whether children are vulnerable to RF has been debated for the last 20 years, when children were widely exposed to mobile phones. Human and animal model studies yielded significant findings regarding cellular phone use: increased headache, sleep disruption, neurotransmitter release, synaptic plasticity alterations, and neuronal cell cycles.[30-34] However, the experimental environment and RF doses may differ from those of actual exposures.

The Korean study conducted in 1993–1999 involving 1,928 children with leukemia and 956 children with brain tumors. It revealed that the risk of leukemia was 2.15 times higher in the group living within 2 km from AM radio transmitters than in the group living more than 20 km from it.[35]

In 2000, the "Stewart report" by the UK Independent Expert Group on Mobile Phones declared that children may be more vulnerable to EMF than any other age groups.[4,36] They stated that "*children are exposed to electromagnetic waves over a longer life time than adults and their nervous systems are in the process of development. As the conductivity of the children is higher due to higher moisture and ionic content than adults, and more than adults, children's head absorbs a lot of RF energy*" (Fig 3).[4] Stewart's report suggested that children should not be encouraged to use mobile phones unnecessarily and that mobile phone companies should not promote their use in children.[4] Since Stewart's report, debate regarding the vulnerability of a child's brain surfaced from the Netherlands and Russia.[37,38]

3. Studies of mobile phone RF exposure in children

The skull thickness of adults is approximately 2 mm. However, the skull thickness of a 5-year-old child is approximately 0.5 mm and 1 mm in 10 years.[39] Therefore, radiation penetration is larger in children than in adults.[39,40] As a child's head diameter is smaller, the energy-absorbing "hot spots," the most sensitive parts of RF, are more pronounced.[41] Several engineering strategies to avoid the hazard of RF do not consider a child's head

Children may be more vulnerable to EMF than any other age groups.

- *Children are exposed to electromagnetic waves over a longer life time than adults.*
- *Their nervous systems are in the process of development.*
- *The conductivity of the children is higher due to higher moisture and ionic content than adults.*
- *Children's head absorbs a lot of RF energy more than adults.*

From "Stewart report" by the UK Independent Expert Group on Mobile Phones (2000) [4]

Fig. 3. The vulnerability of children to electromagnetic field exposure according to the UK Independent Expert Group on Mobile Phones. EMF, electromagnetic field; RF, radiofrequency.

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specificity.[6)]

The results of the study that assessed the associations between RF exposure and cell phone use, residential RF-EMF levels, and cognitive function tests were inconsistent.[42-46)] Ten-year-old children living in areas with higher RF exposure did not show any effects in most of the cognitive parameters; however, they did show lower verbal scores and higher internalizing and total problems.[46)] In a study of children aged 5–6 years, greater residential RF exposure from base stations and the presence of indoor sources were associated with improved inhibitory control and flexibility of cognition but also reduced visuomotor coordination.[47)]

The associations between RF exposure and mobile phone use and sleep in children are inconsistent.[48-50)] Habitual and frequent use of mobile phones was associated with lower sleep quality, while higher tablet use was associated with decreased sleep efficiency.[49)] Arousal and blue light may underlie these problems. Residential exposure to RF-EMF from base stations was not associated with sleep onset delay, night awakening, parasomnia, and daytime sleepiness in 7-year-old children; however, higher mobile phone use was associated with less favorable sleep duration, night awakening, and parasomnia.[50)]

Cell phone use by pregnant mothers during the pre- and postnatal periods can contribute to behavioral problems in children.[51)] In children exposed to cell phones during the pre- and postnatal periods, the odds ratio for behavioral problems was 1.8 after the adjustment of potential confounders.[52)]

Recently, the European Union-funded international study evaluating the association between RF exposure by mobile phones and brain tumor risk in children and adolescents (MOBI-KIDS) was conducted.[53)] This large study included nearly 900 eligible patients from 14 countries, including Korea, and the final results are still pending.[54)]

The 5G technologies using electromagnetic waves can make hyper-connected network environments capable of augmented reality and 3-dimensional service. The 5G frequency comprises 3.5-GHz and 28-GHz bands. The effect of the 3.5-GHz band on humans may be similar to that of 4G and can utilize the existing base station, but 28 GHz may be different to the human body and the base stations must be installed more closely. Therefore, the long term effects of 5G on children's health are unestablished. The impact of 5G technologies on children has never been evaluated.[55)]

4. Precautionary principles for children

International policies and advisory responses regarding children's exposure to RF-EMF vary. RF-EMF-related advisory policies for children are as follows: banning mobile phone advertising or sale to children, SAR labeling, and preferring wired connection to WiFi in schools. In Korea, only the policy of SAR labeling on mobile phone is strictly followed. Similar to other scientific uncertainties, precautionary principles should be followed for the EMF problem (EC, 2017).[56)] The meaning of precautionary principle is as follows: *when human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm (UNESCO 2015)*. For children, strict standards are required until scientific knowledge is established, specifically in facilities such as schools and preschools, where they stay longer. This article suggests precautions to reduce the risk of excessive EMF exposure in children (Table 1).

Table 1. Precautions to reduce the risk of excessive electromagnetic field (EMF) exposure in children

Children can be exposed to EMF by electronic devices, high-voltage transmission lines, mobile phones, WiFi, etc.
For parents: · Avoid long-term exposure to strong EMFs in home, school, or other places children spend much of their time. · Avoid using electrical devices within 30 cm of the body. · Avoid using smartphones directly against your child's head. · Keep your child's body from getting hot while using mobile phones. · Do not allow your child to use smart devices during meals or for the last hour before bed. · Note that the effects of various devices using virtual reality and WiFi have on the neural development of children remain unknown. · Most products that claim to reduce EMFs are ineffective or unproven. · Ask your child's pediatrician for information to guide your child's use of smart devices.
For teachers, policymakers, and commercial companies: · Teachers: Educate children on how to avoid excessive EMF exposure. · Policymakers: Create policies to reduce children's EMF exposure from the environment. · Commercial companies: Create products that reduce children's exposure to EMFs and issue warnings about them.

EMFs, electromagnetic fields.

Conclusion

The nervous systems of children are more vulnerable to the effects of electromagnetic waves than those of adults. Although studies on the effects of EMFs on children's health are unestablished, precautionary principles should be followed for children and the exposure to EMFs among children should be minimized. The fact that EMFs are possibly carcinogenic according to the IARC should not be overlooked or interpreted with bias, and the opinions of clinicians should be given more weight than those of industries in the establishment of safety policies for EMF use. Moreover, a study that assesses the effects of 5G frequency technology on children's health is required.

Conflicts of interest

The author declares no conflicts of interest.

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COMMENT

Health risks from radiofrequency radiation, including 5G, should be assessed by experts with no conflicts of interest

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Abstract. The fifth generation, 5G, of radiofrequency (RF) radiation is about to be implemented globally without investigating the risks to human health and the environment. This has created debate among concerned individuals in numerous countries. In an appeal to the European Union (EU) in September 2017, currently endorsed by >390 scientists and medical doctors, a moratorium on 5G deployment was requested until proper scientific evaluation of potential negative consequences has been conducted. This request has not been acknowledged by the EU. The evaluation of RF radiation health risks from 5G technology is ignored in a report by a government expert group in Switzerland and a recent publication from The International Commission on Non-Ionizing Radiation Protection. Conflicts of interest and ties to the industry seem to have contributed to the biased reports. The lack of proper unbiased risk evaluation of the 5G technology places populations at risk. Furthermore, there seems to be a cartel of individuals monopolizing evaluation committees, thus reinforcing the no-risk paradigm. We believe that this activity should qualify as scientific misconduct.

Introduction

Most politicians and other decision-makers using guidelines for exposure to radiofrequency (RF) radiation seem to ignore the risks to human health and the environment. The fact that the International Agency for Research on Cancer (IARC) at the World Health Organization (WHO) in May 2011 classified RF radiation in the frequency range of 30 kHz to 300 GHz to be a 'possible' human carcinogen, Group 2B (1,2), is being ignored. This has been recently exemplified in a hearing at the Tallinn Parliament in Estonia (3).

An important factor may be the influence on politicians by individuals and organizations with inborn conflicts of interests (COIs) and their own agenda in supporting the no-risk paradigm (4,5). The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has repeatedly ignored scientific evidence on adverse effects of RF radiation to humans and the environment. Their guidelines for exposure are based solely on the thermal (heating) paradigm and were first published in ICNIRP 1998 (6), updated in ICNIRP 2009 (7) and have now been newly published in ICNIRP 2020 (8), with no change of concept, only relying on thermal effects from RF radiation on humans. The large amount of peer-reviewed science on non-thermal effects has been ignored in all ICNIRP evaluations (9,10). Additionally, ICNIRP has successfully maintained their obsolete guidelines worldwide.

COIs can be detrimental, and it is necessary to be as unbiased as possible when assessing health risks. There are three points that should be emphasized. Firstly, the evidence regarding health risks from environmental factors may not be unambiguous, and therefore informed judgements must be made. Furthermore, there are gaps in knowledge that call for experienced evaluations, and no conclusion can be reached without value judgements. Secondly, paradigms are defended against the evidence and against external assessments by social networks in the scientific community. Thirdly, the stronger the impact of decisions about health risks on economic, military and political interests, the stronger will stakeholders try to influence these decision processes.

Since the IARC evaluation in 2011 (1,2), the evidence on human cancer risks from RF radiation has been strengthened based on human cancer epidemiology reports (9-11), animal carcinogenicity studies (12-14) and experimental findings on oxidative mechanisms (15) and genotoxicity (16). Therefore, the IARC Category should be upgraded from Group 2B to Group 1, a human carcinogen (17).

The deployment of the fifth generation, 5G, of RF radiation is a major concern in numerous countries, with groups of citizens trying to implement a moratorium until thorough research

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Key words: Switzerland, European Union, World Health Organization, International Commission on Non-Ionizing Radiation Protection, Scientific Committee on Emerging and Newly Identified Health Risks, Swedish Radiation Safety Authority, 5G, electromagnetic field, appeals, moratorium, microwave radiation, radiofrequency electromagnetic field, health risks, non-ionizing radiation guidelines, conflicts of interest

on adverse effects on human health and the environment has been performed. An appeal for a moratorium, currently signed by >390 international scientists and medical doctors, was sent to the European Union (EU) in September 2017 (18), currently with no EU response (19). Several regions have implemented a moratorium on the deployment of 5G motivated by the lack of studies on health effects, for instance Geneva (20).

In the present article, the current situation in Switzerland is discussed as an example (21). Additionally, the ICNIRP 2020 evaluation is discussed (8).

Evaluation of health risks in Switzerland

Several Swiss citizens have brought to our attention that Associate Professor Martin Röösli is the chair of two important government expert groups in Switzerland (directeur), despite possible COIs and a history of misrepresentation of science (22,23). These groups are Beratende Expertengruppe NIS (BERENIS; the Swiss advisory expert group on electromagnetic fields and non-ionizing radiation) (24), and the subgroup 3, the Mobile Communications and Radiation Working Group of the Department of the Environment, Transport, Energy and Communications/Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation, evaluating RF-radiation health risks from 5G technology (25,26).

The conclusions made in the recent Swiss government 5G report are biased and can be found here (27,28). This 5G report concluded that there is an absence of short-term health impacts and an absence or insufficient evidence of long-term effects [see Table 17 (Tableau 17) on page 69 in the French version (27) and Table 17 (Tabelle 17) on page 67 in the German version (28)].

Furthermore, it was reported that there is limited evidence for glioma, neurilemmoma (schwannoma) and co-carcinogenic effects, and insufficient evidence for effects on children from prenatal exposure or from their own mobile phone use. Regarding cognitive effects, fetal development and fertility (sperm quality), the judgement was that the evidence on harmful effects is insufficient. These evaluations were strikingly similar to those of the ICNIRP (see Appendix B in ICNIRP 2020; 8). Other important endpoints, such as effects on blood-brain barrier, cell proliferation, apoptosis (programmed cell death), oxidative stress (reactive oxygen species) and gene and protein expression, were not evaluated.

According to Le Courrier November 19, 2019, Martin Röösli presented the conclusion in an interview in the following way: '*Sur l'aspect sanitaire pur, «le groupe de travail constate que, jusqu'à présent, aucun effet sanitaire n'a été prouvé de manière cohérente en dessous des valeurs limites d'immissions fixées», résume Martin Röösli, professeur d'épidémiologie environnementale à l'Institut tropical et de santé publique suisse*' (29). [*Regarding the health issue, the working group concludes that, until now, no health effect has been consistently proven below the given exposure limits, summarizes Martin Röösli, professor in environmental epidemiology at the Swiss Tropical and Public Health Institute*].

This Swiss evaluation is scientifically inaccurate and is in opposition to the opinion of numerous scientists in this field (18). In addition, 252 electromagnetic field (EMF) scientists from 43 countries, all with published peer-reviewed research on the biologic and health effects of nonionizing electromagnetic fields (RF-EMF) have stated that:

'*Numerous recent scientific publications have shown that RF-EMF affects living organisms at levels well below most international and national guidelines. Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plant and animal life*' (30).

We are concerned that the Swiss 5G report may be influenced by ties to mobile phone companies (COIs) by one or several members of the evaluating group.

COIs

Funding from telecom companies is an obvious COI. Martin Röösli has been a member of the board of the telecom funded Swiss Research Foundation for Electricity and Mobile Communication (FSM) organization and he has received funding from the same organization (31-33).

It should be noted that the FSM is a foundation that serves formally as an intermediate between industry and researchers. According to their website, among the five founders of FSM who '*provided the initial capital of the Foundation*' four are telecommunications companies: Swisscom, Salt, Sunrise, 3G Mobile (liquidated in 2011). The fifth founder is ETH Zurich (technology and engineering university). There are only two sponsors, Swisscom (telecommunications) and Swissgrid (energy), who '*support the FSM with annual donations that allow for both the management of the Foundation and research funding*' (34).

The same situation applies to being a member of ICNIRP (Table I) (35). In 2008, the Ethical Council at Karolinska Institute in Stockholm stated that being a member of ICNIRP is a potential COI. Such membership should always be declared. This verdict was based on activities by Anders Ahlbom in Sweden, at that time a member of ICNIRP, but is a general statement (2008-09-09; Dnr, 3753-2008-609). In summary: '*It is required that all parties clearly declare ties and other circumstances that may influence statements, so that decision makers and the public may be able to make solid conclusions and interpretations. AA [Anders Ahlbom] should thus declare his tie to ICNIRP whenever he makes statements on behalf of authorities and in other circumstances*' (translated into English).

COIs with links to industry are of great importance; these links may be direct or indirect funding for research, payment of travel expenses, participation in conferences and meetings, presentation of research, etc. Such circumstances are not always declared as exemplified above. A detailed description was recently presented for ICNIRP members (22).

ICNIRP

ICNIRP is a non-governmental organization (NGO) based in Germany. Members are selected via an internal process, and the organization lacks transparency and does not represent the

Table I. Members of the WHO core group and additional experts of the Environmental Health Criteria Document 2014 (54), EU SCENIHR 2015 (52), the SSM 2015-2020 (93) and ICNIRP commission or the Scientific Expert Group 1992-2020 (94).

Members	WHO, 2014	SCENIHR, 2015	SSM, 2015-2020	ICNIRP, 1992-2020
Emilie van Deventer	X		X	X[a]
Simon Mann	X			X
Maria Feychting	X		(X)[b]	X
Gunnhild Oftedal	X			X
Eric van Rongen	X		X	X
Maria Rosaria Scarfi	X	X	X	X
Jukkka Juutilainen	X			X
Denis Zmirou	X			
Theodoros Samaras		X		
Norbert Leitgeb		X		
Anssi Auvinen		X		X
Heidi Danker Hopfe		X	X	
Kjell Hansson Mild		X		
Mats Olof Mattsson		X		X
Hannu Norppa		X		
James Rubin	X	X		
Joachim Schüz		X		
Zenon Sienkiewicz	X	X		X
Olga Zeni	X	X		
Anke Huss			X	X[c]
Clemens Dasenbrock			X	X
Lars Klaeboe			X	
Martin Röösli	X		X	X
Aslak Harbo Poulsen			X	

[a]WHO Observer in the main commission (95); [b]2002-2011; [c]2020-2024. The table is based on members of WHO, SCENIHR and SSM during the defined time period(s). No other individuals among those within WHO or SCENIHR were found in the list of SSM participants. A total of 15 additional experts in WHO were not members of SCENIHR, SSM or ICNIRP. SCENIHR, Scientific Committee on Emerging and Newly Identified Health Risks; SSM, Swedish Radiation Safety Authority; WHO, World Health Organization; EU, European Union; ICNIRP, International Commission on Non-Ionizing Radiation Protection.

opinion of the majority of the scientific community involved in research on health effects from RF radiation. Independent international EMF scientists in this research area have declared that: '*In 2009, the ICNIRP released a statement saying that it was reaffirming its 1998 guidelines, as in their opinion, the scientific literature published since that time has provided no evidence of any adverse effects below the basic restrictions and does not necessitate an immediate revision of its guidance on limiting exposure to high frequency electromagnetic fields. ICNIRP continues to the present day to make these assertions, in spite of growing scientific evidence to the contrary. It is our opinion that, because the ICNIRP guidelines do not cover long-term exposure and low-intensity effects, they are insufficient to protect public health*' (30).

ICNIRP only acknowledges thermal effects from RF radiation. Therefore, the large body of research on detrimental non-thermal effects is ignored. This was further discussed in a peer-reviewed scientific comment article (3).

In 2018, ICNIRP published '*ICNIRP Note: Critical Evaluation of Two Radiofrequency Electromagnetic Field Animal Carcinogenicity Studies Published in 2018*' (36). It is surprising that this note claims that the histopathological evaluation in the US National Toxicology Program (NTP) study on animals exposed to RF radiation was not blinded (12,13). In fact, unfounded critique of the NTP study had already been rebutted (37); however, this seems to have had little or no impact on this ICNIRP note casting doubt on the findings of the animal study: '*This commentary addresses several unfounded criticisms about the design and results of the NTP study that have been promoted to minimize the utility of the experimental data on RFR [radiofrequency radiation] for assessing human health risks. In contrast to those criticisms, an expert peer-review panel recently concluded that the NTP studies were well designed, and that the results demonstrated that both GSM- and CDMA-modulated RFR were carcinogenic to the heart (schwannomas) and brain (gliomas) of male rats*' (37).

In contrast to the opinion of the 13 ICNIRP commission members, the IARC advisory group of 29 scientists from 18 countries has recently stated that the cancer bioassay in experimental animals and mechanistic evidence warrants high priority re-evaluation of the RF radiation-induced carcinogenesis (38).

ICNIRP draft. On July 11, 2018, ICNIRP released a draft on guidelines (39) for limiting exposure to time-varying electric, magnetic and electromagnetic fields (100 kHz to 300 GHz). It was open for public consultations until October 9, 2018. Appendix B was based on assessment of health risks based on a literature survey (39).

Surprisingly, the IARC classification of RF-EMF exposure as Group 2B ('possibly' carcinogenic to humans) from 2011 was concealed in the background material to the new ICNIRP draft on guidelines. Notably, one of the ICNIRP commission members, Martin Röösli (40), was also one of the IARC experts evaluating the scientific RF carcinogenicity in May 2011 (41). He should be well aware of the IARC classification. The IARC classification contradicts the scientific basis for the ICNIRP guidelines, making novel guidelines necessary and providing a basis to halt the rollout of 5G technology.

Therefore, the ICNIRP provides scientifically inaccurate reviews for various governments. One issue is that only thermal (heating) effects from RF radiation are considered, and all non-thermal effects are dismissed. An analysis from the UK demonstrates these inaccuracies (4), also discussed in another article (5). All members of the ICNIRP commission are responsible for these biased statements that are not based on solid scientific evidence.

ICNIRP release of novel guidelines for RF radiation. On March 11, 2020, ICNIRP published their novel guidelines for exposure to EMFs in the range of 100 kHz to 300 GHz, thus including 5G (8). The experimental studies demonstrating a variety of non-thermal biological/health effects (9,10) are not considered, as in their previous guidelines (6,7). Additionally, the ICNIRP increased the reference levels for the general public averaged over 6 min for RF frequencies >2-6 GHz (those that will be used for 5G in this frequency range), from 10 W/m^2 (Tables 5 and 7 in ref. no. 6) to 40 W/m^2 (Table 6 in ref. no. 8), which paves the way for even higher exposure levels to 5G than the already extremely high ones.

Background dosimetry is discussed in Appendix A of the ICNIRP 2020 guidelines (8). The discussion on 'Relevant Biophysical Mechanisms' should be criticized. The only mechanism considered by ICNIRP is temperature rise, which may also occur with 5G exposure, apart from the established non-thermal biological/health effects (42,43). It is well known among experts in the EMF-bioeffects field that the recorded cellular effects, such as DNA damage, protein damage, chromosome damage and reproductive declines, and the vast majority of biological/health effects are not accompanied by any significant temperature rise in tissues (44-47). The ion forced-oscillation mechanism (48) should be referred to as a plausible non-thermal mechanism of irregular gating of electrosensitive ion channels on cell membranes, resulting in disruption of the cell electrochemical balance and initiating free radical release and oxidative stress in the cells, which in turn causes genetic damage (15,49). The irregular gating of ion channels on cell membranes is associated with changes in permeability of the cell membranes, which ICNIRP admits in its summary (8).

Health risks are discussed in Appendix B of the ICNIRP 2020 guidelines (8). Again, only thermal effects are considered, whereas literature on non-thermal health consequences is disregarded (9,10,50). In spite of public consultations on the draft, the final published version on health effects is virtually identical to the draft version, and comments seem to have been neglected (19). In the following section, Appendix B on health effects (8) is discussed.

Appendix B starts with: '*The World Health Organization (WHO) has undertaken an in-depth review of the literature on radiofrequency electromagnetic fields (EMFs) and health, which was released as a Public Consultation Environmental Health Criteria Document in 2014... Further, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), a European Commission initiative, also produced a report on potential health effects of exposure to electromagnetic fields (SCENIHR 2015), and the Swedish Radiation Safety Authority (SSM) have produced several international reports regarding this issue (SSM 2015, 2016, 2018). Accordingly, the present guidelines have used these literature reviews as the basis for the health risk assessment associated with exposure to radiofrequency EMFs rather than providing another review of the individual studies*'.

In the last 11 years since its previous ICNIRP 2009 statement (7), ICNIRP has not managed to conduct a novel evaluation of health effects from RF radiation. However, as shown in Table I, several of the present ICNIRP members are also members of other committees, such as the EU Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), the Swedish Radiation Safety Authority (SSM) and the WHO, thus creating a cartel of individuals known to propagate the ICNIRP paradigm on RF radiation (4,5,22,51). In fact, six of the seven expert members of the WHO, including Emelie van Deventer, were also included in ICNIRP (5,7). Therefore, Emilie van Deventer, the team leader of the Radiation Programme at WHO (the International EMF Project), is an observer on the main ICNIRP commission, and SSM seems to be influenced by ICNIRP. Among the current seven external experts (Danker-Hopfe, Dasenbrock, Huss, Harbo Polusen, van Rongen, Röösli and Scarfi), five are also members of ICNIRP, and van Deventer used to be part of SSM.

As discussed elsewhere (5), it is unlikely that a person's evaluation of health risks associated with exposure to RF radiation would differ depending on what group the person belongs to. Therefore, by selecting group members, the final outcome of the evaluation may already be predicted (no-risk paradigm). Additionally, we believe that this may compromise sound scientific code of conduct.

The SCENIHR report from 2015 (52) has been used to legitimate the further expansion of the wireless technology and has been the basis for its deployment in a number of countries. One method, applied in the SCENIHR report, to dismiss cancer risks involves the selective inclusion of studies, excluding studies reporting cancer risks and including some investigations with inferior epidemiological quality. The report has been heavily criticized by researchers with no COI (53): '*In January of 2015, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) published its final opinion on (P)otential health effects of exposure to electromagnetic fields... SCENIHR has not answered the question it was appointed to investigate. The Committee has answered a* *different question, limiting its conclusions to whether certainty or causal effect is established, instead of possibility of health risks... Overall, SCENIHR has not conducted a scientific review process for judging possible health risks. This results in erroneous and deceptive conclusions by failing to conclude such possible health risks do exist. Evidence that SCENIHR has presented clearly and conclusively demonstrates that EMF health risks are possible, and in some cases are established. The Committee is obligated to draw to the attention of the European Commission that EMF is a new and emerging problem that may pose an actual or potential threat*'.

Regarding the SSM, only yearly updates are available and no overall evaluations are made. Therefore, no thorough review is presented. Over the years, the ICNIRP has dominated this committee (Table I). Therefore, it is unlikely that the opinion of the SSM will differ from that of the ICNIRP.

In 2014, the WHO launched a draft of a Monograph on RF fields and health for public comments (54). It should be noted that the WHO issued the following statement: '*This is a draft document for public consultation. Please do not quote or cite*'. ICNIRP completely ignored that request and used the aforementioned document. The public consultations on the draft document were dismissed and never published.

In addition to van Deventer, five of the six members (Mann, Feychting, Oftedal, van Rongen, and Scarfi) of the Core Group in charge of the WHO draft were also affiliated with ICNIRP, which constitutes a COI (Table I). Scarfi is a former member of ICNIRP (5). Several individuals and groups sent critical comments to the WHO on the numerous shortcomings in the draft of the Monograph on RF radiation. In general, the WHO never responded to these comments and it is unclear to what extent, if any, they were even considered. Nevertheless, the final version of the WHO 'in-depth review' has never been published. Instead, WHO made a call on October 8, 2019 (Emelie van Deventer), for systematic reviews to analyze and synthesize the available evidence: '*Through this Call, WHO invites eligible teams to indicate their interest in undertaking a systematic review on one (or more) of the following topics: SR1 - Effect of exposure to RF on cancer (human observational studies); SR2 - Effect of exposure to RF on cancer (animal studies); SR3 - Effect of exposure to RF on adverse reproductive outcomes (human observational studies); SR4 - Effect of exposure to RF on adverse reproductive outcomes (animal and in vitro studies); SR5 - Effect of exposure to RF on cognitive impairment (human observational studies; SR6 - Effect of exposure to RF on cognitive impairment (human experimental studies); SR7 - Effect of exposure to RF on symptoms (human observational studies); SR8 - Effect of exposure to RF on symptoms (human experimental studies; SR9 - Effect of exposure to RF on biomarkers of oxidative stress; SR10 - Effect of exposure to heat from any source and pain, burns, cataract and heat-related illness*'.

The authors of the present article were part of a team that applied to review SR1- human cancer. On December 20, 2019, the following reply was received from the WHO Radiation Programme: '*After careful review, we have decided to choose another team for this systematic review*'.

Transparency is of importance for the whole process. Therefore, a query was sent to the WHO requesting information regarding the following points: '*Who did the evaluation of the groups that answered the call? What criteria were applied? How many groups had submitted and who were these? Which groups were finally chosen for the different packages?*'. In spite of sending the request four times, January 2, January 3, April 7 and April 30, 2020, there has been no reply from WHO. This appears to be a secret process behind closed doors. These circumstances have also been reported in Microwave News (55).

It is important to comment on the current ICNIRP evaluation. Notably, on February 27, 2020, two weeks before the ICNIRP publication, the WHO Team on Public Health, Environmental and Social Determinants of Health issued a statement on 5G mobile networks and health: '*To date, and after much research performed, no adverse health effect has been causally linked with exposure to wireless technologies*' (56). This statement is not correct based on current knowledge (4,5,9-11,17,19) and was without a personal signature. The lack of research on 5G safety has been previously discussed (19). Furthermore, there is no evidence that can 'causally link' an adverse effect to an exposure. Causality is no empirical fact, it is an interpretation.

In the following section, only one (cancer) of the eight different end points in the ICNIRP publication (8) is discussed, since it deals with our main research area.

viii) Cancer.

'I*n summary, no effects of radiofrequency EMFs on the induction or development of cancer have been substantiated.*

Summary

The only substantiated adverse health effects caused by exposure to radiofrequency EMFs are nerve stimulation, changes in the permeability of cell membranes, and effects due to temperature elevation. There is no evidence of adverse health effects at exposure levels below the restriction levels in the ICNIRP (1998) guidelines and no evidence of an interaction mechanism that would predict that adverse health effects could occur due to radiofrequency EMF exposure below those restriction levels'.

Comments

The ICNIRP draft (39) has been previously described to some extent (19). The published final version on health effects is virtually similar to the draft. It cannot be taken at face value as scientific evidence of no risk from RF radiation. One example is the following statement (p. 41): '*...a set of case-control studies from the Hardell group in Sweden report significantly increased risks of both acoustic neuroma and malignant brain tumors already after less than five years since the start of mobile phone use, and at quite low levels of cumulative call time'.*

This allegation is not correct according to our publication for glioma (11). In the shortest latency group >1-5 years, the risk of glioma was not increased (odds ratio (OR), 1.1; 95% CI, 0.9-1.4) for use of wireless phones (mobile phone and/or cordless phone). There was a statistically significant increased risk of glioma per 100 h of cumulative use (OR, 1.011; 95% CI, 1.008-1.014) and per year of latency (OR, 1.032; 95% CI, 1.019-1.046) (11). These published results are in contrast to the ICNIRP claims.

Regarding acoustic neuroma, the corresponding detailed results are reported in our previous study (57). The shortest latency period >1-5 years yielded an OR of 1.2 (95% CI, 0.8-1.6) for use of wireless phones; the risk increased per 100 h of cumulative use (OR, 1.008; 95% CI, 1.002-1.014) and per year of latency (OR, 1.056; 95% CI, 1.029-1.085) (57). Therefore, the allegation by ICNIRP is false.

It is remarkable that ICNIRP is uninformed and that their writing is based on a misunderstanding of the peer-reviewed published articles as exemplified above. Additionally, our studies (11,57) and another study by Coureau *et al* (58), as well as the IARC evaluation from 2011 (1,2), are not included among the references. Several statements by ICNIRP are made without any scientific references. On the other hand, the Danish cohort study on mobile phone use (59) is included, in spite of the fact that it was judged by IARC (1,2), as well as in our review (60), to be uninformative. A biased article written by authors including ICNIRP members, used to 'prove' the no-risk paradigm for RF radiation carcinogenesis (23), is cited by ICNIRP. Notably, the article has not undergone relevant peer-review and we believe that it should not have been published in its current version. The shortcomings in the aforementioned article are discussed in the following sections. As discussed below, another claim (23) is incorrect regarding increased risk of brain tumors associated with use of wireless phones: '*However, they are not consistent with trends in brain cancer incidence rates from a large number of countries or regions, which have not found any increase in the incidence since mobile phones were introduced'.*

The criticism of the ICNIRP draft guidelines from 2018 by the EMF call (61) can also be applied to the current ICNIRP publication. The call has been signed by 164 scientists and medical doctors, as well as 95 NGOs: '*The International Commission on Non-Ionizing Radiation Protection (ICNIRP) issued draft Guidelines on 11th July 2018 for limiting exposure to electric, magnetic and electromagnetic fields (100 kHz to 300 GHz).1 These guidelines are unscientific, obsolete and do not represent an objective evaluation of the available science on effects from this form of radiation. They ignore the vast amount of scientific findings that clearly and convincingly show harmful effects at intensities well below ICNIRP guidelines.2 The guidelines are inadequate to protect humans and the environment. ICNIRP guidelines only protect against acute thermal effects from very short and intense exposure. The guidelines do not protect against harmful effects from low-intensity and long-term exposure, such as cancer, reproductive harm, or effects on the nervous system, although these effects are convincingly shown to appear from chronic exposure at intensities below ICNIRP limits.2,3*

ICNIRP's mandate to issue exposure guidelines needs to be seriously questioned. ICNIRP is not independent of industry ties as it claims.12,13 Its opinions are not objective, not representative of the body of scientific evidence, but are biased in favor of industry. It is obvious from their reluctance to consider scientific findings of harm that ICNIRP protects industry, not the public health, nor the environment.

We ask the United Nations, the World Health Organization, and all governments to support the development and consideration of medical guidelines16, that are independent of conflict of interests in terms of direct or indirect ties to industry, that represent the state of medical science, and that are truly protective'.

In the recent report on ICNIRP published by two Members of the European Parliament it is concluded: '*That is the most important conclusion of this report: For really independent scientific advice we cannot rely on ICNIRP. The European Commission and national governments, from countries like Germany, should stop funding ICNIRP. It is high time that the European Commission creates a new, public and fully independent advisory council on non-ionizing radiation'* (22).

Other examples of scientific misrepresentation

Published article. This section discusses an article with conclusions not substantiated by scientific evidence, representing a biased evaluation of cancer risks from mobile phone use and is an example of lack of objectivity and impartiality (23). The aforementioned report was used by ICNIRP 2020 (8) to validate that no risks have been found for brain and head tumors. Therefore, the article should be discussed in further detail.

The aforementioned article has numerous severe scientific deficiencies. One is that the results on use of cordless phones as a risk factor for brain tumors are not discussed. In fact, detailed results on cordless phones in studies by Hardell *et al* (11,57) are omitted.

When discussing glioma risk, all results on cumulative use of mobile phones, as well as ipsilateral or contralateral use associated with tumor localization in the brain, are omitted from the figures in the main text. Some results in the article by Röösli *et al* (23), such as cumulative use, can be found in the Supplementary Material, although the increased risk among heavy users is disregarded (11,57,58,62). In Supplementary Figure 4, all odds ratios regarding long-term (≥10 years) use of mobile phones are above unity (>1.0) for glioma and neuroma (23). No results are provided for ipsilateral mobile phone use (same side of tumor localization and mobile phone use), which is of large biological importance. Results on cumulative use, latency and ipsilateral use are especially important for risk assessment and have shown a consistent pattern of increased risk for brain and head tumors (11,57).

In the aforementioned article, recall bias is discussed as the reason for increased risk (23). The studies by Hardell *et al* (11,57) included all types of brain tumors. In one analysis, meningioma cases in the same study were used as the 'control' entity (11), and still a statistically significant increased risk of glioma was identified for mobile phone use (ipsilateral OR, 1.4; 95% CI, 1.1-1.8; contralateral OR, 1.0; 95% CI, 0.7-1.4) and for cordless phone use (ipsilateral OR, 1.4; 95% CI, 1.1-1.9; contralateral OR, 1.1; 95% CI, 0.8-1.6). If the results were 'explained' by recall bias, similar results would have been obtained for both glioma and meningioma. Thus, this type of analyses would not have yielded an increased glioma risk. Also, for acoustic neuroma a statistically significant increased risk was found using meningioma cases as 'controls' (57). Therefore, the results in the studies by Hardell *et al* (11,57) cannot be explained by a systematic difference in assessment of exposure between cases and controls. These important methodological findings were disregarded by Röösli *et al* (23).

In the analyses of long-term use of mobile phones, a Danish cohort study on mobile phone use is included (59), which was concluded to be uninformative in the 2011 IARC evaluation (1,2). A methodological shortcoming of the aforementioned study was that only private mobile phone subscribers in Denmark between 1982 and 1995 were included in the exposure group (59). The most exposed group, comprising 200,507 corporate users of mobile phones, were excluded and instead included in the unexposed control group consisting of the rest of the Danish population. Users with mobile phone subscription after 1995 were not included in the exposed group and were thus treated as unexposed at the time of cut-off of the follow up. No analysis of laterality of mobile phone use in relation to tumor localization was performed. Notably, this cohort study is now included in the risk calculations, although Martin Röösli was a member of the IARC evaluation group and should have been aware of the IARC decision. The numerous shortcomings in the Danish cohort study, discussed in detail in a peer-reviewed article (60), are omitted in the article by Röösli *et al* (23).

Regarding animal studies, a study by Falcioni *et al* (14) at the Ramazzini Institute on RF radiation carcinogenesis is only mentioned as a reference, but the results are not discussed. In fact, these findings (14) provide supportive evidence on the risk found in human epidemiology studies (3), as well as the results in the NTP study (12,13).

Furthermore, for incidence studies on brain tumors, the results are not presented in an adequate way. There is a lot of emphasis on the Swedish Cancer Register data (63,64), but the numerous shortcomings in the reporting of brain tumor cases to the register are not discussed. These shortcomings have been presented in detail in a previous study (63), but are disregarded by Röösli *et al* (23).

There is clear evidence from several countries regarding increasing numbers of patients with brain tumors, such as in Sweden (63,64), England (65), Denmark (66) and France (67).

The article by Röösli *et al* (23), does not represent an objective scientific evaluation of brain and head tumor risk associated with the use of wireless phones, and should thus be disregarded. By omitting results of biological relevance and including studies that have been judged to be uninformative, the authors come to the conclusion that there are no risks: '*In summary, current evidence from all available studies including in vitro, in vivo, and epidemiological studies does not indicate an association between MP [mobile phone] use and tumors developing from the most exposed organs and tissues'.*

Röösli *et al* (23), disregard the concordance of increased cancer risk in human epidemiology studies (11,57,58,62) animal studies (12-14,68,69) and laboratory studies (15,16,37). It is unfortunate that the review process of the aforementioned article has not been of adequate quality. Finally, there is no statement in the article of specific funding of this particular work, which is not acceptable. Only a limited number of comments on general funding are provided. It is not plausible that there was no funding for the study. We believe that, due to its numerous limitations, the aforementioned article should not have been published.

CEFALO. In 2011, a case-control study on mobile phone use and brain tumor risk among children and adolescents termed CEFALO was published (70). The study appears to have been designed to misrepresent the true risk, since the following question regarding cordless phone use was asked: '*How often did [child] speak on the cordless phone in the first 3 years he/she used it regularly?*'.

There are no scientific valid reasons to limit the investigation to the first 3 years. The result is a misrepresentation and a wrong exposure classification, since Aydin *et al* (70) willingly omitted any increase in the child's use of and exposure from cordless phone radiation after the first 3 years of use. This unscientific treatment of cordless phone exposure was not mentioned in the article other than in a footnote of a table and in the methods section (70); however, no explanation was provided: '*Specifically, we analyzed whether subjects ever used baby monitors near the head, ever used cordless phones, and the cumulative duration and number of calls with cordless phones in the first 3 years of use*'.

Since previous studies have demonstrated that these phone types, in addition to mobile phones, increase brain tumor risk (11,57), we believe that the exclusion of a complete exposure history on the use of cordless phones represents scientific misconduct.

In a critical comment the authors of the present study wrote: '*Further support of a true association was found in the results based on operator-recorded use for 62 cases and 101 controls, which for time since first subscription >2.8 years yielded OR 2.15 (95% CI 1.07-4.29) with a statistically significant trend (P = 0.001). The results based on such records would be judged to be more objective than face-to-face interviews, as in the study that clearly disclosed to the interviewer who was a case or a control. The authors disregarded these results on the grounds that there was no significant trend for operator data for the other variables - cumulative duration of subscriptions, cumulative duration of calls and cumulative number of calls. However, the statistical power in all the latter groups was lower since data was missing for about half of the cases and controls with operator-recorded use, which could very well explain the difference in the results*' (71).

Our conclusion was that: '*We consider that the data contain several indications of increased risk, despite low exposure, short latency period, and limitations in the study design, analyses and interpretation. The information certainly cannot be used as reassuring evidence against an association, for reasons that we discuss in this commentary*' (71).

This is in contrast to the authors that claimed that the study was reassuring of no risk in a press release from Martin Röösli, July 28, 2011: '*Kein erhöhtes Hirntumorrisiko bei Kindern und Jugendlichen wegen Handys... Die Resultate sind beruhigend*' ['*No increased brain tumour risk in children and adolescents for mobile phone users... The results are reassuring*'] (72).

A similar press release was issued by Maria Feychting at the Karolinska Institute in Stockholm stating: '*Reassuring results from first study on young mobile users and cancer risk... The so called CEFALO study does not show an increased brain tumor risk for young mobile users*' (73). Considering the results and the numerous scientific shortcomings in the study (70), the statements in these press releases are not correct.

Discussion

There is no doubt that several individuals included in Table I are influential, being members, as well as having consulting assignments, in several organizations, such as ICNIRP, BERENIS, the SSM, the Program Electromagnetic Fields and Health from ZonMw in the Netherlands, and the Rapid Response Group for the Japan EMF Information Center (74).

In fact, there appears to be a cartel of individuals working on this issue (75). Associate Professor Martin Röösli has had the chance to provide his view on the content of the present article relating to him. The only message from him was in an e-mail dated January 16, 2020: '*Just to be clear, all my research is funded by public money or not-for -profit fundations [foundations]. I think you will not help an important debate if you spread fake news*'. Obviously, as described in the present article, his comment is not correct considering his funding from the telecom industry (76,77).

As shown in Table I, few individuals, and mostly the same ones, are involved in different evaluations of health risks from RF radiation and will thus propagate the same views on the risks in agencies of different countries associated with the ICNIRP views (4,5). Therefore, it is unlikely that they will change their opinions when participating in different organizations. Furthermore, their competence in natural sciences, such as medicine, is often low or non-existent due to a lack of education in these disciplines (2). Therefore, any chance for solid evaluations of medical issues is hampered. Additionally, it must be concluded that if the 'thermal only' dogma is dismissed, this will have wide consequences for the whole wireless community, including permissions for base stations, regulations of the wireless technology and marketing, plans to roll out 5G, and it would therefore have a large impact on the industry. This may explain the resistance to acknowledge the risk by ICNIRP, EU, WHO, SSM and other agencies. However, the most important aspects to consider are human wellbeing and a healthy environment. Telecoms can make profit in a variety of ways, and wireless is just one of them. They have the capacity to maintain profits by using different techniques, such as optical fiber, that will provide more data with less RF radiation exposure. Particularly when considering the liability, they are incurring in their misguided insistence of wireless expansion that may ultimately catch up to them in the form of lawsuits, such as those previously experienced by asbestos and tobacco companies (78,79).

A recent book describes how deception is used to capture agencies and hijack science (80). There are certain tools that can be used for this. One is to re-analyze existing data using methods that are biased towards predetermined results (23). For example, this can be performed by hiring 'independent experts' to question scientific results and create doubt (81,82). As clearly discussed in a number of chapters of the books (80-82), front groups may be created to gain access to politicians and to influence the public with biased opinions. Other methods may involve intimidating and harassing independent scientists that report health risks based on sound science, or removing all funding from scientists who do not adhere to the no-risk pro-industry paradigm. Another tool would be economic support and courting decision makers with special information sessions that mislead them on science and mask bribery (3,5,19,80-82). An industry with precise marketing goals has a big advantage over a loose scientific community with little funding. Furthermore, access to regulatory agencies and overwhelming them with comments on proposed regulations is crucial (3). To counteract all these actions is time consuming and not always successful (19). Nevertheless, it is important that these circumstances are explored and published in the peer-reviewed literature as historical notes for future use.

Based on the Swiss and ICNIRP experiences, some recommendations can be made. One is to include only unbiased and experienced experts without COIs for evaluation of health risks from RF radiation. All countries should declare a moratorium on 5G until independent research, performed by scientists without any ties to the industry, confirms its safety or not. 2G, 3G, 4G and WiFi are also considered not to be safe, but 5G will be worse regarding harmful biological effects (42,83,84). The authors of the present article recommend an educational campaign to educate the public about the health risks of RF radiation exposure, and safe use of the technology, such as the deployment of wired internet in schools (85), as previously recommended by the European Council resolution 1815 in 2011 (86) and The EMF Scientist Appeal (87). Additionally, it is recommended that the government takes steps to markedly decrease the current exposure of the public to RF radiation, (88,89). Notably, DNA damage has been identified in peripheral blood lymphocytes using the comet assay technique, and in buccal cells using the micronucleus assay, in individuals exposed to RF radiation from base stations (90).

Finally, an alternative approach to the flawed ICNIRP safety standards may be the comprehensive work of the European Academy for Environmental Medicine (EUROPAEM) EMF working group that has resulted in safety recommendations, which are free from the ICNIRP shortcomings (50). Recently, the International Guidelines on Non-Ionising Radiation (IGNIR) have accepted EUROPAEM safety recommendations (91). The Bioinitiative group has recommended similar safety standards based on non-thermal EMF effects (92). WHO and all nations should adopt the EUROPAEM/Bioinitiative/IGNIR safety recommendations, supported by the majority of the scientific community, instead of the obsolete ICNIRP standards.

In conclusion, it is important that all experts evaluating scientific evidence and assessing health risks from RF radiation do not have COIs or bias. Being a member of ICNIRP and being funded by the industry directly, or through an industry-funded foundation, constitute clear COIs. Furthermore, it is recommended that the interpretation of results from studies on health effects of RF radiation should take sponsorship from the telecom or other industry into account. It is concluded that the ICNIRP has failed to conduct a comprehensive evaluation of health risks associated with RF radiation. The latest ICNIRP publication cannot be used for guidelines on this exposure.

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Authors' contributions

LH and MC contributed to the conception, design and writing of the manuscript. Both authors read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

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Competing interests

The authors declare that they have no competing interests.

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Original article

Hematobiochemical and histopathological alterations of kidney and testis due to exposure of 4G cell phone radiation in mice

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ABSTRACT

The radiofrequency electromagnetic radiation emitted by smart phones on biological systems has wide media coverage and public concern in recent years. The aim of this study was to explore the effects of fourth-generation cell phone radiation exposure on hematological (Total leukocyte count, Total erythrocyte count, and hemoglobin %), biochemical (Serum creatinine) parameters, and histopathological changes in the kidney and testis of Swiss albino mice. A total of 30 male Swiss albino mice weighing 45–65 g was randomly divided into three groups (n = 10). The first group A was the control group, the second group B, was exposed to 40 minutes of mobile phone radiation daily, the third group C was exposed to 60 minutes of radiation daily from two 2400 Megahertz fourth-generation connected mobile phones for 60 days, respectively. The electromagnetic radiation frequency radiometer measured the frequency of electromagnetic radiation emitted from cell phones. The specific absorption rate was calculated as 0.087 W/kg. The control group was kept under similar conditions, but the electromagnetic field was not given for the same period. All the mice were sacrificed at the end of the experiment. The blood samples were collected for hematobiochemical study, and then kidney and testis tissues were collected for histopathological study. Results of the study showed that the body weight and total erythrocyte count values were significantly ($p < 0.05$) decreased while total leukocyte count, hemoglobin %, and serum creatinine values were significantly ($p < 0.05$) increased in both the radiation exposure groups relative to the control group. Histopathological observation showed the kidney of 60 minutes exposed mice interstitial inflammation that causes marked mononuclear cellular infiltration compared to the 40 minutes and control mice. Compared to control mice, histopathological examinations of testicular tissue from the exposed mice, showed irregular in shapes and non-uniform sizes and fewer spermatogenic cells layer that leads to the larger lumen in the seminiferous tubules. It is concluded that fourth-generation cell phone radiation exposure may affect blood hemostasis and inflammation of mice's kidney and testis tissue. Based on these studies, it is important to increase public consciousness of potential adverse effects of mobile phone radiofrequency electromagnetic radiation exposure.

1. Introduction

Mobile phone use has dramatically increased over the last decade. Researchers had recommended that electromagnetic fields (EMF) released into the atmosphere from a mobile phone has deleterious effects on human beings (Azab, 2017; Elmas, 2016). At present mobile phones have started using fourth generation (4G) wireless communication technology (2200–2400 Megahertz (MHz)) that offer a very high internet speed. The adverse effects of EMF are a global public concern at present. Numerous adverse effects of cell phone use have been reported on different body organs such as the brain (Hardell et al., 2011; Kesari et al., 2011), ear (Colletti

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et al., 2011), and reproductive organs (Erogul et al., 2006; Falzone et al., 2011; Khillare and Behari, 1998). Many other studies have confirmed that the electromagnetic frequencies from mobile phone can cause numerous deleterious effects on molecular and cellular levels, such as DNA injury, various forms of cancer, oxidative stress, lipid peroxidation, increased free radicals, and chromosomal abnormalities (Akdag et al., 2016; Çam and Seyhan, 2012; Chauhan et al., 2017; Dasdag et al., 2015; Deshmukh et al., 2013; Megha et al., 2015). Blood parameters are the most significant way of assessing the state of health of animal models (Alghamdi and El-Ghazaly, 2012). EMF exposure from cell phones to humans contributes to reduced blood cells and an imbalance in plasma enzymes (Alghamdi and El-Ghazaly, 2012; Hasan and Issmer, 2014). In animal studies, long-term exposures to EMF can have detrimental effects on the liver, blood cells, and other activities. Hoverer, varying degrees of EMF have a conflicting influence on the blood and blood formation in animals (Sani et al., 2018; Usman et al., 2011). The impact of EMF in rats causes decreased hemoglobin oxygen-binding capacity; i.e., hypoxia does not exclude kidney damage contributions. It also has to be supposed that radiation influences hematopoiesis in the blood and bone marrow in the animals (Singh et al., 2004).

EMF has many biochemical consequences, such as the degradation of large cell molecules and ionic equilibrium imbalances. EMF exposure is associated with increased amounts of reactive oxygen species (ROS) formation (Kivrak et al., 2017). These ROS may cause injury to cellular constituents, including lipids, proteins, and DNA. Free radical generation may happen in various ways, such as UV light, immune response, radioactivity, stress, cigarettes, and physiological redox (Okano, 2008). It has been shown that electromagnetic radiation influences their impact on living organisms by producing or rising ROS. ROS leads to various physiological influences, such as DNA damage. Exposure to cell phone radiation oxidative stress (OS) has been increased in hematopoietic sites (Moustafa et al., 2001). The kidneys could absorb EMF from 900-MHz cell phones as, most of the time, they are carried by the belt (Oktem et al., 2005). Current concerns on mobile phone exposure are mainly focused on the kidney and testis. Because the mobile phone is usually kept in a pocket that is very close to the urogenital organ. The 2400 MHz 4G radiofrequency electromagnetic radiation (RF-EMR) has been exposed to male mice over a long period in this study.

The exposure of wireless electromagnetic radiation may injure both the hepatic, renal, and splenic tissues. Hasan and Islam (2020) reported that mononuclear cellular aggregates surrounding the bile duct and hepatic artery with congestion in the portal vein and the central vein of the liver after daily exposure of 4G connected 2400 MHz mobile phone radiation to mice whole-body for a month. With EMF exposure time, the amount of harm increased. The extent of potential harm expanded with the duration of EMF exposure (Lee et al., 2010).

Studies show that exposure to toxic chemicals, ionizing radiation, radiofrequency (RF) radiation, and other environmental nuisances are mainly related to male infertility (Bin-Meferij and El-Kott, 2015). In contrast, many studies have found that mobile phones have harmful effects on the male reproductive system (Kesari et al., 2011). EMF has probable harmful effects on male reproductive functions, specially Leydig cells, seminiferous tubules, and spermatozoa. The harmful effects of EMF on the male reproductive system based on the wave frequency and duration of exposure are the main factors (Kesari et al., 2011, 2010). Many cross-sectional experiments have already shown that cellular device usage may be related to semen quality, and increase cell phone use may cause male infertility (Ozguner et al., 2005; Pareek et al., 2005). (Lee et al. (2010) examined testicular histological changes in rats exposed to 848.5 MHz radiofrequency radiation (RFR) for 12 weeks. The possible adverse effects of mobile phone exposure on male fertility have been widely studied in the past decade by several researchers who have documented notable adverse effects of radiation on testis and seminal parameters, including motility, concentration and changes in testicular morphology, increased permeability of the blood-testis barrier, decreased sperm count, and percent normal morphology (Agarwal et al., 2008; Aitken et al., 2005; Fejes et al., 2005). Most mobile phone users bring their mobile phone in their pant pocket throughout the day that is very close to their genitals (Lavranos et al., 2012). Experiment results evaluated to identify testicular damages caused by low-intensity RF indicate contradictory findings (Dasdag et al., 1999; Ozguner et al., 2005; Ribeiro et al., 2007; Saunders and Kowalczuk, 1981; Yan et al., 2007). The leading cause associated with these adverse consequences was increased oxidative stress inside the reproductive organs (De Iuliis et al., 2009; Kesari et al., 2010; Mailankot et al., 2009; Naziroğlu et al., 2013; Qin et al., 2012). There has been a marked decrease in male fertility (Sepehrimanesh et al., 2014; Yildirim et al., 2015). Therefore, it is essential to evaluate the impact of RF-EMR on male fertility more reliably because men frequently carry mobile phones in their pockets, which is close to their reproductive organs.

Much of the previous research had already been conducted using second generation (2G) or third generation (3G) wireless mobile radiation exposure causes many physiological changes; however, no study has been undertaken using the 4G cell phone radiation (2200–2400 MHz) exposure in animal model. Besides this, mobile phone radiation can be consumed more by pelvic organs, particularly the kidney and testis, than many other inner organs. Therefore this experiment aimed to evaluate the impact of a 4G cell phone radiation exposure on hematobiochemical and possible histopathological effects on the kidney and testis of the Swiss albino mice model.

2. Materials and methods

2.1. Statement of the experiment

The research work was conducted in the Department of Anatomy and Histology, Faculty of Veterinary Science, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh during the period from August 2018 to December 2019 to assess the impacts of 4G cell phone radiation on hematological (Total leukocyte count, Total erythrocyte count, and hemoglobin %), biochemical (Serum creatinine) parameters and histopathological changes in the kidney and testis of Swiss albino mice.

2.2. Ethical approval

As per the standardized instruction, all of the animals received human care. These research interventions have been permitted and carried out in compliance with animal welfare recommendations and use as defined by the Animal Welfare and Experimental Ethics Committee, Bangladesh Agricultural University, Mymensingh, Bangladesh (Protocol Number: AWEEC/BAU/2019-56).

2.3. Animals and experimental procedures

Swiss albino male mice (6 weeks old) (45 ± 65 g) have been obtained from the International Center for Diarrheal Disease Research (ICDDRB), Mohakhali, Dhaka. All the mice appeared to have good health and lacked any visible deformities. In the temperature-controlled environment, the mice were kept 52 cm × 36 cm × 25 cm in plastic cages. Daily diet and drink water ad libitum were given. After one week of acclimatization, the mice were haphazardly categorized into three equivalent groups; each group includes ten mice. The group named were A, B, and C. Individual weights of all mice were documented before radiation exposure. Among all of the three groups, group A has been considered controlled without radiation exposure. Group B was exposed to 40 min of radiation, and group C was exposed to 60 min of radiation from 4G cell phone connected handsets. Both experimental and operational requirements were designed to comply with the Care and Use of Laboratory Animals published by the U.S. National Institutes of Health.

2.4. The electromagnetic radiation exposure system

Two 2400 Megahertz (MHz) 4G connected mobile phones (Huawei GR5 2017) have been used for the generation of the radiofrequency electromagnetic radiation (RF-EMR) with different duration of exposure every day for 60 days (2 months). The cell phone with auto-answer mode was centrally installed on the roof of the mice cage from the inside for unified radiation exposure during the exposure time, trying to avoid contact with both animals and phones (Kumar et al., 2009; Narayanan et al., 2009). At first, we confirmed that there was no other source of electromagnetic fields (EMF). The temperature and humidity of the exposure room and the mouse cage were measured regularly during the RF-EMR application using a digital thermometer. When the mice were exposed to radiation, the frequency of RF-EMR emitted from cell phones was first measured by the electromagnetic radiation frequency radiometer (ED-78S Electrosmog frequency meter) in an active call using 2400 MHz range and assure that radiation exposure is uniformly distributed on the mice. The Specific absorption rate (SAR) was calculated as 0.087 W/kg. When the exposure begins, a call was made to the cell phone placed in the mice cage by another 4G connected 2400 MHz mobile phone and kept in answer mode for 40 and 60 min, respectively. During RF-EMR exposure, the mobile phone was held in the loudspeaker mode. Group B was exposed for 40 min per day hourly from 10.00 AM to 10.40 AM; Group C was exposed for 60 min, from 10.00 AM to 11.00 AM per day. The control group A was placed away from the radiofrequency source in the plastic cage. However, it was not receiving any exposure to radiation. This is similar to the exposure method used in previous studies for the 900-MHz RF-EMR application (Baş et al., 2013; Keleş et al., 2018; Odac et al., 2016; Odaci et al., 2015). That whole exposure time has been continued for two months.

2.5. Bodyweight

Each mouse's body weight was weighed using a digital scale at the beginning of the exposure to radiation and on the day of sacrificing.

2.6. Hematological analysis

The blood samples were obtained by sacrificing the mice at the end of the experiment. Approximately 1 ml of blood from the syringe was collected for hematological tests in the test tube containing anticoagulant Ethylene diamine tetraacetic acid (EDTA). The remaining amount of syringe blood has been used to obtain the serum. The below hematological variables were tested using Sysmex automated CBC analyzers: Total erythrocyte count (TEC), Hemoglobin (Hb) percentage (%), and Total leukocyte count (TLC).

2.7. Biochemical analysis

Approximately 2 ml of blood was obtained in a sterile glass test tube. The blood containing syringe was held upright at room temperature for 6 h. The tubes were then incubated in the refrigerator (4°C) overnight. Serum samples were isolated and centrifuged to eliminate excess blood cells where possible. Serum samples were deposited in the capped tube at −20°C for analysis of serum creatinine by using a CS-T240 auto-chemistry analyzer.

2.8. Sample collection for gross and histological study

Following blood collection, the kidney and testis were obtained for gross and histopathological inspection. Both kidneys and testis of different groups of mice were collected for the gross study. Parameters such as color and weight were taken into consideration for gross observation. The weight of the kidney and testis in the control group and the exposed group of mice were measured on a graded scale. After gross examination, samples were stored in 10% formaldehyde for 48 h. After processing to make paraffin blocks, 7 mm sections were cut using a rotary microtome (Leica RM2135) and stained with Haematoxylin & Eosin (H & E) stain for routine histological examination as per the proper procedure described by the (Zare et al., 2007).

2.9. Statistical analysis

The statistical analysis has been carried out using Graph pad prism software version 7.0 (GraphPad Software Inc., San Diego, CA). For statistical analysis One-way ANOVA followed by Turkeys Multiple Comparison Test was performed. A p-value <0.05 was considered to be statistically significant. Data were expressed as mean ± standard error (mean ± SEM).

3. Results

3.1. Effects on body weight

The mean body weight of mice in different groups has been presented in (Fig. 1A). The initial and final body weight of control mice was 25.36 ± 0.48 and 40.30 ± 0.21 g, respectively. In 40- and 60-minutes exposed mice, the mean body weight at the beginning of exposure and the end of the experiment were 26.47 ± 1.53, 28.74 ± 1.67 and 27.66 ± 1.65, 31.49 ± 0.89 g, respectively. After the end of the exposure, the body weight was significantly ($p < 0.05$) decreased in both exposed mice compared to the control mice.

3.2. Effects on hematological and biochemical parameters

The effects of mobile phone radiations on different hematological parameters, i.e., Total leukocyte count (TEC), Total erythrocyte count (TLC), and hemoglobin percentage (Hb%) in mice, were presented in (Fig. 1B). In the control mice, the mean value of TEC, TLC and Hb% were 7.23 ± 0.08, 5.81 ± 0.29 and 6.46 ± 0.13. The values of TLC and Hb% were increased significantly ($p < 0.05$) in 40 min (7.06 ± 0.13, 7.13 ± 0.31) and 60 min (7.87 ± 0.22, 7.76 ± 0.14) exposed mice compared to the control mice. In comparison to the 40 min exposed (6.70 ± 0.13) and control (7.23 ± 0.08) mice the values of TEC decreased significantly ($p < 0.05$) in 60 min (6.15 ± 0.27) exposed mice. The results of mobile phone radiations on Serum creatinine in different groups of mice were presented in (Fig. 1C). There was a significant increase ($p < 0.05$) in serum creatinine value in 40 min (0.80 ± 0.03) and 60 min (1.50 ± 0.06) exposed mice compared to the control mice (0.58 ± 0.06). Serum levels of creatinine indirectly reflect the kidney injury.

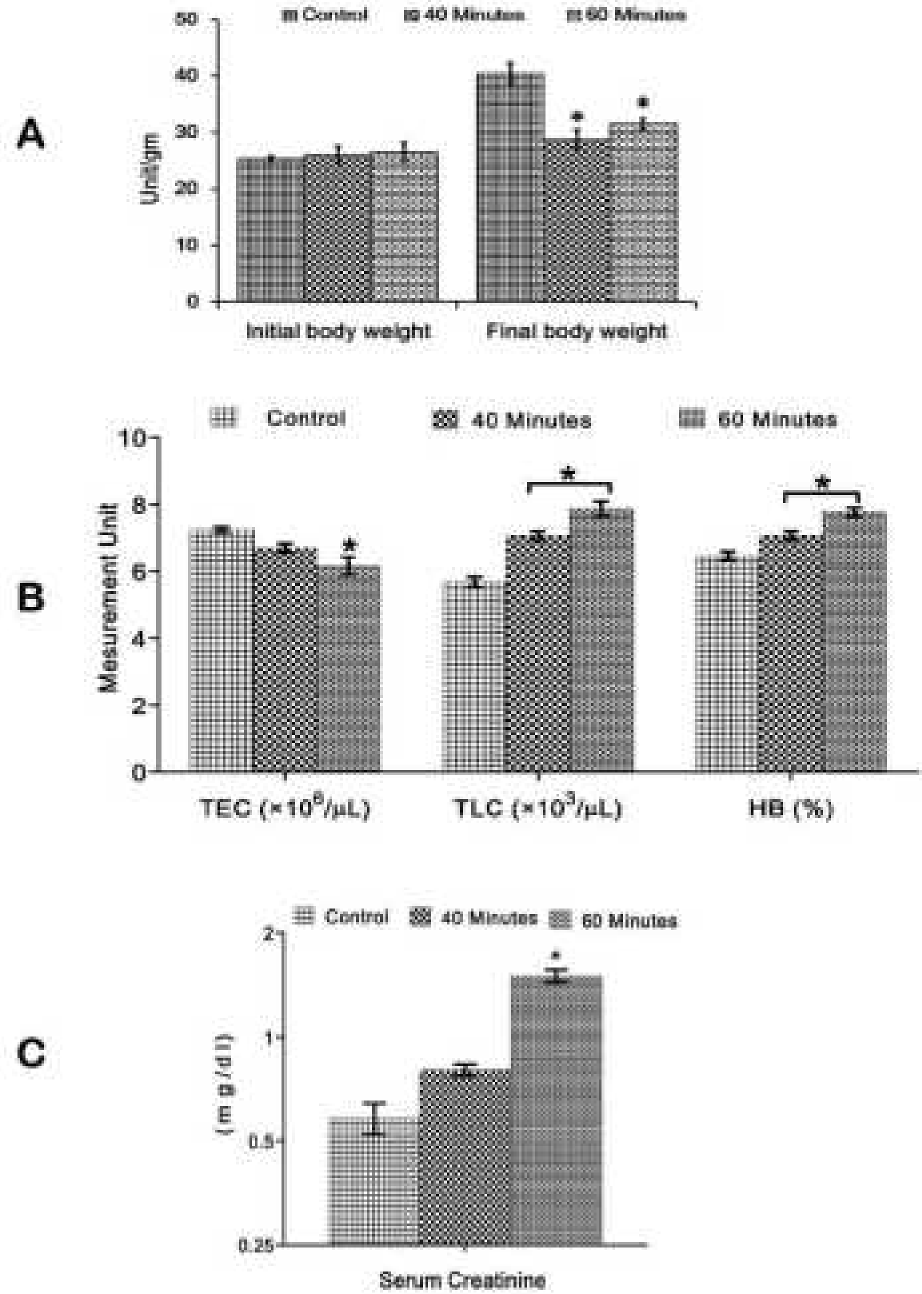

Fig. 1. (A) Initial and final body weight of different groups of mice. (B) Effects of mobile phone radiation on Total Erythrocyte Count (TEC), Total Leukocyte Count (TLC) and Hemoglobin (HB) % in mice. (C) Effects of mobile phone radiations on Serum creatinine in mice. Values were given as mean ± SE. *= Significant at 5% ($p < 0.01$) level of probability.

3.3. *Gross architectural change of the kidney and testis*

The kidney of control and 40 min exposed mice were reddish-brown with a smooth and shiny surface (Fig. 2A-B). No anatomical changes were found in these groups of mice while 60 min of the exposed mice showed pale colour on the kidney surface (Fig. 2C). The testis was white in colour, oval in shape in control and both exposed groups of mice. There were no morphological changes observed in control and exposed groups of mice (Fig. 2D-F).

3.4. *Histopathological study*

Examination of H & E-stained sections of the kidney collected from the control and 40 min exposed mice group revealed the normal histological architecture (Fig. 3A-B). Regarding the histopathological changes, the kidney of 60 min exposed mice showed interstitial inflammation that causes marked mononuclear cellular infiltration with severe vascular congestion in comparison to the control and 40 min exposed mice (Fig. 3C-F). Histopathological observations of the testes of control mice revealed the normal architecture of the seminiferous tubule. The seminiferous tubules were hexagonal or rounded and separated by a thin intertubular interstitial connective tissue. In the seminiferous tubules, the spermatogenic cells and the Sertoli cells were regularly arranged. Interstitium tissue contained the interstitial cells (Leydig cells). The Leydig cells seemed to be regular in form and size throughout the interstitial connective tissue between the seminiferous tubules. The germinal epithelia are formed of normal spermatogenic layers represented by spermatogonia, primary and secondary spermatocytes, spermatids and sperms. The spermatids are seen

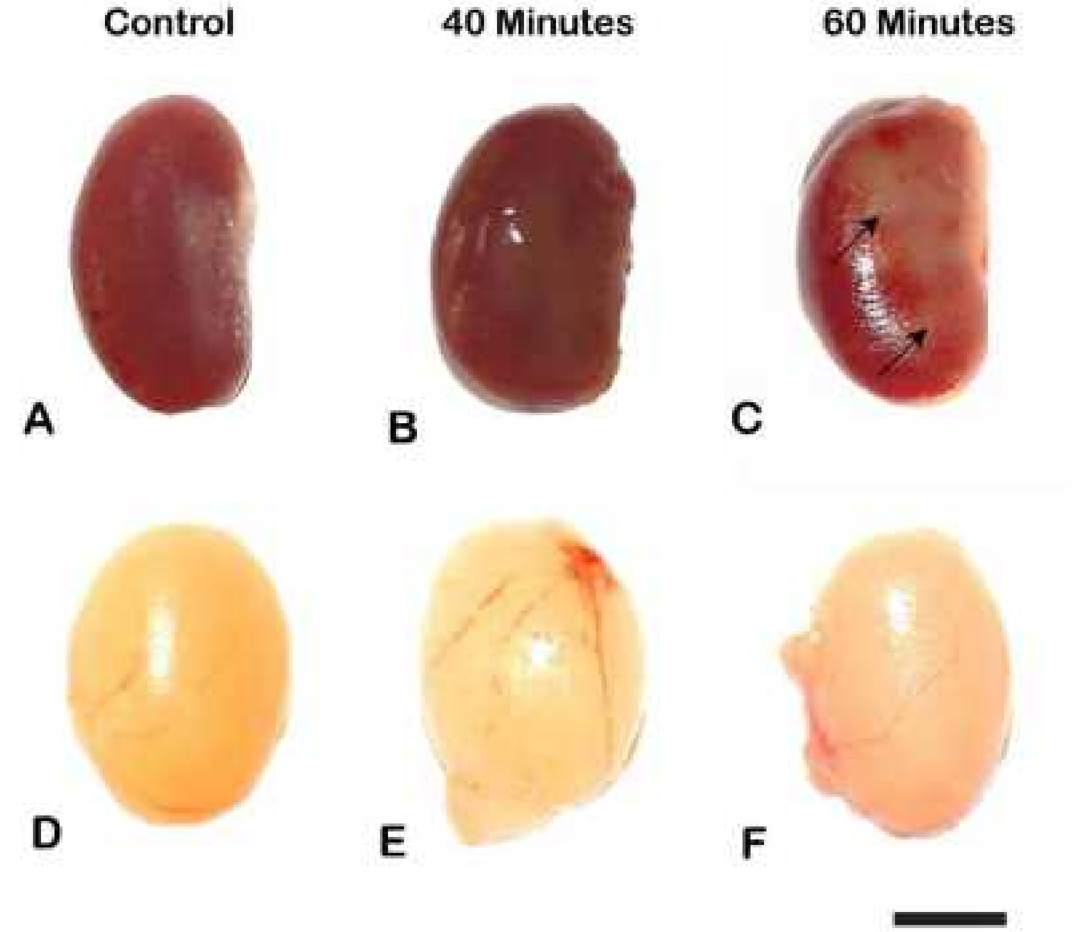

Fig. 2. Gross observation of the kidney of control (A), 40 min (B), and 60 min (C) exposed mice. Healthy appearance of the kidney was observed in control and 40 min exposed mice wherein 60 min exposed mice showed pale color (arrow) on the surface of the kidney; Gross observation of the testis of control (D), 40 min (E) and 60 min (F) exposed mice. Healthy morphological appearance of testis was found in control and exposed mice. Scale bar stands for 50 mm.

external to the spermatocytes. The spermatids then further develop into spermatozoa. They usually lie in groups with their heads projecting between the deeper cells and are connected with one of the Sertoli cells of the lining epithelium. The spermatogenic cells lines throughout different phases of growth and development were regularly arranged (Fig. 4A). The testis of 40 min exposed mice showed testicular atrophy and degenerative changes in spermatogenic cells lining the seminiferous tubules, with incomplete spermatogenesis. The seminiferous tubules were in a less regular shape. There was an alternation of the lining epithelium and reduced spermatogenic cells with a large lumen in the seminiferous tubules (Fig. 4B). The testis section of 60 min exposed mice revealed irregular shapes and non-uniform sizes seminiferous tubules. There were reduced spermatogenic cells with accumulation of spermatozoa in some of the seminiferous tubules, which were not seen in the control group. Occlusion of the lumen, as well as an increase in the size of seminiferous tubules, was evident (Fig. 4C-D). The mean height ofthe germinal epithelium was significantly decreased in both exposed groups. Testis lesions were more prominent in 60 min exposed mice in comparison with the testis of 40 min exposed mice (Fig. 4B-D).

4. Discussion

The harmful effects of mobile phone radiation exposure are poorly elucidated in vital organs such as the kidney and the testis. In the present study, therefore, we evaluated the effects of EMF on the hematobiochemical parameters and the potentially harmful effects of EMF on the kidneys and testis of mice model. Mobile phone users in various countries and continents are exposed to different frequencies. EMF exposure depends on the frequency of the cell phone (Meo et al., 2011). Many histological and biological experiments have been performed to assess the harmful effects of electromagnetic radiation on public health concerning the central nervous system, tumors, the renal system, fertility, growth, and immune function. The mice were exposed to 2400 MHz Radiofrequency Electromagnetic Radiation (RF-EMR) in this experiment because 2200–2400 MHz frequency 4G connected cell phones are extensively used in Bangladesh well as many other parts of the world. The present study results showed that the bodyweight of exposed mice was significantly reduced compared to the control mice, which agrees with the results of Wilson et al. (1999). The results (Shabat and Shahwan, 2017) noted that the mean weight of 3hrs and 5hrs high electromagnetic radiation (EMR) exposed groups decreases the initial mean weight. Likewise, (Marino et al., 1976) observed that mice exposed to low electric fields (150 V/cm) at 60 Hz for one month had reduced body weight and decreased water intake. Although (Lee et al., 2004) identified no significant weight difference in rats exposed to the magnetic field. (Gerardi et al., 2008) noted that the bodyweight increases as rats are exposed to electromagnetic radiation at a very well-defined frequency for a long-term duration.

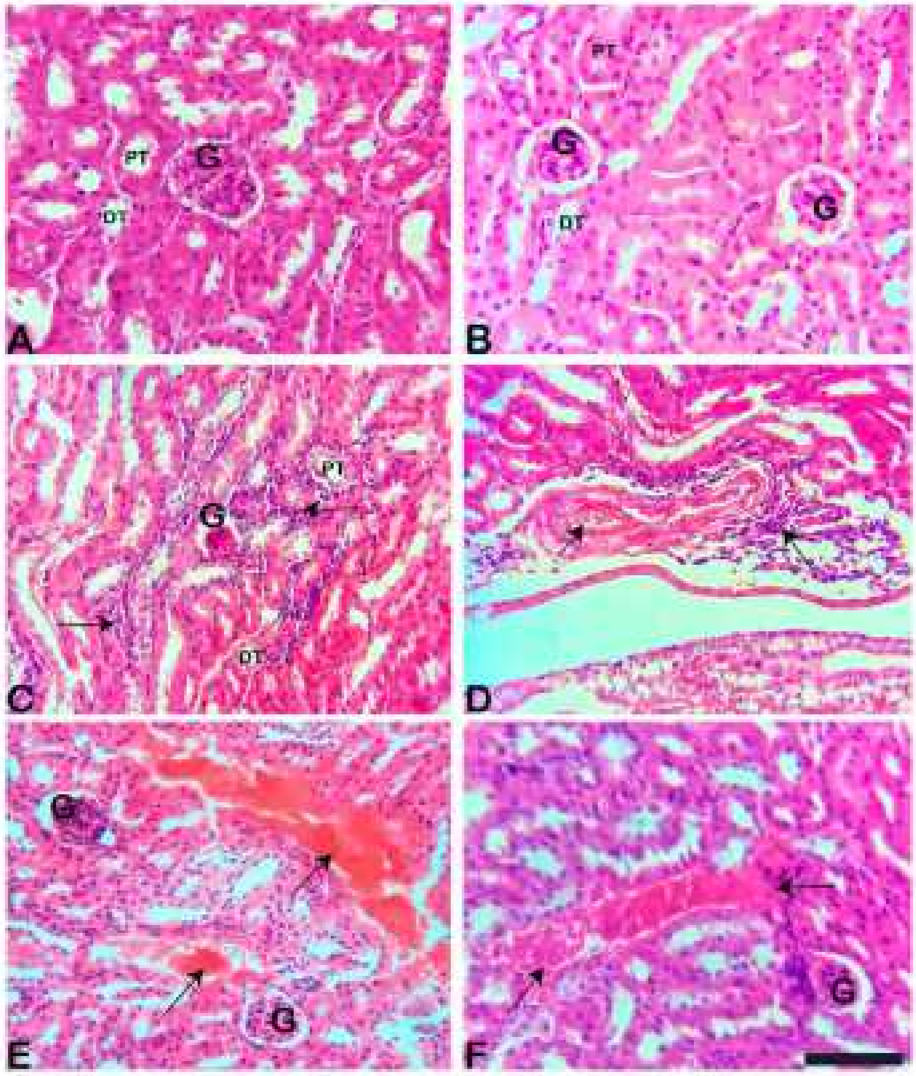

Fig. 3. Histological observation of the kidney of control (A), 40 min (B) & 60 min (C) exposed mice kidney sections stained with H & E stain. (A-B) showing control & 40 min exposure mice: no congestion, hemorrhage and normal architecture of renal corpuscles with their glomeruli and renal tubules were found in this group of mice; (C-F) exposure to 60 min: showing marked mononuclear cellular infiltration (arrow) with severe vascular congestion (arrow). Scale bar stands for 100 μm. G = Glomerulus, PT = Proximal Tubule & DT = Distal Tubule.

Changes in antioxidant, biochemical, enzymological, and hematological levels indicate weakening animal homeostasis leading to stress and a reduction in functional ability (Gecit et al., 2014; Saravanan et al., 2012). Assessments of blood parameters are the most important means to determine the health status of experimental animals (Sud and Sekhon, 1989). It helps in evaluating and recognizing the effects of EMF induced hazardous alterations to humans. The present study results revealed that mobile phone radiations affected the hematological profile of the test animals remarkably. There were significant increases TLC and Hb% in radiation-exposed groups compared to the control group. In this background, there is an increase in the concentration of Hb, RBC, WBC, and platelet numbers in rats following 1 h/day EMF exposure for 30 consecutive days has been shown (Amara et al., 2006; Salem et al., 2005). Previous epidemiological studies have shown an increased risk of leukemia due to both electric and magnetic fields (Bastuji-Garin et al., 1990; Garland et al., 1990). Our findings were similar to previous research in where shown that exposure to EMF has led to a noticeable rise in the number of WBCs and differential WBC counts (Alghamdi and El-Ghazaly, 2012; Amara et al., 2006; Aziz et al., 2010; Chater et al., 2006; Sisodia et al., 2013). The increase in TLC may be related to electromagnetic field exposure, which triggers the hemopoietic mechanism to discharge more white blood cells, which increases its number in blood circulation (Aziz et al., 2010; Sisodia et al., 2013). Our results comply with previous research done by Forgács et al. (2006) and Roberts et al. (1986) in which reports indicate that many hematological parameters such as white blood cell count, differential white blood cell count, platelet levels, red blood cell count, mitotic index of hematopoietic stem-cells, as well as hematocrit, hemoglobin and bone marrow megakaryocytes are susceptible to exposure to RF/Megawatt (MW). This suggests that these blood components are broken due to irradiation by electromagnetic radiation from cell phones. The TEC values of 60 min exposed mice were decreased significantly in compared to the control mice. Previous research studies stated that exposure to EMF in experimental models induced a reduction in RBCs' count and their correlations (Alghamdi and El-Ghazaly, 2012; Ghadhban and Mhaibes, 2018; Marzook et al., 2016; Sisodia et al., 2013). The reduction of the hematological parameters after exposure to EMF can be related to direct damage and excess production of reactive oxygen species (ROS) by association with electromagnetic radiation (Eid et al.,

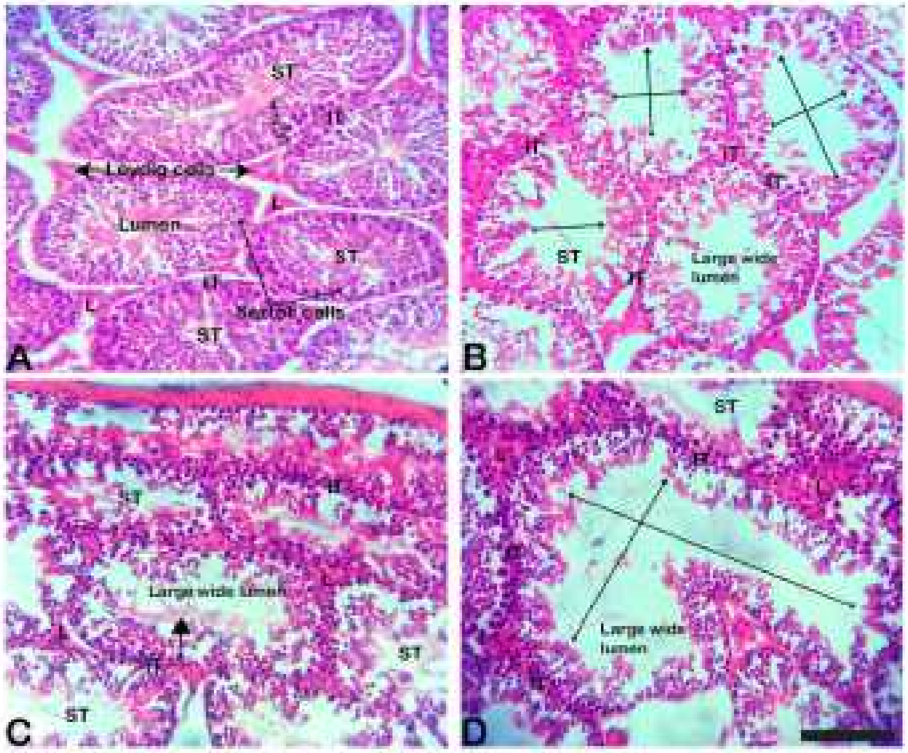

Fig. 4. Histological observation of testis of control (A), 40 min (B) & 60 min (C) exposed mice testis sections stained with H & E stain. The transverse section of the testis of (A) control mice showed normal seminiferous tubule. The seminiferous tubule has well-developed interstitial tissue, seminiferous tubeles lined with numerous Sertoli cells, and different stages of spermatogenic cells; (1) spermatogonia, (2) primary spermatocytes, (3) round secondary spermatocytes or early spermatids, and (4) spermatids. The Leydig cells were present between seminiferous tubules and seemed to be appropriate in both size and structure in the interstitial connective tissue. The testis of 40 min (B) exposed mice showing seminiferous tubules with irregular outlines, lost normal distribution of the epithelial lining, and fewer spermatogenic cells, which lead to the empty large wider tubule (large arrow) in the seminiferous tubules. The interstitium contains few Leydig cells compared to the control. (C-D) Testes of mice treated with 60 min EMR showed irregular shapes and non-uniform sizes of seminiferous tubules. There were reduced spermatogenic cells in the seminiferous tubules and accumulation of spermatozoa with exudate in the tubular lumen (arrowhead). The spermatogenic cells appeared pyknotic nuclei of some spermatogonia with degenerated spermatogenic cells, widening of the seminiferous tubular lumen (large arrow), and spermatozoa absence within the lumen. Scale bar stands for 100 µm. ST = Seminiferous Tubule, = Interstitial Tissue, L = Leydig cell.

2015; Sisodia et al., 2013). The free radicals affect the red blood cell membrane and cytoskeleton and leading to the leakage of hemoglobin from the cells (Creang et al., 2009; Eid et al., 2015). Red blood cell hemolysis reflects the degradation of cell integrity that can contribute to intracellular hemoglobin leakage (Eid et al., 2015). Spleen hyperfunction enhances red blood cell, leukocyte, and platelet breakdown rate. Due to hyperfunction of the spleen, the hematological variation has been happened in rats due to exposure to EMF was reported by Osbakken et al. (1986). The results revealed that the EMR waves damage the blood cell walls, leading to a decrease in the TLC count.

Besides, we also have investigated kidney dysfunction after exposure to EMF. Our study results indicated that the Serum creatinine value was significant increases in radiation exposed mice. Similarly, Tsuji et al. (1996) reported the increased blood urea nitrogen and creatinine levels in mice exposed to EMFs (5 T) for 48 h. Creatinine is generally created in muscles and exists freely in blood plasma and urine. Its higher serum levels act as an indicator of impaired renal function. This may be due to renal failure correlated with congestion in some tubules and focal leukocytic infiltration by pathological examination. Increased Serum creatinine levels in mice also agree with the findings of Asgari et al. (2014), who stated that Serum creatinine levels increased significantly in rats exposed to 3 h of mobile phone radiation a day compared to the control rats ($P < 0.01$). Studies have found that urea and creatinine increase dramatically when microwaving exposure duration increases (Morelli et al., 2005). Hepatic, renal, and splenic tissues were damaged due to exposure to electromagnetic radiation from cell phones (Al-Glaib et al., 2008). Damage to these tissues can lead to an increase in serum creatinine levels. There is a correlation between cell phone radiation and cellular damage that may contribute to elevated creatinine serum concentrations (Al-Glaib et al., 2008). Kidneys could mainly absorb the 900-MHz radiation from cell phones because they are often carried in the belt (Oktem et al., 2005), which may influence serum creatinine level.

There is a relation between mobile phone radiation and cellular damage that can lead to higher serum creatinine levels (Grundler et al., 1992). Grossly the kidney of control and 40 min exposed groups of mice were reddish-brown with a smooth and shiny surface. However, in 60 min exposed group showed pale color on the surface of the kidney. Our findings agreed with (Zare et al., 2007) that the morphology of the kidney of electromagnetic field exposed group mice was congested and pale. The testis was white in color and oval in shape in control and exposed mice.

The histopathological effects of 4G electromagnetic field radiation released from a cell phone device have been evaluated in this study by assessing the presence of pathological lesions in the kidney and testis. In the present study, there was no histological changes in the kidney of the control and 40 min exposed mice. In histopathological alterations, the 60-minute exposed mice reveals mononuclear cellular aggregates and intense venous congestion compared to the control mice. Similar findings were made by (Bayazit, 2009; Jaya et al., 2015; Makker et al., 2009; Ozguner et al., 2006) reporting that electromagnetic radiation (EMR) exposure induces many atrophied glomeruli, infiltration of leucocytes between the tubules of the kidney, and vacuolation of some tubules. Previous research found similar tissue changes using low frequencies EMR (Attia and Yehia, 2002; Forgács et al., 2004). Chauhan et al. (2017) stated that microwave radiation exposure causes shrunken glomeruli and irregular kidney tubules. Damage to these tissues may result in a rise in serum creatinine levels. EMR and high-power waves cause increased temperature rises. These waves interacted together and produced free radicals that cause increased lipid peroxidation and exhibit their damaging effects on cells like by ionizing rays. Free radicals damage the lipids of the cell and modify their composition and break protein boundary cause cell death. The oxidative stress induced by reactive oxygen species (ROS) is an essential element for tissue injury due to exposure to radiation (Al-Glaib et al., 2008; Markov, 2013).

Radiation is a potent toxicant, and exposure to the whole body may affect the animal's overall physiology and can have an effect on the normal histology and physiopathology of the testes (Sepehrimanesh et al., 2014). Radiation also has effects on steroidogenic and spermatogenic activity by the production of oxidative stress, antioxidant suppression mechanism, and various molecular processes included in decision-making about the death and life of germ cells that later changed normal testicular structure (Peltola et al., 1992). In the present experiment, histological examination of seminiferous tubules of irradiated mice showed marked pathological alterations in the form of shrinkage of tubules, distortion of cellular arrangement. These findings are in close agreement with the earlier report of (Goyal et al., 2011; Pareek et al., 2005), which documented the distorted architecture of seminiferous tubules in the form of shrunken tubules, pycnotic nuclei, necrotic cells, and degenerative effects of gamma rays on spermatogenesis in lethally irradiated mice.

In the present investigation, histological observation of testis of 40- and 60-minutes exposed mice showed that the seminiferous tubules were less regular in shape and alternation of the epithelium lining and fewer spermatogenic cells layer that led to the large wide lumen in the seminiferous tubules. There was an accumulation of spermatozoa and occlusion of the lumen in some of the seminiferous tubules. Similar findings were reported by Esa et al. (2018), who stated that the testicular tissue in mice exposed to a 3 kV EMF shows that the seminiferous tubules had almost the same size but less regular shape. EMF has caused noticeable changes in the seminiferous tubules in the testes of mice exposed to 5 kV contributing to uneven shapes and dimensions. Similar to the present study, Chauhan et al. (2017) stated that radiation-exposed group mice showed alternation of the epithelium lining of seminiferous tubules and occlusion of the lumen and size of seminiferous tubules was reduced with cell population. Several studies have shown that testis size and seminiferous tubules diameter were decreased following exposure to microwave radiation (Falzone et al., 2011; Ozguner et al., 2002). The excess free radical formation leads to histological and morphological changes in the testis and spermatogenic cell morphology. The ability of EMF to cause oxidative stress in the testes strongly suggests that the testis is a vulnerable tissue that is strongly dependent on oxygen for spermatogenesis and yet highly sensitive to the toxic effects of reactive oxygen enzymes (Chauhan et al., 2017; Dasdag et al., 1999). (Ozlem Nisbet et al., 2012) noticed that when rat exposure to electromagnetic radiation of 900–1800 MHz resulted in vacuolar degeneration, severe necrosis, and seminiferous epithelium desquamation. Long time exposure to 900 MHz EMF induced apoptosis of spermatogenic cells and responsible for reduced Leydig cell number as well assignificantly decreased mature spermatogenic cells and testosterone amount stated by many authors (Kim et al., 2014; 2009;; Sepehrimanesh et al., 2014). The present study revealed similar findings that there was a significantly decreased spermatogenic cell layer in radiation-exposed mice.

5. Conclusion

Cell phones are a fundamental part of our social lives. However, people are still worried about the potential effects of smartphones. In this study, we tended to focus mostly on the potentially harmful effects of 4G electromagnetic radiation from mobile phones. This study indicated that long-time exposure to mobile phone radiation could lead to degenerative changes on specific hematobiochemical parameters, including kidney and testis histology. The results indicate that kidney and testis were oxidative. Most reports concerning Electromagnetic effects with low frequency were concentrated at a specific organ or process. This study recommends that different vital organs are equally affected by similar bloodstream during high frequencies of EMF exposure due to excessive smartphone use. This research gives an insight into mobile emitted radiation that might induce alterations in the blood and the kidney and testis tissue. However, the study alerts us all to the potentially detrimental effects of long-term electromagnetic radiation exposure. To escape these harmful effects of cell phone radiation, excessive mobile phone use should be avoided. Hopefully, comprehensive long-term studies at the molecular level are undoubtedly required in order to draw definitive conclusions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contributions

The experiment was planned and designed by MRI and IH. MRI has set up all the research facilities and supervised the entire research. IH conducted the entire laboratory works. IH participated in the histological analysis. IH with TA, MRA and MRI interpreted the findings of the statistical research activities and also engaged in the manuscript draft and carefully reviewed and revised the manuscript. The final version of the manuscript is read and agreed upon by all authors. Each author also guarantees that this contentor related information has not really been submitted to or will not be published anywhere.

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Effect of mobile phone signal radiation on epigenetic modulation in the hippocampus of Wistar rat

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ABSTRACT

Exponential increase in mobile phone uses, given rise to public concern regarding the alleged deleterious health hazards as a consequence of prolonged exposure. In 2018, the U.S. National toxicology program reported, two year toxicological studies for potential health hazards from exposure to cell phone radiations. Epigenetic modulations play a critical regulatory role in many cellular functions and pathological conditions. In this study, we assessed the dose-dependent and frequency-dependent epigenetic modulation (DNA and Histone methylation) in the hippocampus of Wistar rats. A Total of 96 male Wistar rats were segregated into 12 groups exposed to 900 MHz, 1800 MHz and 2450 MHz RF-MW at a specific absorption rate (SAR) of 5.84×10^{-4} W/kg, 5.94×10^{-4} W/kg and 6.4×10^{-4} W/kg respectively for 2 h per day for 1-month, 3-month and 6-month periods. At the end of the exposure duration, animals were sacrificed to collect the hippocampus. Global hippocampal DNA methylation and histone methylation were estimated by ELISA. However, DNA methylating enzymes, DNA methyltransferase1 (DNMT1) and histone methylating enzymes euchromatic histone methylthransferase1 (EHMT1) expression was evaluated by real-time PCR, as well as further validated with Western blot. Alteration in epigenetic modulation was observed in the hippocampus. Global DNA methylation was decreased and histone methylation was increased in the hippocampus. We observed that microwave exposure led to significant epigenetic modulations in the hippocampus with increasing frequency and duration of exposure. Microwave exposure with increasing frequency and exposure duration brings significant ($p < 0.05$) epigenetic modulations which alters gene expression in the hippocampus.

1. Introduction

Electromagnetic radiations are the fourth-largest and most rapidly increasing, the anthropogenic source of pollution on the earth. Globally wireless communication systems have increased tremendously in the last decade, which principally uses radiofrequency microwaves. The United States, National Toxicology Program (NTP), U.S. Dept. of Health and Human Services conducted two-year toxicology studies in rats and mice to elucidate potential health hazards from exposure to radiofrequency (700–2700 MHz). NTP reported evidence of cell phone signal exposure with tumors in the heart, brain and adrenal glands (https://ntp.niehs.nih.gov/whatwestudy/topics/cellphones/index.html). Different experimental studies in animal model also reported for, radiofrequency microwave-induced oxidative stress, DNA damage, enhanced neuronal loss, altered neurotransmitters, increased blood-brain barrier permeability and cognitive impairment (Dasdag and Akdag, 2016; Dasdag et al., 2009; Deshmukh et al., 2013b; Maskey et al., 2010; Mausset-Bonnefont et al., 2004; Megha et al., 2015b; Nittby et al., 2009; Pall, 2018; Salford et al., 2003). However, microwave exposed DNA damage also reported in different tissues in rat as well in human being (Akdag et al. 2016, 2018; Bektas et al., 2020). Various epidemiological studies in human too reported about MW radiation-induced increased brain glucose metabolism (Volkow et al., 2011), brain physiology, attention, reaction time, working memory (Schmid et al., 2012), systemic immune response (Kimata, 2005), glioma risk (Carlberg and Hardell, 2017). However, few studies in humans have been reported

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about the insignificant effect of microwave radiation on human health (Elder et al., 2007; Hardell, 2017).

Hippocampus is a small curved part of the brain, located within the medial temporal lobe, and is well associated with learning, memory and spatial navigation. Higher polyunsaturated fatty acid content and metabolic rate as compared to other cells make neuronal cells more susceptible to molecular damage by different types of environmental stress as well as oxidative stress (Fritze et al., 1997; Hermann and Hossmann, 1997; Salim, 2017). Rich polyunsaturated fatty acid content makes neurons vulnerable to peroxidation due to the generation of ROS (Ferrante et al., 2017) and peroxidated fatty acids are well associated with neurodegeneration (Pratico, 2002). Mobile phone users constantly put their mobile in close contact with the head, therefore central nervous system (CNS) is the region primarily affected by MW radiation. ROS triggers oxidative stress in CNS (Salim, 2017) which could be a potent inducer of epigenetic modulation, responsible for cognitive dysfunctions.

Epigenetic modulations are the key regulators of gene expression without altering the genomic constitution. Intrinsic as well as extrinsic signals allow sustained changes in gene expression and allow an organism to adapt to its dynamic environment through modulated gene activity (Dauncey, 2012; Jaenisch and Bird, 2003; Mehler, 2008). DNA methyltransferase1 (DNMT1) transfers a methyl group to cytosine in genomic DNA, and responsible for the maintenance of methylation patterns (Chan et al., 2019). Whereas euchromatic histone methyltransferase1 (EHMT1) methylates histone H3 lysine-9 (H3K9), which brings transcriptional repression by modifying chromatin structure (Koemans et al., 2017). Disturbed methylation patterns of DNA and Histone associated with various pathological conditions including cancer, developmental abnormalities and cognitive functions (Chan et al., 2019; Koemans et al., 2017).

Increasing exposure to man-made electromagnetic radiation-induced changing environmental conditions is a threat to human health. Therefore, it is time to evaluate the impact of mobile phone signal radiation at genetic as well as epigenetic level. In an earlier study, we have reported about microwave-induced DNA damage (Deshmukh et al., 2016), reactive oxygen species (ROS) generation, oxidative stress (Deshmukh et al., 2013a) and ER-stress (Kumar et al., 2019) in rat brain. However, in neither study, we find any reports about microwave-induced epigenetic modulations in any experimental model, nor any study reported about the effect of microwave radiation on DNA/histone methylating enzymes (DNA methyltransferase1 and euchromatin histone methyltransferase1) expression in any experimental model. Therefore, the present study was designed to address the knowledge gap about microwave-induced epigenetic modifications and epigenotoxic nature of microwave, by evaluating the percentage of DNA/histone methylation and expression of DNA/histone methylating enzymes (DNMT1 and EHMT1) in the hippocampus following microwave exposure in male Wistar rat. In this study, we hypothesized that chronic microwave radiation may induce epigenetic changes in the form of altered DNA/histone methylation pattern, which disturb chromatin structure and transcription factors binding site in DNA, that could be responsible factor for microwave-induced carcinogenicity, reproductive toxicity, developmental abnormalities (Vornoli et al., 2019), and cognitive impairment (Deshmukh et al., 2015).

2. Methods

2.1. Experimental animal group

We obtained 96 male Wistar rats (100 ± 10 g) from the central animal house of the institute and randomly divided into 12 groups (Sham exposed, 900 MHz, 1800 MHz and 2450 MHz, each for one-month, three-month and six-month respectively), and animals were placed in galvanized wired cages. They were made familiarized to laboratory conditions for 7 days and kept under standard conditions (Humidity 40–50% and temperature 22 ± 2 °C) with 12-h light and dark cycle. Nutritionally adequate diet from Nutri-lab (Bengaluru, India) and water provided *ad-libitum.* Rats were divided into 12 groups as shown in supplementary table 1.

This study and protocol were approved by the Institutional Animal Ethical Committee, UCMS & GTB hospital (University of Delhi), Dilshad Garden, Delhi-110095 **(UCMS/IAEC/2016/093)**. Care of animals was undertaken as per guidelines suggested by the committee for the purpose of control and supervision of experiments on animals (CPCSEA), Govt. of India.

2.2. Microwave exposure system

Male Wistar rats were exposed to RF-MW under the gigahertz electromagnetic (GTEM) cell. The schematic diagram of the microwave exposure system with a signal generator and GTEM cell (Supplementary figure 1). RF-MW exposure system was designed with the help of the Centre for Applied Research in Electronics (CARE) at the Indian Institute of Technology, New Delhi, India. For uniformity of the electric field, the system was calibrated and experimentally validated before animal exposure by an E-Field probe (Rohde & Schwarz NRV-Z32, Germany). RF-MW exposure was operated in well-controlled temperature and lighting conditions.

Sham exposed animal groups were control groups, which were kept under the same conditions and duration of time without any exposure to RF-MW. Each group of rats was given whole body RF-MW exposure in GTEM cell (Amitec Electronics Ltd., India), kept 1 m away from the signal input port, at defined frequency of 900 MHz, 1800 MHz, and 2450 MHz, and SAR of 5.84×10^{-4} W/kg, 5.94×10^{-4} W/kg and 6.4×10^{-4} W/kg respectively by the established power balance method as suggested by Ardoino et al., (2005), as shown above in Table 1 (supplementary data) at power level 1 mW for 2 h per day for one-month, three-month and six-month. For Specific Absorbance Rate (SAR) measurement representative rats with 106 g average weight was used, and SAR was calculated by power balance method using following equation:

$$P_{abs}/rat = 1/n\ (P_{in} - P_{out} - P_{refl})$$

Where, P_{abs} = Radio frequency (RF) power in watt absorbed per animal, n = number of animals within the cell, P_{in} = input power (Watt), P_{out} = output power (Watt) and P_{refl} = reflected power (Watt).

2.3. Expression of DNA methyltransferases and histone methyltransferases

Immediately after completion of each specified duration (1-month, 3-month, and 6-month) for RF-MW exposure, animals were decapitated and the hippocampus was isolated from the brain. Total RNA was extracted from the hippocampus using TRIzol reagent (Life Technologies, USA) as per the manufacturer's given protocol. One microgram of total RNA was converted into cDNA with an iScript cDNA synthesis kit (Bio-Rad, USA) as suggested by the manufacturer. Further RT-PCR (qRT-PCR) was performed in 20 μl vol. with SsoFast Eva Green supermix (Bio-Rad, USA) on CFX Connect™ Real-Time PCR (Bio-Rad, USA) with primers listed in Table 1. Each sample was run in triplicate and the relative fold change of selected genes was calculated by the comparative $2^{-\Delta\Delta}$Ct method (Livak and Schmittgen, 2001).

Table 1
Primer sequences used for qRT-PCR.

Gene	Forward primer (5′-3′)	Reverse primer (5′-3′)
DNMT1	GAGGCACTGTCCGTCTTTGA	CTGATTGATTGGCCCCAGGT
EHMT1	TGGATTCCCTGGATCTCCGT	GCACCAAGAGTGGTGCTTTG
GAPDH	TGCCCCCATGTTTGTGATG	TGGTGGTGCAGGATGCATT

2.4. Western-blotting of ER-stress associated transcription factor

Total proteins were extracted from the hippocampus of the male Wistar rat by using TRIS-NaCl buffer, immediately after decapitation and western blots were performed as suggested by Mahmood and Yang, (2012). Briefly, samples with 50 ng of protein were loaded onto 10% polyacrylamide gel with 0.1% SDS and separated by electrophoresis at 100 V for 180 min. Proteins were then transferred onto PVDF membrane and blocked with 5% BSA for 1 h. Primary antibody against DNMT1 and EHMT1, protein at 1:1000 (Signal way antibody, USA) was added next and left overnight at 4 °C. After washing with PBST, membranes were incubated with secondary HRP conjugated antibodies for 2 h and after washing with PBST again, proteins were visualized with ECL reagents (Bio-Rad, USA) on chemidock (My ECL imager, Thermo, USA). The bands were analyzed with Kodak ID image analysis software. All band intensities were normalized to β-actin.

2.5. 5-Methylcytosine DNA ELISA

Genomic DNA was isolated from the hippocampus of the rat brain by using spin column method as per the manufacturer's protocol (Promega DNA isolation kit, USA). Global percentage DNA methylation was estimated by measuring 5-methylcytosine (5-mC), using a 5-mC DNA ELISA kit (Zymo Research, USA), as per manufacturer's protocol. Briefly, 100 ng of isolated genomic DNA along with positive and negative controls of double-stranded DNA (provided with the kit) was denatured and used to coat the wells of microtitre plate with given coating buffer. All standards and hippocampal DNA were assayed in duplicate. Anti-5-mC antibody and HRP conjugated secondary antibody used for colour development. Absorbance measured at 405 nm and the percentage of 5-mC DNA calculated by using a second-order regression equation.

2.6. Histone H3K9 methylation

Histone protein isolation and assessment of their methylation from the hippocampus of the rat brain were performed by using a Histone H3K9 methylation assay kit (Epigentek, EpiQuik Global Histone H3K9 Methylation Assay) as per manufacturer's protocol. Extracted histone protein of 200 ng/μl was used for the evaluation of histone methylation percentage as suggested by the manufacturer. The percentage of H3K9 methylation was measured by using the standard curve, which was plotted with positive and negative control run along with the extracted histone protein.

2.7. Statistical analysis

Statistical analysis was carried out at SPSS (IBM SPSS statistics version 25) and values were expressed as mean ± SD (standard deviation). The significance of difference among the group was determined by a one-way analysis of variance (ANOVA) followed by Pearson's correlations and Tukey's post hoc test. Statistical significance was accepted at $p < 0.05$.

3. Result

DNA methyltransferases1 (DNMT1) and euchromatic histone methyltransferase1 (EHMT1) gene expression were evaluated by quantitative real-time PCR, in all specified groups of rats in Table 1. DNA methyltransferases1 and euchromatic histone methyltransferase1 have a crucial role in DNA and histone methylation respectively. In the present study, the expression of the *Dnmt1* gene was decreased, however, the *Ehmt* gene was increased in microwave exposed rat groups, with respect to sham exposed rat groups (Fig. 1A and 2A).

To validate the gene expression pattern of qRT-PCR, the expression levels of DNMT1 and EHMT1 further analyzed by Western blot by using a respective antibody, anti-DNMT1 antibody and anti-EHMT1 antibody (Signalway antibody, USA) in the hippocampal cell lysates. The Western blot analysis also indicated that expression of DNMT1 decreased and EHMT1 increased, with increasing frequency and duration of exposure (Fig. 1B and C, Fig. 2B and C).

3.1. EHMT1 expression

Expression of *Ehmt1* mRNA was increased with increasing microwave exposure frequency as 1.17-fold in 900 MHz, 1.29-fold in 1800 MHz and 1.63-fold in the 2450 MHz exposure group when compared with the sham-exposed group (Fig. 1A). In post hoc analysis, the difference was found significant ($p < 0.05$) when the sham-exposed group was compared with 900 MHz, 1800 MHz, and 2450 MHz exposure groups. When we compared the 900 MHz with 2450 MHz and the 1800 MHz with the 2450 MHz exposure group, we again noticed a significant ($p < 0.05$) change. However, 900 MHz and 1800 MHz exposed groups did not show any significant differences between each other.

After three-month of exposure, significant ($p < 0.05$) upregulation of *Ehmt1* mRNA expression in the hippocampus was noticed. After the 3-month exposure gene expression increases, 1.32-fold in 900 MHz, 1.40-fold in 1800 MHz and 1.70-fold in 2450 MHz frequency exposed group when compared to sham-exposed group respectively (Fig. 1A). We also observed a higher fold change in the three-month exposure group at the respective frequency. In the post hoc test, a significant ($p < 0.05$) increase in fold change was observed when the sham-exposed group was compared with 1800 MHz and 2540 MHz exposure frequency. The 900 MHz group and 2450 MHz group show a significant difference, but no significant difference in fold change was observed when we compared 900 MHz with 1800 MHz and 1800 MHz with 2450 MHz.

Similarly, in the six-month exposure group, significant ($p < 0.05$) upregulation of *Ehmt1* mRNA expression in the hippocampus of rat brain was also observed with increasing microwave exposure frequency, 1.6-fold in 900 MHz, 1.75-fold in 1800 MHz and 2.32-fold increase in 2450 MHz microwave exposure group with respect to sham-exposed group respectively (Fig. 1A). In the six-month exposure group, we observed greater fold change with respect to the three-month and one-month exposure group at respective frequency. Post hoc test, shown significant ($p < 0.05$) increase in fold change was noticed with respect to the sham-exposed group. The significant difference of fold change was obtained when we compared 900 MHz frequency fold change with 2450 MHz frequency and 1800 MHz frequency fold change with the 2450 MHz frequency fold change. However, no significant difference was found when we compared 900 MHz fold change with 1800 MHz fold change.

The gene expression profile was validated with Western blot analysis of EHMT1 protein (Fig. 1B). Data were normalized with housekeeping protein β-actin shown in the bar diagram (Fig. 1C). In post hoc analysis all the changed expression was found significant ($p < 0.05$).

3.2. DNMT1 expression

Expression of *Dnmt1* mRNA after one month was 0.71-fold downregulated in 900 MHz, 0.57-fold downregulated in 1800 MHz and 0.39-fold downregulated in the 2450 MHz exposure group (Fig. 2A). Post hoc analysis was found significant ($p < 0.05$) when we compared 900 MHz with 2450 MHz and 1800 MHz with a 2450 MHz exposure group. However, 900 MHz and 1800 MHz exposed groups did not show significant downregulation when compared with each other.

Significant ($p < 0.05$) downregulation of *Dnmt1*mRNA expression in the hippocampus was noticed. Gene expression decreases with increasing microwave exposure frequency 0.67-fold in 900 MHz, 0.53-fold in 1800 MHz and 0.37-fold in 2450 MHz frequency exposed group when compared to sham-exposed group respectively (Fig. 2A). Following three-month exposure, we observed more downregulation in gene expression with respect to one-month exposure at respective frequency. Significant ($p < 0.05$) decrease in fold change was observed

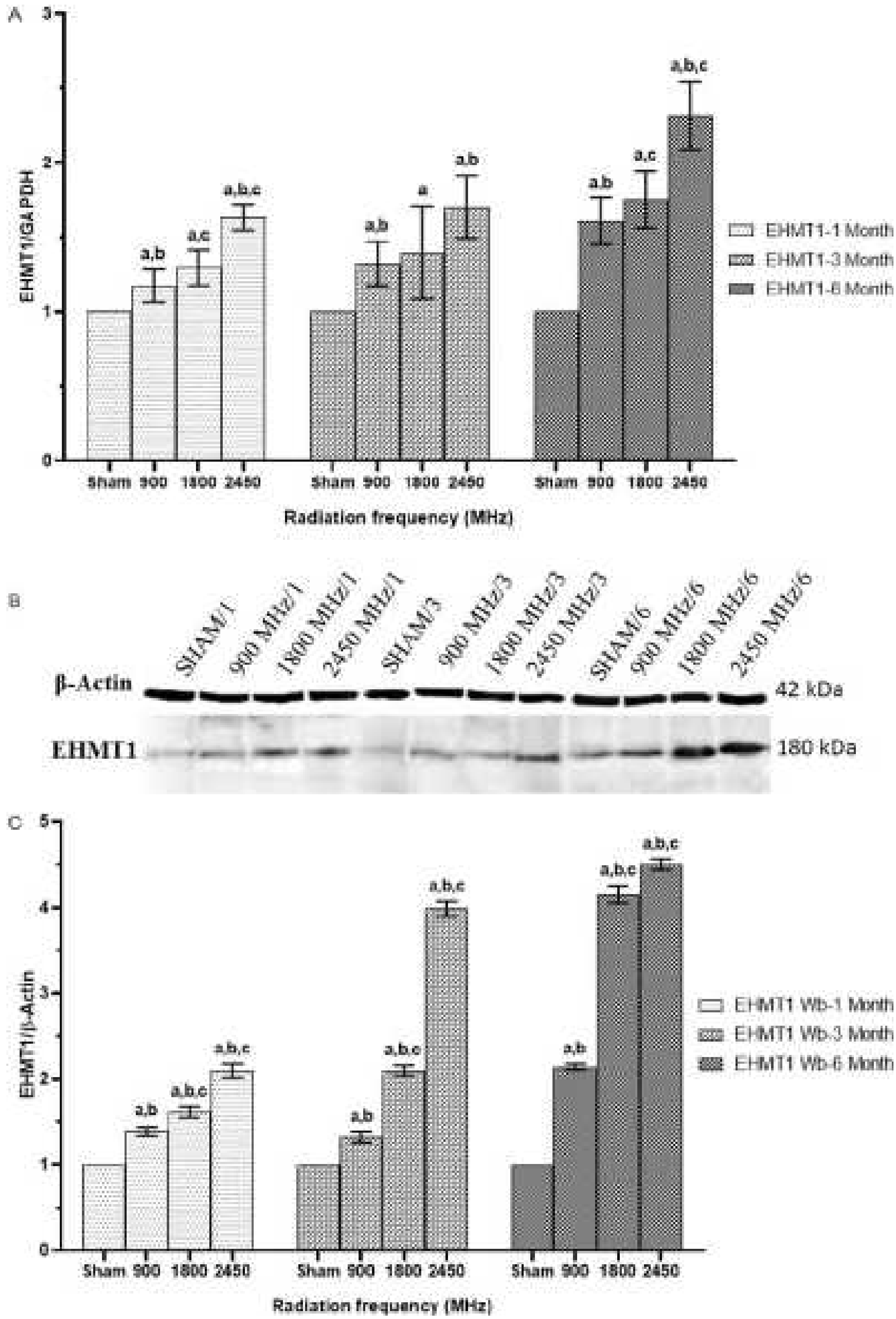
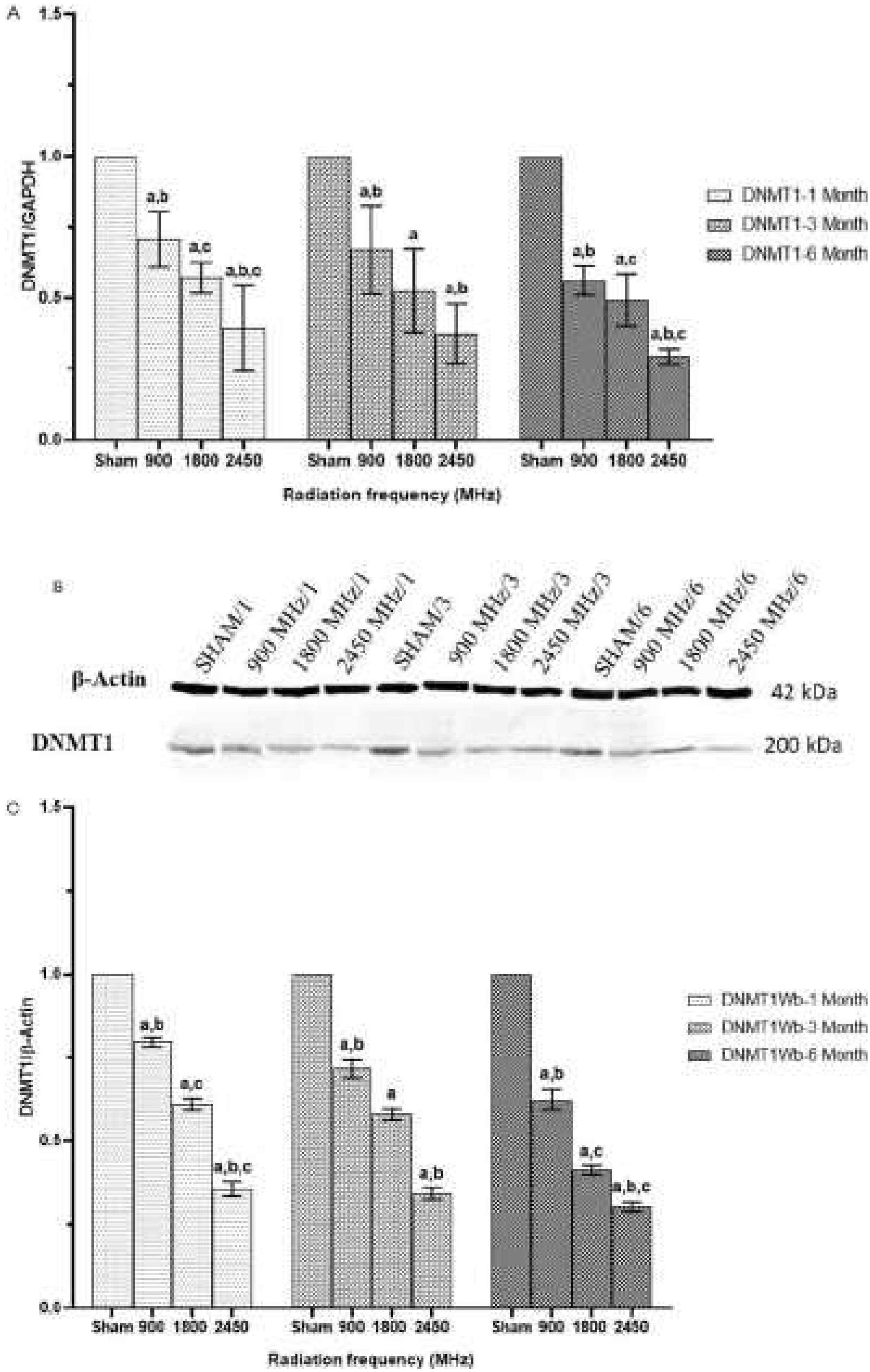


Fig. 1. (A) Effect of microwave exposure on *Ehmt1* gene expression in rat brain. The relative transcription levels of euchromatic histone methyltransferase1 (EHMT1) in the hippocampus of Wistar rat in response to radiofrequency microwave exposure for one-month, three-month and six-month. Total RNA was extracted from the hippocampus of sham-exposed and microwave exposed Wistar rats and was analyzed by quantitative real-time PCR to deduce the expression level of *Ehmt1* genes. The expressional value of the hippocampus of the microwave exposed Wistar rat were normalized to those of sham-exposed rat. The relative transcriptional values of the *Ehmt1* gene were calculated by normalizing to the GAPDH expression using $2^{-\Delta\Delta Ct}$ (n = 8) method and we found its increasing as with increasing frequency and exposure duration. (B) Western blot of Ehmt1 in the hippocampus of Wistar rat after one-month, three-month and six-month microwave exposure at 900, 1800 and 2450 MHz frequency. (C) Band intensity of Western blot was quantified by dosimetry, and the protein level was normalized relative to β-actin which was shown in the bar diagram. Each bar represents the mean value with ±SD of experiments in triplicates. Statistical significance value accepted in a two-tailed *t*-test, if $p < 0.05$. Respective p-value *a,b,c significantly different from respective control (p < 0.05) calculated by one way ANOVA followed by Tukey's test.*



(caption on next page)

Fig. 2. (A) Effect of microwave exposure on *Dnmt1* gene expression in rat brain. The relative transcription levels of DNA methylatransferase1 (DNMT1) in the hippocampus of Wistar rat in response to radiofrequency microwave exposure for one-month, three-month and six-month. Total RNA was extracted from the hippocampus of sham-exposed and microwave exposed Wistar rats and was analyzed by quantitative real-time PCR to deduce the expression level of *Dnmt1* genes. The expressional value of the hippocampus of the microwave exposed Wistar rat were normalized to those of sham-exposed rat. The relative transcriptional values of the *Dnmt1* gene were calculated by normalizing to the GAPDH expression using $2^{-\Delta\Delta Ct}$ (n = 8) method and we found its increasing as with increasing frequency and exposure duration. (B) Western blot of Dnmt1 in the hippocampus of Wistar rat after one-month, three-month and six-month microwave exposure at 900, 1800 and 2450 MHz frequency. (C) Band intensity of Western blot was quantified by dosimetry, and the protein level was normalized relative to β-actin which was shown in the bar diagram. Each bar represents the mean value with ±SD of experiments in triplicates. Statistical significance value accepted in a two-tailed *t*-test, if $p < 0.05$. The respective p-value, *a,b,c significantly different from respective control (p < 0.05) by one way ANOVA followed by Tukey's test.*

when we compared 900 MHz with 2450 MHz exposure group, however no significant decrease in fold change was noticed when we compared 900 MHz with 1800 MHz and 1800 MHz with 2450 MHz exposure group.

Similarly, in the six-month exposure group, significant ($p < 0.05$) downregulation of *Dnmt1*gene mRNA expression with increasing microwave exposure frequency in the hippocampus of rat brain was observed, 0.56-fold in 900 MHz, 0.49-fold in 1800 MHz and 0.30-fold downregulation in 2450 MHz microwave exposure with respect to sham-exposed group respectively (Fig. 2A). In the six-month exposure group, we noticed more downregulation in gene expression with respect to the three-month exposure group at respective frequency. In the post hoc test, a significant ($p < 0.05$) decrease in fold change was noted when we compared the 900 MHz frequency fold change with 2450 MHz frequency and 1800 MHz frequency fold change with 2450 MHz frequency fold change. However, no significant difference was found when we compared 900 MHz fold change with 1800 MHz fold change.

The expression pattern of the *Dnmt1*gene was validated with the Western blot of DNMT1 (Fig. 2B). In the post hoc test, significant ($p < 0.05$) downregulation was noticed in all groups when compared to the sham-exposed group. Data were normalized with housekeeping protein β-actin and shown in the bar diagram (Fig. 2C).

3.3. Histone (H3K9) methylation

Percentage methylation of histones was estimated after one-month, three-month and six-month of microwave exposure as shown in Fig. 3. After one month of microwave exposure, the percentage of methylated H3K9 was observed to be increasing with increasing frequency. Methylated H3K9 in the sham-exposed group was 4.15%, whereas it was 4.90% in 900 MHz, 6.43% in 1800 MHz and 7.40% in the 2450 MHz exposed group. In the post hoc test, a Significant ($p < 0.05$) increase in methylated H3K9 was observed in the post hoc test when we compared the sham-exposed group with 1800 MHz and 2450 MHz exposed group, but not with 900 MHz exposed group. A significant increase in methylated H3K9 was also noticed when we compared 900 MHz exposure group with 1800 MHz and 2450 MHz exposure groups. However, no significant increase was observed when compared 1800 MHz exposure group with a 2450 MHz exposure group.

Methylated H3K9 histone protein was 5.29% in the sham-exposed group, 7.70% in 900 MHz, 8.79% in 1800 MHz and 9.38% in the 2450 MHz following three-month MW exposure. Increased methylation percentage was also noticed with respect to one-month exposure at respective frequency. In the post hoc test, a significant ($p < 0.05$) increase in methylated H3K9 histone protein was observed when we compared sham with 900 MHz, 1800 MHz, and 2450 MHz. A significant increase was also noticed when compared to 900 MHz with 2450 MHz but not between 900 MHz and 1800 MHz. However, no significant difference was observed when we compared the 1800 MHz exposure group with the 2450 MHz exposure group.

An increase in methylated H3K9 histone protein was obtained in the hippocampus of microwave exposed Wistar rat brain as 5.69% in sham-exposed group, 8.67% in 900 MHz, 9.58% in 1800 MHz and 10.38% in 2450 MHz following six-month exposure. Increased methylation percentage was again noticed with respect to three-month exposure at respective frequency. Significant ($p < 0.05$) increase in methylated H3K9 histone protein was observed, when we compared the sham-exposed group with 900 MHz, 1800 MHz, and 2450 MHz exposure group. But when we compared 900 MHz with 1800 MHz and 2450 MHz and 1800 MHz with 2450 MHz, no significant difference was obtained.

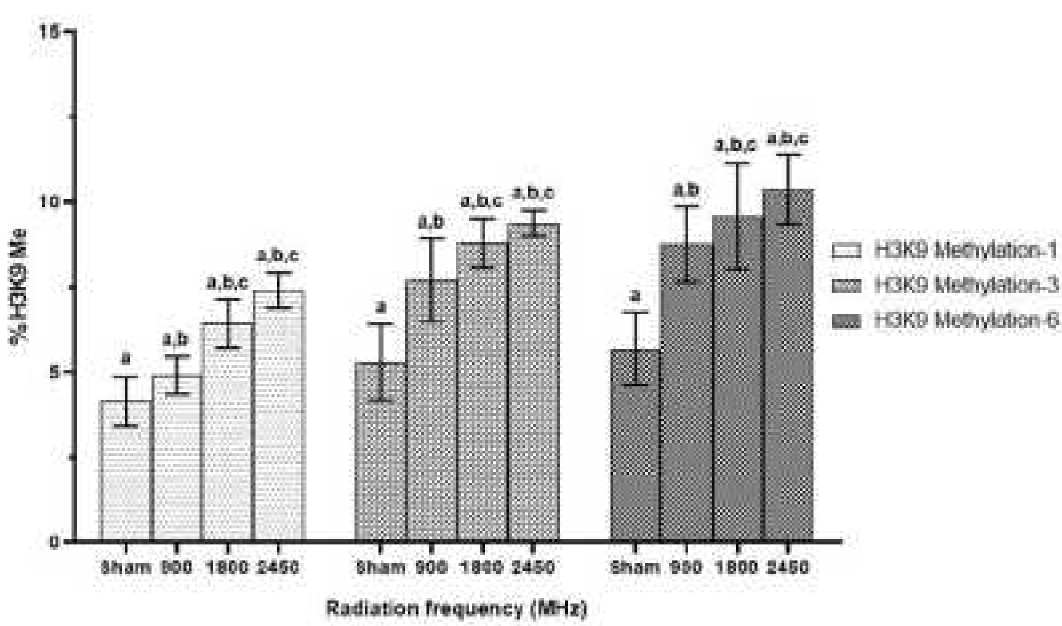


Fig. 3. Percentage Histone methylation (H3K9) in rat brain. *Values are expressed as mean ± SD (8 animals* per *group). The respective p-value, a,b,c significantly different from respective control (p < 0.05) by one way ANOVA followed by Tukey's test.*

3.4. 5-mC DNA methylation

Methylation of cytosine residue of DNA is well associated with the regulation of gene expression. Percentage methylation of DNA was evaluated as shown in Fig. 4. After one-month of exposure, the percentage methylation of 5-mC DNA was decreased with increasing frequency that is 17.23%, 16.81%, 15.04% and 12.96% in the sham-exposed group, 900 MHz groups, 1800 MHz group, and the 2450 MHz exposure group respectively. Significant ($p < 0.05$) decrease in methylation percentage was observed when the sham-exposed group was compared with 2450 MHz, but not when compared with 900 MHz and 1800 MHz. A significant decrease in methylation was observed, when we compared 900 MHz with the 2450 MHz exposure group but not with the 1800 MHz exposure group.

In three-month exposure group, a reduced percentage of methylated DNA was noticed with increasing microwave exposure frequency, 13.91% in the sham-exposed group, 12.69% in 900 MHz, 12.58% in 1800 MHz and 10.48% in 2450 MHz exposed group. Reduced methylation was also observed when compared with the one-month exposure group at respective frequency. In the post hoc test, a significant ($p < 0.05$) decrease in the percentage of methylated DNA was observed using post hoc test when compared to the sham-exposed group with 2450 MHz exposure group but not with 900 MHz and 1800 MHz exposure group. Further, a significant decrease in methylated DNA was also noticed when we compared 900 MHz with 2450 MHz and 1800 MHz with 2450 MHz exposure group.

In the six-month exposure group, a similar decreasing pattern of methylated DNA was noticed with increasing microwave exposure frequency. The sham-exposed group has 12.21% methylated DNA, whereas it is 11.27% in 900 MHz, 8.92 in 1800 MHz and 5.35% in the 2450 MHz exposed group in the hippocampus of Wistar rat. Reduced methylation was also observed when compared with the three-month exposure group at respective frequency. In the post hoc test, a significant ($p < 0.05$) decrease in methylated DNA was observed when we compared the sham-exposed group with 1800 MHz and 2450 MHz exposure groups. A significant decrease was also reported when compared to 900 MHz with 2450 MHz as well as 1800 MHz with a 2450 MHz exposure group.

4. Discussion

Mobile phone signal radiofrequency microwave (900, 1800 and 2450 MHz, 2 h per day for one, three and six month) induce epigenetic modulations in the hippocampus with significant increase in histone (H3K9) methylation, significant decrease in DNA methylation and significant fold change in transcriptional as well as translational level of DNA/histone methyltransferase (DNMT1/EHMT1) enzyme.

We are in constant exposure to electromagnetic radiation, notably under the blanket of artificial electromagnetic radiation, especially microwave radiation, emitted from wireless communication system (mobile phones, Wi-Fi/Bluetooth devices), and surveillance technologies (radar, security scanner) (Bandara and Carpenter, 2018). Due to the dramatic increase of wireless communication systems (cellular phones), the concern raised about the possible effects of mobile phone signals on human health (Myers, 2018). Various study group reported about microwave exposure induced alteration in blood, cord blood (Bektas et al., 2018), placenta (Bektas et al., 2020), ear canal hair follicle (Akdag et al., 2018),as well as in testes (Alkis et al., 2019a). Hippocampus is the primary region of the brain which regulates learning, memory, and behavior (Rubin et al., 2014). Studies reported the evidence in human model of neurodevelopmental or behavioral disorder in children (Divan et al., 2008), altered brain metabolism (Volkow et al., 2011), brain electrical activity (Schmid et al., 2012), DNA damage in peripheral blood lymphocytes (Zothansiama et al., 2017), risk of brain tumor (Carlberg and Hardell, 2017), fatigue, depression, and headaches (Yakymenko et al., 2011). However, microwave exposure affects neurodevelopment and behavior in mice (Aldad et al., 2012), oxidative stress, apoptosis of glial cells (Alkis et al., 2019b; Dasdag et al. 2004, 2009), amyloid protein, protein carbonyl (Dasdag et al., 2012), male fertility (Kesari et al., 2018), neuro inflammations (Megha et al., 2015a) cognitive functions, (Deshmukh et al., 2015; Kleinlogel et al., 2008), and micro RNA expression (Dasdag et al. 2015a, 2015b) in rats, but neither study has reported for epigenetic modulations with microwave exposure.

Our prior study reported that mobile phone signal exposure impairs cognitive functions (Deshmukh et al., 2015), heat shock protein modulation (Deshmukh et al., 2012), neurotransmitter alteration (Megha et al., 2015b), oxidative stress (Alkis et al., 2019b; Megha et al., 2012), and ER-stress in rat brain (Kumar et al., 2019), prompted us to speculate

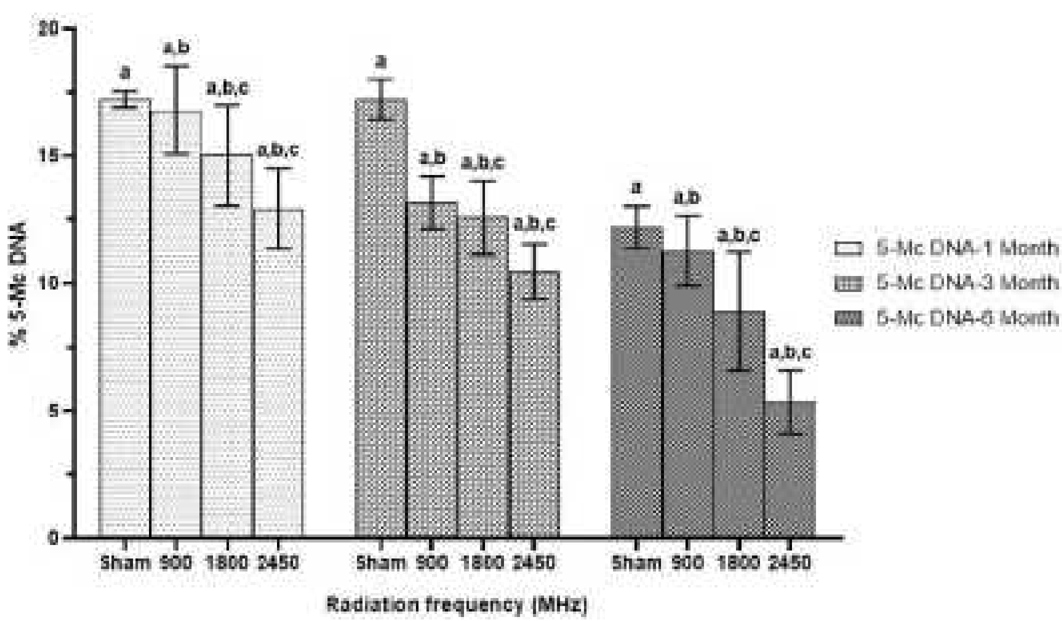


Fig. 4. Percentage methylation of 5-methyl cytosine DNA (5-mC-DNA) in rat brain. *Values are expressed as mean ± SD (8 animals* per *group).* Respective p-value *a,b,c significantly different from respective control ($p < 0.05$) calculated by one way ANOVA followed by Tukey's test.*

that above said changes in neuronal development and behavior crucially driven by epigenetic modulations. We explored our speculation in the present study by evaluating whether mobile phone signal exposure (900–2450 MHz) modulate DNA/histone methylating enzymes and DNA/histone methylation in the hippocampus of Wistar rat. Mobile phone radiofrequency microwave radiation led to significant fold change in euchromatic histone methyltransferase1 EHMT1 (Fig. 1), DNA methyltransferase1 DNMT1 (Fig. 2) enzyme as apparent by hypermethylation of histone, H3K9 (Fig. 3) and hypomethylation of DNA, 5-mC (Fig. 4) at selected mobile phone signal radiofrequency microwave.

We previously reported that radiofrequency microwave exposure of rat to 900–2450 MHz for one to six month exposure induces cognitive impairment. In this study, we extended our observations by elucidating whether radiofrequency microwave exposure induces epigenetic modulations with augmented levels of methyltransferase (DNMT1 and EHMT1) enzymes in the hippocampus compared to sham-exposed rats. Being hippocampus is crucially involved in learning, memory, and behavior, microwave-induced epigenetic modifications of the hippocampus more likely the causative factor.

Hippocampus is the vulnerable and sensitive target of mobile phone signal radiation which may deficits learning and memory (Zhao et al., 2012). However, no data available on the microwave exposure risk to epigenetic modulations. Cognitive functions including long-term/short-term memory are a unique feature of the healthy brain. Differential gene expression changes protein synthesis in memory-related regions of the hippocampus (Bailey et al., 2004). Altered synaptic properties propagate through persisting molecular changes which translate into changes in memory and memory recall processes. Epigenetic modulations (DNA/histone methylation) around gene promoters induce changes in gene expression thus causing cognitive and memory dysfunction (Barroso and Chevet, 2016; Ramos-Lopez et al., 2018). We observed increased H3K9 methylation and euchromatic histone methyltransferase1 enzyme with respect to sham exposed rat, similar observation is reported by Iacono et al., who showed increased H3K9 methylation associated with cognitive dysfunction in mice (Iacono et al., 2018). The ability of learning and memory depends on the transient translation of gene expression which influences synapse activity and connectivity of neurons. Histone methylation under the control of EHMT1 expression, which brings chromatin remodeling (Lagali et al., 2010). EHMT1 enzyme induces histone methylation at lysin residue, which modifies chromatin structure and disturbs gene regulatory networks that affect learning and memory (Koemans et al., 2017). Chromatin is a highly dynamic biomolecule which is readily modulated under the influence of internal or external stimuli. Epigenetic modulations bring reversible covalent modifications of histone or DNA. Epigenetic modulations of histone and DNA modulate DNA–histone interactions and the access of DNA replication and transcription complex, which functions as a transcription gatekeeper that brings cell-specific gene activation or repression (Ng et al., 2009; Parkel et al., 2013). H3K9 methylation is a repressive mark for gene activation (Hathaway et al., 2012) and depressive behavior in animal models as well as in humans (Tsankova et al., 2006). Jarome and Lubin (2013), reported the association of histone methylation in neurodegeneration in mouse brain due to chromatin structure disturbance and blockade of normal gene expression via disruption of transcription regulatory network (Graff et al., 2012; Jarome and Lubin, 2013).

Studies have reported that learning triggers change in DNA methylation in the hippocampus (Lubin et al., 2008). DNA methylation brings transcriptional activation in the adult central nervous system (Chahrour et al., 2008; Suzuki and Bird, 2008). In the present study, we observed decreased DNA methylation and DNMT1 enzyme in microwave exposed rats with respect to sham-exposed rats. We also observed decreasing DNA methylation with increasing frequency (900 MHz–2450 MHz) and with increasing duration of exposure (one-month to six-month exposure group). DNMT1 enzyme is the only maintenance methyltransferase enzyme that maintains and regulates cellular epigenome. It is vital for native chromatin structure as well as embryonic development and neuronal survival (Baets et al., 2015). DNA demethylation hampers the binding of the methyl-CpG binding protein, MeCP2 at the *Zif268* promoter. Binding of MeCP2 with methylated DNA and cyclic adenosine monophosphate response element binding-1 (CERB-1) protein, regulates the transcription of the gene (Chahrour et al., 2008). Lubin et al. reported that the cAMP response element-binding site residing around the *Zif268* DNA promoter region is methylated in adult hippocampal neurons. Learning induces DNA methylation which regulates the transcription of brain-derived neurotrophic factors (BDNF) (Lubin et al., 2011). Repression of DNA methylation via infusion of the DNA methyltransferase1 inhibitor in the hippocampus brings the differential regulation of BDNF variants and reduces the process of learning and memory (Lubin et al., 2008). DNA repair process also mediates active DNA demethylation in the adult hippocampus which involves enzymes removing the methyl group from 5-methylcytosine or removing the whole nucleotide (Kangaspeska et al., 2008; Ooi and Bestor, 2008). Growth arrest and DNA-damage inducible gene 45 alpha (GADD42A), a key regulator of DNA demethylation are also crucially involved in DNA repair, maintenance of genomic stability and cell cycle checkpoints. Several study reports support that DNA demethylation is actively dependent on daily activity and DNA demethylation imparts another level of complexity in the epigenetics of neurobiology (Lubin, 2011). Hence, it also opens a new window with a potential mechanism for the manipulation of DNA demethylation specifically in the restoration of cognitive functions where DNA methylation profile is altered.

Epigenetic modifications play a crucial role in the regulation of cognitive and learning-dependent synaptic plasticity (Gupta et al., 2010; Jiang et al., 2008; Lubin et al., 2011). However, epigenetic modulations are not the only mechanism but also influences several other mechanisms through chromatin structure regulation and transcription and translation machinery via ER-stress and unfolded protein response. DNA methylation in concert with histone methylation redirects the microenvironment of gene promoters and influences transcription of the genes in the hippocampus of the rat brain (Barrett and Wood, 2008; Graff and Mansuy, 2008).

5. Conclusion

In summary, 900–2450 MHz for 2 h daily for one-month, three-month and six-month exposure led to hypermethylation of histone (H3K9) protein by upregulating euchromatic histone methyltransferase1 enzyme, whereas hypomethylation of DNA (5-Mc) by down-regulating DNA methyltransferase1 enzyme with increasing microwave frequency as well as exposure duration of Wistar rat. Band 3 (1800 MHz) is widely used frequency band for communication. Higher frequency corresponds to higher energy, hence more adverse effect than 900 MHz frequency but lower than 2450 MHz, which we also observed in this study in the form of epigenetic modulations, gene expression as well as in protein expression in experimental Wistar rats. We found maximum bio-molecular alteration in six-month exposure group at 2450 MHz frequency, as it possesses maximum energy. Higher frequency and longer duration of exposure responsible for the larger changes in bio-molecular characteristics. Hence 2450 MHz frequency for six month of exposure is the most effective frequency and duration to impart health hazards. The result may deliver insight into the pathway of cognitive impairment induced by mobile phone signal radiofrequency, which may be useful for assessment of mobile phone radiation risk in mental health and setting guidelines for policy makers.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2020.110297.

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The International Commission on Non-Ionizing Radiation Protection: Conflicts of interest , corporate capture and the push for 5G

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The International Commission on Non-Ionizing Radiation Protection: Conflicts of interest, corporate interests and the push for 5G

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This report was commissioned, coordinated and published by two Members of the European Parliament – Michèle Rivasi (Europe Écologie) and Klaus Buchner (Ökologisch-Demokratische Partei), and financed by the Greens/EfA group in the European Parliament.

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Foreword by Klaus Buchner and Michèle Rivasi

This report deals with an issue of which the importance cannot be overrated: the possible health effects of Radiofrequency Radiation (RfR) or electro magnetic fields (EMF); It deals more specifically with how the scientific debate has been hijacked by corporate interests from the Telecom industry.

After having read the reports of a journalistic collective called Investigate Europe, the many articles from Microwave News as well as all the publications from independent scientists from around the world, who for years have all been ringing alarm bells on adverse health effects from the use of mobile phones and EMF, we decided that we needed to dig deeper into this strange, unknown to the public but powerful scientific NGO based in Germany called the 'International Commission on Non-Ionizing Radiation Protection' (ICNIRP).

The findings of this report ('The International Commission on Non-Ionizing Radiation Protection: Conflicts of interest and the push for 5G') give us an uncomfortable déjà-vu: many facts and processes that lead to the actual situation whereby European authorities – from the European Commission to most of the member states – simply close their eyes for real scientific facts and early warnings. We have seen exactly the same scenario in the debate on Tobacco, asbestos, climate change and pesticides.

Also in it's latest guidelines from March this year, ICNIRP assures the world that there is no scientific evidence of adverse health effects from the radiation that comes with the new communication technologies, within the limits it proposes. But at the same time a growing number of scientists and also citizens are worried that EMFs do cause health problems. ICNIRP pretends to be scientifically neutral, and free from vested interests of the Telecom industry. We show with this study that this is 'playing with the truth' or simply a lie.

Already in 2011 Dr. Jacqueline McGlade, Executive Director of the European Environment Agency said on mobile phones and the potential head cancer risk for EMF: "The European Parliament has responded (resolution of April 2009) to this public concern with a resolution on EMF in 2009 which, among other things, called for lowering exposure to electromagnetic fields and for lower exposure limits that would better protect the public from health hazards. We share these recommendations."

McGlade pleaded interim actions to protect public health, particularly for children on the basis of the precautionary principle, as central to public policymaking where there is scientific uncertainty and high health, environmental and economic costs in acting, or not acting, when faced with conflicting evidence of potentially serious harm. "This is precisely the situation that characterises EMF at this point in its history. Waiting for high levels of proof before taking action to prevent well known risks can lead to very high health and economic costs, as we have seen with asbestos, leaded petrol and smoking," said McGlade.

The EEA plea for a precautionary approach to policy making in this area, is based on an evaluation of the existing evidence and on the lessons from earlier hazards, analysed in the EEA "Late Lessons from Early Warnings" project. David Gee, EEA Senior Advisor on Science, Policy and Emerging Issue and on the drivers of this project said: "Mobile phones have numerous social, economic and even environmental benefits", said. "However, there is significant disagreement in the scientific community about whether mobile phone use increases the risk of head cancers. We recommend using the precautionary principle to guide policy decisions in cases like this. This means that although our understanding is incomplete, this should not prevent policy makers from taking preventative action".

In a recent discussion Gee stated that there are “several striking similarities” between 5G/radiofrequency radiation and many of the technologies or substances that featured in the “Late Lessons” case studies. Gee pointed to “a lot of hubristic hype surrounded the introduction of the new technology”. Gee rightfully points to a “marketing hype which is widespread” on 5G and “a failure to systematically and independently scrutinise the claimed benefits and costs of the new technology”. He sees a “gross imbalance between research on developing and promoting the technology and on anticipating and reducing potential harm to people and environments” as well as a “failure to ensure independent research into health and environmental effects that can help combat manufactured doubt”.

Gee was tough for the scientific community because scientists fail to acknowledge what they do not know and ”to properly understand and embrace knowledge from other relevant disciplines”. Gee also sees “a failure of scientists to be transparent about the paradigms, assumptions, judgements and values used in academic science and in their evaluations of scientific evidence in regulatory science. A failure of scientists and policymakers to appreciate complex and variable realities; multi-causality; and the likelihood of inconsistent scientific results. A failure by policymakers to understand the difference between the high strength of evidence needed to establish robust scientific knowledge and the case specific appropriate strength of evidence needed to justify timely preventive action.”

Late lessons from early warnings, is indeed also a clear pattern that rises from this report. And there have been more and more warnings (but unfortunately so far no lessons learned).

Also the Council of Europe adopted in May 2011 a strong resolution on “the potential dangers of electromagnetic fields and their effect on the environment” in which it called upon governments to take all reasonable measures to reduce exposure to electromagnetic fields and said about ICNIRP: “It is most curious, to say the least, that the applicable official threshold values for limiting the health impact of extremely low frequency electromagnetic fields and high frequency waves were drawn up and proposed to international political institutions (WHO, European Commission, governments) by the ICNIRP, an NGO whose origin and structure are none too clear and which is furthermore suspected of having rather close links with the industries whose expansion is shaped by recommendations for maximum threshold values for the different frequencies of electromagnetic fields”.

In an article, ‘Planetary electromagnetic pollution: it is time to assess its impact’, published in *The Lancet (*December 2018) scientists from the Australian research group ORSAA state that out of 2266 studies on EMFs, no less than 68 percent found “significant biological effects or health effects”. Significant biological effects do not necessarily mean that human health will be harmed, but is an important indicator for risk assessment and then for risk evaluation by regulators. To us the atgument that that there is insufficient scientiifc evidence for regulators to act is factual not corect and simply not true.

The International Agency for Research on Cancer (IARC), a global authority on cancer, concluded in 2011 that radiation from mobile phones is a ‘possible’ head cancer risk. And recently an Advisory Group has recommended that IARC should reassess the cancer risks associated with non-ionizing radiofrequency radiation with high priority. According to the panel’s report, published in The Lancet, the group suggests that the new evaluation should take place between 2022 and 2024.

In 2012 a group of 29 independent scientists and health experts from around the world warned in an update of their Bio Initiative 2007 Report, about “possible risks from wireless technologies and electromagnetic fields”. However, they acknowledge that “sometimes, science does not keep pace with new environmental exposures that are by-products of useful things we want to buy and use in society. So, the deployment runs ahead of knowledge of health risks. It is an old story. This is the case for EMF (electric and magnetic fields) and RFR (Radiofrequency radiation)."

The Bio Initiative report underscores the "critical need to face difficult questions, make mid-course corrections, and try to repair the damage already done in this generation, and to think about protecting future generations".

And they state that the existing public safety limits as formulated by the US regulator FCC and by ICNIRP do not sufficiently protect public health against chronic exposure from very low-intensity exposures: "If no mid-course corrections are made to existing and outdated safety limits, such delay will magnify the public health impacts with even more applications of wireless-enabled technologies exposing even greater populations around the world in daily life."

In 2017, more than 200 doctors and scientists from various countries launched the, so-called 5G Appeal, that has since received more endorsements and whose mission statement starts with : "We the undersigned scientists and doctors(…), recommend a moratorium on the roll-out of the fifth generation, 5G, for telecommunication until potential hazards for human health and the environment have been fully investigated by scientists independent from industry."

Since then there have been five replies on this Appeal by the European Commission, the last one dating from December 2019. The first reply, the Commission states that 'the Commission is not aware of any conflicts of interests of members of international bodies such as ICNIRP or the members of SCENIHR'. One of the leading figures of the appeal professor Lennart Hardell stated that this «does not represent the scientific evidence of inherent conflicts of interest both in ICNIRP and SCENIHR. The European Commission seems to be ill-informed or even misinformed, as the EU seems to take information mainly from these two fraudulent organisations, but not from independent researchers. The EU does not seem to rely on sound science and thereby downplays the RF-related risks."

It is clear from this report that ICNIRP itself does not have a sharp definition of conflicts of interest (CoI's), nor does it have a well-developed policy to avoid these kinds of conflicts. It is a crying shame that under the pretext of 'scientific uncertainty' ICNIRP, but especially the European Commission and member states keep on failing to protect their citizens.

We very much agree with the title and content of the latest publication on Microwave News, which reads " The Lies Must Stop, Disband ICNIRP - Facts Matter, Now More Than Ever" . There are two major casualties in this polarised debate: the truth and public health. Both are too important not to protect with all that we have. That is what we consider as our responsibility as elected politicians .

By MEP's Michèle Rivasi (Europe Écologie) and Dr. Klaus Buchner (Ökologisch-Demokratische Partei)

Introduction & Scope

In the last few decades, since the introduction, and rapid expansion, of new communication technologies, there has been a proliferation of electromagnetic fields worldwide. A lot of countries are now about to roll out 5G networks. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) assures the world that this can be done safely and that there is no scientific evidence of adverse health effects within the limits it proposes. But at the same time a growing number of scientists and also citizens are worried that EMFs do cause health problems.

It is therefore high time to look into the workings of ICNIRP. If the European Commission and national governments keep relying on this commission, as is currently the case, we must be completely sure that it functions wholly independently and that there is no evidence of its members being in situations of conflicts of interest.

ICNIRP is a non-governmental organisation (NGO) or association, registered in Munich, specialising in non-ionizing radiation protection. One of the organisation's tasks is to determine exposure limits for electromagnetic fields used by devices such as cellular phones. On its website, ICNIRP states that it is a non-profit organisation with a scientific mission, and that it is "formally recognised as an official collaborating non-state actor by the World Health Organisation (WHO) and the International Labour Organisation (ILO). ICNIRP is consulted by the European Commission and is linked to many organisations engaged in non-ionizing radiation (NIR) protection worldwide through diverse collaborative projects".

ICNIRP states that its "aim is to protect people and the environment against adverse effects of NIR." To this end, it "develops and disseminates science-based advice on limiting exposure to non-ionizing radiation." ICNIRP works with experts from all over the world, from a wide variety of disciplines, including biology, epidemiology, medicine, physics, and chemistry. ICNIRP's also states that its protection advice is based on current scientific knowledge about the biological effects, and the action mechanisms, of radiation for the whole NIR frequency range.

To a large extent, the European Commission, as well as the WHO, depend on the "exposure guidance" and safety advice given by ICNIRP. Furthermore, many EU member states look to the EC and WHO for (European) advice on this issue. Therefore, it goes without saying that ICNIRP has a significant role to play in ensuring the general public is protected against any possible health risks related to electromagnetic fields (EMF).

In March 2019, in a comprehensive report, *How much is Safe?,* *by Investigate Europe*, a collective of investigative journalists from all over Europe, ICNIRP is described as follows:

''ICNIRP is a particularly influential group, as it not only evaluates radiation and health risk research, but also provides guidelines for radiation safety limits that most countries use. It is a private, German-registered organisation located outside Munich, behind a yellow door on the premises of the German Federal office for radiation protection. Decisions on who to invite in, are taken by ICNIRP itself."

The report highlighted the close links that exist between ICNIRP and other important organisations in the field of health protection.

Most European governments and radiation protection authorities rely mainly on these four scientific bodies for advice on non-ionizing radiation protection:

- The international commission on non-ionizing radiation protection, ICNIRP.
- The EU Scientific Committee on Health, Environment and Emerging Risk, SCENIHR / SCHEER.
- The World Health Organisation WHO's International EMF Project.
- The WHO Cancer Unit IARC, International Agency for Research on Cancer.

Investigate Europe showed the close links between especially the first three bodies. "The groups, however, are to a remarkable degree, staffed by the same experts," it stated. "Of 13 ICNIRP scientists, six are members of at least one other committee. In the WHO group, this applies for six out of seven (members)." The SCENIHR Working Group on EMF also counts two ICNIRP-members.

In view of the rapid expansion of EMF's, in particular in the context of the planned deployment of 5G networks in which telecom and media operators have huge financial and economic vested interests, and given the evidence of closed circles of experts involved in determining health guidelines in this field, critical scrutiny on the functioning of ICNIRP is important and necessary.

New guidelines

In March 2020, ICNIRP published its latest 'Guidelines on Limiting Exposure to Electromagnetic Fields', designed for "the protection of humans exposed to radiofrequency electromagnetic fields (RF) in the range 100 kHz to 300 GHz. The guidelines cover many applications such as 5G technologies, Wi-Fi, Bluetooth, mobile phones, and base stations."

This publication replaces and supersedes earlier publications from 1998 and 2010. In a press release from March 11th 2020, the then ICNIRP Chairman, Dr Eric van Rongen (now co-chair) said: "The new electromagnetic field guidelines have taken seven years to develop and are more appropriate than the 1998 guidelines for the higher frequencies that will be used for 5G in the future. We know parts of the community are concerned about the safety of 5G and we hope the updated guidelines will help put people at ease. When we revised the guidelines, we looked at the adequacy of the ones we published in 1998. We found that the previous ones were conservative in most cases, and they would still provide adequate protection for current technologies."

Van Rongen's main message was that when the new ICNIRP guidelines are followed 5G is absolutely safe. He stated: "The new guidelines provide better and more detailed exposure guidance, in particular for the higher frequency range, above 6 GHz, which is of importance to 5G, and future technologies using these higher frequencies. The most important thing for people to remember is that 5G technologies will not be able to cause harm when these new guidelines are adhered to."

So, this is how ICNIRP presents itself: an independent organisation that gives sound scientific advice on safety guidelines with respect to non-ionizing radiation and that ensures citizens remain safe.

However, this description raises doubts on two levels: Firstly, is ICNIRP really independent and also, are its assurances that non-ionizing radiation is absolutely safe when their guidelines are applied correct? Our report will focus on the question of ICNIRP's independence, but first, we will briefly outline the current debate around the safety guidelines.

The health debate

The possible adverse health effects of non-ionizing radiation, mainly microwave radiation form mobile phones and other wireless devices/infrastructure, is a highly sensitive and polarising issue. In some countries citizens and scientists plead for the application of the 'pre-cautionary principle' in relation to the rolling out of 5G networks, whilst associations such as ICNIRP maintain that "the most important thing for people to remember is that 5G technologies will not be able to cause harm when these new guidelines are adhered to."

In 2012 a group of 29 independent scientists and health experts from around the world published an update of their Bio Initiative 2007 Report, about "possible risks from wireless technologies and electromagnetic fields". The scientists, of which ten holding a medical degree, still update their "rationale for Biologically-based Public Exposure Standards for Electromagnetic Fields (Extremely low frequency, ELF and radiofrequency, RF)" by assessing the latest scientific research and reporting on it. However, they acknowledge that "sometimes, science does not keep pace with new environmental exposures that are by-products of useful things we want to buy and use in society. So, the deployment runs ahead of knowledge of health risks. It is an old story. This is the case for EMF (electric and magnetic fields) and RFR (Radiofrequency radiation)."

The Bio Initiative report underscores the "critical need to face difficult questions, make mid-course corrections, and try to repair the damage already done in this generation, and to think about protecting future generations".

And they state that the existing public safety limits as formulated by the US regulator FCC and by ICNIRP do not sufficiently protect public health against chronic exposure from very low-intensity exposures: "If no mid-course corrections are made to existing and outdated safety limits, such delay will magnify the public health impacts with even more applications of wireless-enabled technologies exposing even greater populations around the world in daily life."

In an article, 'Planetary electromagnetic pollution: it is time to assess its impact', published in *The Lancet Planetary Health* in December 2018, scientists (from the Oceania Radiofrequency Scientific Advisory Association, ORSAA, and the Institute for Health and the Environment, of the University at Albany) state that out of 2266 studies on EMFs, no less than 68 percent found "significant biological effects or health effects". Significant biological effects do not necessarily mean that human health will be harmed, but is an important indicator for risk assessment and then for risk evaluation by regulators.

The authors stated that it is high time for a wide-ranging debate on the rapid global proliferation of artificial electromagnetic fields. “The most notable is the blanket of radiofrequency electromagnetic radiation, largely microwave radiation generated for wireless communication and surveillance technologies, as mounting scientific evidence suggests that prolonged exposure to radiofrequency electromagnetic radiation has serious biological and health effects.”

Unfortunately, this mounting evidence did not result in policy changes, the authors from ORSAA observe. “However, public exposure regulations in most countries continue to be based on the guidelines of the *International Commission on Non-Ionizing Radiation Protection* and Institute of Electrical and Electronics Engineers, which were established in the 1990s on the belief that only acute thermal effects are hazardous. Prevention of tissue heating by radiofrequency electromagnetic radiation is now proven to be ineffective in preventing biochemical and physiological interference”.

“For example, acute non-thermal exposure has been shown by NIH scientists, to alter human brain metabolism, electrical activity in the brain and systemic immune responses. Chronic exposure has been associated with increased oxidative stress and DNA damage, and cancer risk. Laboratory studies, including large rodent studies by the US National Toxicology Program and Ramazzini Institute of Italy, confirm these biological and health effects in vivo. As we address the threats to human health from the changing environmental conditions due to human activity, the increasing exposure to artificial electromagnetic radiation needs to be included in this discussion.”

The results of the National Toxicology Programme (NTP) the mentioned Lancet-authors referred to, were presented at the end of 2018. The U.S. Food and Drug Administration (FDA) nominated radio frequency radiation (RFR) used by cell phones for an NTP study because of the widespread public use of cell phones and the limited knowledge about potential health effects from long-term exposure. The study found that high exposure to RFR (900 MHz) used by cell phones was associated with:

- Clear evidence of tumours in the hearts of male rats. The tumours were malignant schwannomas.
- Some evidence of tumours in the brains of male rats. The tumours were malignant gliomas.
- Some evidence of tumours in the adrenal glands of male rats. The tumours were benign, malignant, or complex combined pheochromocytoma.

However, ICNIRP criticised the NTP-study, saying that it did not prove a link between Radio Frequency, Electro Magnetic Fields and carcinogenesis. But according to scientists like Lennart Hardell, an oncologist, professor and researcher at the University hospital in Örebro in Sweden, the ICNIRP rebuttal of the NTP-study was unfounded. The NTP-study leading scientist Ronald Melnick recently also published a comment on the ICNIRP-note in which he criticizes ICNIRP’s ”incorrect statements” and “false claims”.

James Lin, professor at the University of Illinois in Chicago and also editor of the online journal, *Bioelectromagnetics*, published a remarkable and nuanced review of the NTP-study in late 2019. The review is remarkable because, from 2004 to 2016, James Lin was himself a member of ICNIRP. As stated above, ICNIRP basically dismisses the NTP-study. However, basing his conclusions partly on the NTP-study, Lin now questions if the existing safety guidelines are still adequate: “An outstanding question persists on the adequacy of these guidelines for safe long-term exposure to RF radiation at or below 1.6 or 2.0 W/kg. Perhaps, the time has come to judiciously reassess, revise, and update these guidelines.”

Lin’s review is nuanced in so much as he uses the peer-review process to analyse the conception and all possible methodological ‘problems’ of the NTP-study in depth: “This project is the largest NTP animal cancer study ever. It was nominated by the Food and Drug Administration (FDA) in 1999. The supposedly 5-year project was sole sourced in 2004 to an industrial research firm as the project’s principal investigator. The work began in 2005. However, the project had been protracted for more than a dozen years with huge budget overruns, and an estimated eventual price tag of $25 million.”

Somewhat surprisingly, at the end of his review, Lin advocates for wireless radiation to “get a more stringent cancer risk class": “Now that the NTP review panel has concluded that there is clear evidence of carcinogenicity from long-term RF exposure in rats, is it conceivable that IARC would upgrade its epidemiology-based classification of RF exposure to the next higher levels of carcinogenicity to humans?” Lin seems to suggest that IARC should put cell phone radiation in WHO-hazard class 1 (carcinogenic), instead of today’s 2B (possibly carcinogenic).

Worldwide, there is rapidly growing concern and a proliferation of publications about EMF, specifically concerning the out-roll of new generation 5G. On this subject, we will only cite a 2019 in-depth report called “5G Deployment: State of Play in Europe, USA, and Asia”[1]. It reads: “Increased exposure may result, not only from the use of much higher frequencies in 5G, but also from the potential for the aggregation of different signals, their dynamic nature, and the complex interference effects that may result, especially in dense urban areas. (…) The 5G radio emission fields are quite different to those of previous generations because of their complex beam-formed transmissions in both directions – from base station to handset and for the return.”

The authors state that with 5G we are entering unknown territory. “Although fields are highly focused by beams, they vary rapidly with time and movement and so are unpredictable, as the signal levels and patterns interact as a closed loop system. This has yet to be mapped reliably for real situations, outside the laboratory. (..) The problem is that currently it is not possible to accurately simulate or measure 5G emissions in the real world.”

The debate on the safety of non-ionizing radiation is fascinating, heated and important, and has been on-going for at least 30 years. This paper however does *not* go further into the scientific debate on the possible levels of harm to public health caused by non-ionizing radiation, mainly from mobile phones. We will focus on the independence of ICNIRP and the possible existence of conflicts of interest of its members.

[1] A study requested by the ITRE committee of the European Parliament, published in 2019 by the Policy Department for Economic, Scientific and Quality of Life Policies - Directorate-General for Internal Policies.

The importance of funding

ICNIRP claims it is “free of vested interests”. ICNIRP's funding relies on grants from public bodies. Additionally, ICNIRP members and ICNIRP SEG members may not be employed by industry.

But not being “employed by industry” is not, in itself, sufficient to avoid conflicts of interest. It is also important to ascertain to what extent ICNIRP research activities may be funded by industry.

It is a well-established fact that the source of funding for scientific research can have an influence on the outcomes of research. A clear and precise explanation of how this is may occur can be found on the website of UC Berkeley:

“In a perfect world, money wouldn't matter — all scientific studies (regardless of funding source) would be completely objective. But of course, in the real world, funding may introduce biases — for example, when the backer has a stake in the study's outcome. A pharmaceutical company paying for a study of a new depression medication, for example, might influence the study's design or interpretation in ways that subtly favour the drug that they'd like to market. There is evidence that some biases like this do occur. Drug research sponsored by the pharmaceutical industry is more likely to end up favouring the drug under consideration than studies sponsored by government grants or charitable organisations. Similarly, nutrition research sponsored by the food industry is more likely to end up favouring the food under consideration than independently funded research.”

“This does not lead to the conclusion that we should ignore any research funded by companies or special interest groups”, Berkeley says. But it is a reason for the need “to scrutinize studies funded by industry or special interest groups with extra care. *So, don't, for example, brush off a study of cell phone safety just because it was funded by a cell phone manufacturer — but do ask some careful questions about the research before jumping on the bandwagon*. Are the results consistent with other independently funded studies? Does the study seem fairly designed? What do other scientists have to say about this research? A little scrutiny can go a long way towards identifying bias associated with funding source.”

“A little scrutiny” is perhaps an understatement. In the 2013, the ‘Late lessons from early warnings’ report produced by the European Environment Agency (EEA), a chapter written by Lisa A. Bero, describes the various opinions on how to deal with private funding of scientific research without compromising an independent non-biased outcome and/or publication of that research.

For example, various researchers argue that it is logical for industry to fund research, in so much as it is about their products that concerns exist. Former ICNIRP scientist Norbert Leitgeb, professor at the Institute of Health Care Engineering at the Graz University of Technology in Austria, told *Investigate Europe* that what is crucial is the putting in place of effective firewalls to ensure that “private partners cannot interfere with researchers and influence scientific outcomes or conclusions”.

That the source of funding has an important influence, is also something various ICNIRP-researchers acknowledge. For example, in 2009 two scientists who are now members of the ICNIRP-commission – Anke Huss and Martin Röösli – where co-authors of a systematic review that showed that “industry-sponsored studies were least likely to report results suggesting effects”. They concluded that the correlation between the “source of funding and conflicts of interest are important in this field of research.”

in his evaluation of the NTP-study, another former ICNIRP-member, professor James Lin, also pointed to the dominance of the telecom industry in the research: “The FDA should be applauded for nominating, and NIEHS/NTP should be lauded for having sponsored the research and conducted the Cell Phone Radio Frequency Radiation (RFR) Studies. It’s important for the U.S. government to step in to conduct such a research program, and not leave the matter entirely to the cell phone industry. The wireless industry has had nearly free reign to develop and roll out cellular mobile phones and related RF devices as they see fit. (…)”. Lin goes on to quote figures from the ‘systematic review’: “A systematic review of 59 published studies of controlled exposure to RF radiation with health-related outcomes [10] showed that public agencies or charities funded 11 (19%), the wireless communications industry funded 12 (20%), mixed sources (including industry) funded 14 (24%), and in 22 (37%) the source of funding was not reported.”

This specific debate has been ongoing for many years, as *Investigate Europe* reports: “At least three studies over the years have documented that there is often a link between conclusions of studies and the source of the money that paid for the research. Science funded by industry is less likely to find health risks than studies paid for by institutions or authorities.”

In ‘How much is safe?’ by *Investigate Europe*, Lennart Hardell, an oncologist, professor and researcher at the University hospital in Örebro in Sweden, a critical EMF researcher, warns that although funding for research often goes to universities with “firewalls” put in place between the individual scientist and the funder, the problem is, that researchers can come to depend on this private funding to safeguard the future of their research.

Hardell carries out research on the possible links between long-term mobile use and brain cancer and has published results that indicate that there are correlations between the two. Hardell was a member of the IARC committee that researched EMF-effects, but is not a member of (any) other committees concerned with the effects of non-ionizing radiation. *Investigate Europe*: “According to Hardell, his research is funded through his salary from the hospital, as well as by funds raised by local cancer foundations and national organisations. “Of course, I have also worked a lot on my free time”, he says.”

There are some ICNIRP-researchers who acknowledge that it is possible for the source of funding to influence conclusions, but they say that they are very aware of this and cautious to avoid it. For example, Gunnhild Oftedal, - associate professor at the Norwegian University of Science and Technology, who specialises in research on the effects of electromagnetic fields on humans, and is a member of ICNIRP and therefore part of “the small international network that determines what science to trust” said to *Investigate Europe* that “today we are concerned about it. I have the impression that scientists are much more cautious about receiving support from the industry – at least direct support.”

What about the direct funding received by ICNIRP itself? ICNIRP states that its “funding stems from subsidies granted by national and international public institutions such as the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety

(BMU), the European Union Programme for Employment and Social Innovation (EaSI) 2014-2020 (EC - Directorate General Social Affairs), and the International Radiation Protection Association (IRPA)."

"Occasionally, ICNIRP also receives support to organise meetings or workshops from national ministries or radiation protection agencies, such as the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), and the Turkish Ministry of Health (MoH). Funding is reported yearly in the ICNIRP annual reports". ICNIRP also acknowledges that it receives funding from national or international public organisations and via private donations. But ICNIRP claims that in order to safeguard its independence, "only donations from private individuals or from businesses not related in any way to the field of non-ionizing radiations can be accepted. For reasons of transparency, donations cannot be anonymous and are listed in an ICNIRP donors' report."

According to the ICNIRP 2018 annual report, it received € 132,150 in subsidies. The Australian research group ORSAA points out that these kinds of funding sources are not always as neutral as they may seem: "ICNIRP funding partly comes from government regulatory bodies, such as, for example, the Australian Radiation Protection & Nuclear Safety Agency (ARPANSA). What is actually going on is best described as 'money laundering' by the Telecom industry through government (ARPANSA) and onto WHO's International EMF Project and ICNIRP."

In Australia, as is the case for many countries worldwide, the government issues spectrum licences to Telecom operators for large sums of money – often in the billions. In Australia, this licensing is the remit of the industry regulator ACMA, the Australian Media Communications Authority. ORSAA explains that ACMA also collects a separate levy, or tax, from the wireless industry, money that is earmarked for scientific research on RF-EMR health effects: "This has remained a set amount of $1M per annum since 1997, despite the massive increases in wireless industry revenues."

According to ORSAA, ACMA then diverts $300,000 to another government body, ARPANSA (Australian Radiation Protection & Nuclear Safety Agency) for its public information campaign, and $700,000 to the National Health & Medical Research Council (NHMRC). From the $300,000 received annually by ARPANSA, a portion goes to the WHO's IEMFP (some years ago this was around $50,000 a year), and finally, it appears that a portion goes to ICNIRP. So, after a long trajectory, money from the Telecom industry does end up with ICNIRP, which is contrary to the statement on the ICNIRP website: "Only donations from private individuals or from businesses not related in any way to the field of non-ionizing radiations can be accepted."

Still according to ORSAA, "the money that the Australian NHMRC receives in order to provide grants for medical research has mostly gone to industry-friendly researchers who have direct links with the wireless industry. For example, the largest recipient of these NHMRC research funds is Prof. Rodney Croft, a psychology researcher at the University of Wollongong, who held the role of Director of the Australian Centre for Electromagnetic Bio-effects Research (ACEBR) for many years[2]. Rodney Croft has essentially been the head of RF-EMR health research in Australia, despite his questionable qualifications for this health research role.

[2] See also portrqit of Rodney Croft on pqge 50 of this report.

Notably, he has led ICNIRP's RF-EMR exposure guidelines development team and now he has been elected as the next Chairman of ICNIRP as from May 2020. Prof. Croft has received ample direct industry funding in addition to his lucrative NHMRC grants, which should be termed indirect industry funding."

Finally, ICNIRP states on its website that all its experts "are required to comply with the ICNIRP policy of independence and declare their personal interests. (...) These are key elements to ICNIRP's commitment to independence and transparency, which ICNIRP believes is fundamental to carrying out its scientific mission."

Whether those declarations of interests are really checked is something that the Italian 'Vallisoletana Association of people affected by mobile phone antennas' (AVAATE) questioned in their public statement from July 2015, attacking ICNIRP: "It is hard to understand whether ICNIRP investigates the Declarations filed by appointed members of the ICNIRP Commission and Scientific Expert Committee, since in some cases these members report that they work or have worked for these organisations but do not specify what they have done or whether they are paid. It is also hard to understand how ICNIRP controls the content of the declarations by the appointed members of their Expert Committees, when in most cases the most contentious aspects of the biographical statement are not reported in these statements."

The citizens behind AVAATE also ask "how ICNIRP controls the content of the declarations by the appointed members of their Expert Committees when, at least in five cases, the persons concerned have not signed their statements".

Corporate capture

In the debate on EMF and possible health effects, terms like 'corporate capture' of scientific research and 'war game science' are often used, and references to the tactics of the tobacco industry are often made. According to several authors, these tactics also influence organisations like ICNIRP and WHO's International EMF Project.

In the 2013 'Late lessons from early warnings' report produced by the European Environment Agency (EEA), in collaboration with a broad range of external authors and peer reviewers, these tactics are described in detail in the chapter entitled 'Tobacco industry manipulation of research'. The focus is on "the strategies used by the tobacco industry to deny, downplay, distort and dismiss the growing evidence that, like active smoking, ETS causes lung cancer and other effects in non-smokers." Author Lisa A. Bero concentrated "on the 'argumentation' that was used to accept, or reject, the growing scientific evidence of harm. Who generated and financed the science used to refute data on adverse health effects? What were the motivations? What kind of science and information, tools and assumptions were used to refute data on the adverse health of tobacco?"

Bero says: "The release of millions of internal tobacco industry documents due to law suits in the US has given insights into the inner workings of the tobacco industry and revealed their previously hidden involvement in manipulating research. However, this insight is not available for most corporate sectors."

Bero also discusses the possibilities of 'full disclosure' of funding sources and special interests in research and risk assessment in order to secure independence and prevent bias towards particular viewpoints. She states that “while smoking bans are now being introduced in more and more countries, other industries are drawing inspiration from tobacco company strategies, seeking to maintain doubt about harm in order to keep hazardous products in the marketplace.”

With respect to the EMF-debate, according to Bero, public institutions or authorities should adhere to the following: “when data on risk appear to be controversial, users of the data investigate the sources of the controversy. Does the controversy exist only because the findings of interest group-funded research are contrary to data collected by others? Is the controversy supported primarily by evidence published in interest group-supported publications? (…) Policymakers should apply these questions to all situations in which a company has an interest in creating controversy about the risks of its products.”

According to Bero, the tobacco industry's methods for influencing the design, conduct and publication of research are similar to those of other corporate interests.

One of the leading researchers in the US who defends the viewpoint that the same tactics are being used by Telecom companies is Theodora Scarato, Executive Director of the US based [Environmental Health Trust](#) (EHT). As a policy analyst, Scarato manages and updates the comprehensive EHT database on international policy that documents the 20+ nations that have protective policies in place to reduce public exposure to cell phone and wireless radiation.

Scarato and EHT claim that “Just as the Tobacco Industry created a ‘Playbook’ to defend cigarettes and manufacture doubt about the health effects of cigarettes, the Wireless Industry seems [to have a fine-tuned the “Playbook” of advertising, public relations and industry-funded science](#) to defend wireless products and falsely reassure the public that cell phones and wireless products are safe.”

“Key to this public relations effort are industry created resources, websites and materials that communicate the myth of no proof of harm from wireless products. These are all part of the Playbook to manufacture doubt that a problem exists. Examples of such propaganda range from glossy brochures, Questions and Answers on Hot Topics such as “children and cell phones”, websites on EMF and Health and research forums.”

And according to Scarato, “these materials are paid for, designed and prepared by ‘non-profit’ organisations that are created by telecom and wireless companies pooling money together. When citizens raise concerns about a particular product or when research comes out indicating a health risk, companies can simply pull from these materials to respond as if there are no concerns”.

These kind of tactics, used to influence science and risk assessment, also have their repercussions for standard-setting bodies like ICNIRP and WHO’s International EMF Project, according to scientific researcher Don Maisch (in his PhD thesis ‘An examination of the manipulation of telecommunications standards by political, military, and industrial vested interests at the expense of public health protection’): “In an ever increasingly globalised world the reliance on international organisations to set standards to protect public health seems inevitable. Proposed internationalised standards such as ICNIRP’s recommendations act as an aid to economic development by not hindering trade that might conflict with stricter national standards (such as the Russian Federation, the Czech Republic's former standard and China for example). In the delicate trade-off between economic benefits and adequate health protection, international organisations should ideally be "eternally vigilant" to ensure that their tasks are not co-opted by vested interest groups that are the producers of risks to be regulated."

This appears to be a global issue. US researcher, Norm Alster, in his report 'Captured Agency' describes what this kind of corporate capture can lead to by referring to the workings of the FCC (Federal Communications Commission), which is the main official US institution that deals with Telecom issues, and is sometimes mentioned in critiques of ICNIRP: "That is a term that comes up time and time again with the FCC. Captured agencies are essentially controlled by the industries they are supposed to regulate. A detailed look at FCC actions—and non-actions—shows that over the years the FCC has granted the wireless industry pretty much what it has wanted".

"As a result, consumer safety, health, and privacy, along with consumer wallets, have all been overlooked, sacrificed, or raided due to unchecked industry influence. (…) Most insidious of all, the wireless industry has been allowed to grow unchecked and virtually unregulated, with fundamental questions on public health impact routinely ignored. (…) Industry control, in the case of wireless health issues, extends beyond Congress and regulators to basic scientific research. And in an obvious echo of the hardball tactics of the tobacco industry, the wireless industry has backed up its economic and political power by stonewalling on public relations and bullying potential threats into submission with its huge standing army of lawyers. (…) Industry behaviour also includes self-serving public relations and hyper aggressive legal action. It can also involve undermining the credibility of, and cutting off funding for, researchers who do not endorse cellular safety. It is these hardball tactics that recall 20th century Big Tobacco tactics."

Conflicts of Interest

In 2017, almost 200 doctors and scientists from various countries launched the, so-called 5G Appeal, that has since received more endorsements and whose mission statement starts with : *"We the undersigned scientists and doctors(…), recommend a moratorium on the roll-out of the fifth generation, 5G, for telecommunication until potential hazards for human health and the environment have been fully investigated by scientists independent from industry."*
Since then, as professor Hardell describes in his article "Appeals that matter or not on a moratorium on the deployment of the fifth generation, 5G, for microwave radiation" published in January 2020, there have been five replies on this Appeal by the European Commission, the last one dating from December 2019. The first reply, by the Commission (from October 13, 2017 by the Directorate-General Health and Food Safety) states that *'the Commission is not aware of any conflicts of interests of members of international bodies such as ICNIRP or the members of SCENIHR'*.

However, according to Hardell, "that does not represent the scientific evidence of inherent conflicts of interest both in ICNIRP and SCENIHR. The European Commission seems to be ill-informed or even misinformed, as the EU seems to take information mainly from these two fraudulent organisations, but not from independent researchers. The EU does not seem to rely on sound science and thereby downplays the RF-related risks."

Given the important effects of funding on research outcomes described above, there can be no doubt that it is extremely important for ICNIRP to ensure it avoids any possibility of conflicts of interests in the way that it, or any of its members, function. In its statutes, it writes: 'No member of the Commission shall hold a position of employment that, in the opinion of the Commission, will compromise its scientific independence.'

The crucial words here are '*in the opinion of the Commission'*. The Commission evaluates itself about possible conflicts of interest. There are no clear rules by which the Commission judges if any of its members interests compromise its scientific independence. In its statement on the declarations of interests ICNIRP writes:

"The evaluation of personal integrity is very complex and might never be achievable in a perfect way. It is the duty of the ICNIRP Commission to carefully consider and decide if the declared interests potentially constitute a conflict of interest."

It is clear from this that ICNIRP itself does not have a sharp definition of conflicts of interest (CoI's), nor does it have a well-developed policy to avoid these kinds of conflicts.

It is useful to refer to a recent study requested by the European Parliament's Petitions (PETI) committee which, as a key message, said that "EU institutions and agencies lack a consistent definition of conflicts of interest and common rules on transparency'. This same study also stated that "a coherent policy should be developed for the required length of time between working in the industry and being called to a committee among agencies with a similar function, i.e. risk assessment".

In the online newsletter, *Politico*, the Greek MEP Alexis Georgoulis said: "There is a legal inconsistency between the definitions of the conflicts of interest that should clearly cover any conflicts between public and private functions, but also public functions with other public functions," The report recommends clear clarifications on whether conflicts of interest are potential or also perceived.

So, we will have to look at other, similar, organisations that have more stringent policies in this field. The European Food and Safety Authority (EFSA) seems to be a good candidate. In June 2017, EFSA, after a long history of accusations of CoI's, sharpened its definition and its policy to avoid CoI's.

EFSA defines a conflict of interest as "any situation where an individual has an interest that may compromise or be reasonably perceived to compromise his or her capacity to act independently and in the public interest in relation to the subject of the work performed at EFSA".

This definition is also somewhat broad and vague. EFSA's solution was to set clear rules to which its experts have to comply. For example: Research funding from the private sector benefiting EFSA's experts should not exceed 25% of the total research budget.

The EFSA-rules are minimum requirements. According to *Corporate Europe Observatory* they are not strict enough to completely avoid conflicts of interest. So, it is reasonable to say that

ICNIRP, that presents itself as an independent, scientific advisory board, should, at the very least, comply with the EFSA rules.

In this paper, we will therefore:

* Give an overview of the history and all existing knowledge on the independence of, and the conflicts of interest within, ICNIRP. These chapters provide the context in which we have a closer look at the ICNIRP-members.

* Try to identify all the potential sources of conflicts of interest of ICNIRP-members. Such as: research funding from the private sector; financial investments in, and employment by, telecom business operators; consultancy work for the telecom industry.

* Try to find out if the ICNIRP-members comply to the EFSA-rules on conflicts of interest and give an assessment on the independence of ICNIRP.

These are the ICNIRP experts whose professional backgrounds we will research (see the portraits of each member in Part V):

As from December 2019, the composition of the ICNIRP Commission for the term of office 2020-2024 is as below. The new term of office starts in May 2020.

MEMBERS OF THE ICNIRP COMMISSION:

GUNDE ZIEGELBERGER (SCIENTIFIC SECRETARY), GERMANY
RODNEY CROFT (CHAIR), AUSTRALIA
ERIC VAN RONGEN (VICE-CHAIR) , THE NETHERLANDS

TANIA CESTARI, BRAZIL
NIGEL CRIDLAND, UNITED KINGDOM
GUGLIELMO D'INZEO, ITALY
AKIMASA HIRATA, JAPAN
ANKE HUSS, NETHERLANDS
KEN KARIPIDIS, AUSTRALIA
CARMELA MARINO, ITALY
SHARON MILLER, USA
GUNNHILD OFTEDAL, NORWAY
TSUTOMU OKUNO, JAPAN
MARTIN RÖÖSLI, SWITZERLAND
SOICHI WATANABE, JAPAN

MEMBERS WHO HAVE LEFT THE ICNIRP COMMISSION IN MAY 2020
Maria Feychting
Adèle Green
Zenon Sienkiewicz

MEMBERS OF THE SCIENTIFIC EXPERT GROUP (SEG):
JACQUES ABRAMOWICZ - PG COSMETICS, PG ULTRASOUND
ANSSI AUVINEN - PG DATA GAPS
CHRISTIAN CAJOCHEN - PG SHORT WAVE LIGHT
JOSE GOMEZ-TAMES - PG HF DOSIMETRY REVIEW
PENNY GOWLAND - PG DATA GAPS
JOHN HANIFIN - PG SHORT WAVE LIGHT
JUKKA JUUTILAINEN - PG DATA GAPS
KEN KARIPIDIS - PG COSMETICS, PG DATA GAPS
MASAMI KOJIMA - PG LASER POINTERS
ILKKA LAAKSO - PG HF DOSIMETRY
ISABELLE LAGROYE - PG DATA GAPS
SARAH LOUGHRAN - PG SHORT WAVE LIGHT, PG HF GUIDELINES
JACK LUND - PG LASER GUIDELINES
SIMON MANN - PG HF DOSIMETRY
RÜDIGER MATTHES - PG HF DOSIMETRY
JOHN O'HAGAN - PG LASER GDL, PG LASER POINTERS, PG LED, PG SHORT WAVE
CHIYOJI OHKUBO - PG DATA GAPS
MARGARETHUS PAULIDES - PG HF DOSIMETRY
KENSUKE SASAKI - PG HF DOSIMETRY REVIEW
DAVID SAVITZ - PG ULTRASOUND
KARL SCHULMEISTER - PG DATA GAPS, PG LED, PG LASER GDL, PG POINTERS
DAVID H. SLINEY - PG LASER GDL, PG LASER POINTERS, PG LED, PG SHORT WAVE LIGHT
RIANNE STAM - PG COSMETICS
BRUCE STUCK - PG HF GDL, PG DATA GAPS, PG LED, PG LASER POINTERS, PG LASER GDL
JOHN TATTERSALL - PG HF GUIDELINES
TIM TOIVO - PG COSMETICS
ANDREW WOOD - PG DATA GAPS, PG HF DOSIMETRY
TONGNING WU

I- Historic overview of ICNIRP and accusations of COI

In this chapter, we give an overview of the history of ICNIRP as an organisation and examples of accusations of Conflicts of Interests (COI) and other controversies concerning the organisation's work. The authors do not want to suggest that this overview is, by any means, complete or comprehensive.

About ICNIRP's history, on its website, the organisation simply states that its beginnings go back to 1973 "when, during the 3rd International Congress of the International Radiation Protection Association (IRPA), for the first time, a session on non-ionizing radiation protection was organized. In 1977 the International Non-Ionizing Radiation Committee (INIRC) was created. This Committee was the immediate forerunner of ICNIRP that was chartered as an independent Commission in 1992 during the IRPA 7th International Congress."

In a speech in Rio de Janeiro, in 2008, Paolo Vecchia, the Italian former ICNIRP-chair (2004-2012), explained in more detail: "In June 1974, IRPA President, Italian Carlo Polvani (1973-1977), proposed "a possible role of IRPA in establishing criteria and standards in the field of health protection against non-ionizing radiations" and the IRPA Executive Council decided to set up a Working Group to review the health protection problems arising from different non-ionizing radiation (NIR)."

One could argue that IRPA itself, and then much later it's spin-off ICNIRP, came into existence as a "fall-out" of the first US atomic bomb testing. On its website, on the subject of its historical background, IRPA states: "Before the Second World War, radiation protection had been a largely secondary concern of radiologists and radiological physicists. With the concentration of effort under the Manhattan Project it was soon realised that this would involve working with quantities and types of radiation and radioactive materials that had not previously been envisaged. As a result, a distinct group of scientists within the project were assigned full time to what was termed "Health Physics"."

In an article from 2017 on the history of of ICNIRP, at the occasion of it's 25th anniversary founder Mike Repacholi wrote: "Concern about health risks from exposure to non-ionizing radiation (NIR) commenced in the 1950s after tracking radars were first introduced during the Second World War. Soon after, research on possible biological effects of microwave radiation in the former Soviet Union and the U.S. led to public and worker exposure limits being much lower in Eastern European than in Western countries, mainly because of different protection philosophies." As we will see further in this chapter this divide between Russia and the West on safety measures on non-ionizing radiation exists till today.

At the end of its conference in 1955, the US Atomic Energy Commission voted overwhelmingly to form a professional Health Physics Society and the first IRPA Congress was held in Rome between 5-10 September 1966. It is interesting to see that many of the 12 Executive Council Members of IRPA in 1966 remained in position for many years; a fact that echoes like a prelude to criticism that ICNIRP functions like an 'old-boys network'.

In 1974, IRPA President Polvani insisted that "a separate and independent International Commission on NIR Protection (later ICNIRP) should be established…The ICNIRP would look to IRPA as the sponsoring international scientific organization in a similar way that ICRP looks to the International Congress of Radiology…. And "IRPA should consider broadening its institutional authority to include NIR".

So Carlo Polvani got what he wanted: the General Assembly amended the Constitution of IRPA so that it could "also apply its objectives and purposes in the field of non-ionizing radiation protection". Then the General Assembly created an International NIR Committee […] "with the objective of developing background documents and internationally accepted recommendations". This became INIRC, set up in 1977, that went on to become ICNIRP, in 1992. Already four years earlier, Mike Repacholi (more on him later), a member of IRPA, had begun writing the charter for ICNIRP which was signed in 1992.

But why elaborate so much on IRPA, before turning to ICNIRP itself? Critics often ask from where ICNIRP got its self-acclaimed international and institutional authority? Well, partly from IRPA, which still plays a role in the actual composition of ICNIRP. The IRPA Charter for the creation of ICNIRP, from 1992, says: "The election of the members of the Commission shall be made by the Commission from current members of the Commission and from nominations submitted by the Commission itself, the Executive Council of IRPA and the IRPA Associate Societies, with regard to an appropriate balance of expertise. Attention shall be paid to geographical representation."

At the end of the 15th International Congress of IRPA, planned for 11-15 May 2020, in Seoul, Korea, the new term of office of the new ICNIRP commission (2020-2024) would officially start. This occurred, despite the international congress in South-Korea being postponed until 2021 due to the corona-crisis. This international congress counts telecom companies of all kinds among its sponsors (platinum, silver, bronze as well as others). Since ICNIRP was born from IRPA, and that, like any parent, IRPA still exerts a strong influence over ICNIRP, and considering ICNIRP claims to function free of any vested interests, it seems important to us to look more closely at IRPA.

And maybe also because of the actual role that IRPA wants to play in the ongoing debate around safety and health in relation to EMF. Current IRPA-president, Roger Coates, writes that "a lot of effort over recent times has gone into preparing the IRPA Guidance for Engagement with the Public on Radiation and Risk". This seems to be the typical type of response given by bodies like IRPA, ICNIRP and others concerning public worries about possible health effects: *let's explain things better, because the public doesn't understand (…that everything is safe)*. It is the same kind of response given in the past by the nuclear sector when people started to become worried about nuclear safety issues (for example after Chernobyl).

Some governments – at various levels – try to put into practice a guiding principle of radiation safety, called "ALARA", which stands for "As Low As Reasonably Achievable". This principle means that even when being subjected to a small dose, if receiving that dose has no direct, practical or medical benefit, you should try to avoid it. IRPA-boss Roger Coates states that "the interpretation of what is 'Reasonable' in the implementation of optimisation of radiation protection is one of the key issues for our profession and is one of IRPA's current key themes. It is central to practical protection and is the dominant factor controlling exposures in any well-developed system of protection. But what does 'reasonable' mean?

There are growing concerns within our profession that we are giving more emphasis to 'as low as' and 'minimisation' rather than truly being 'reasonable'."

On the subject of safety: before Roger Coates became IRPA-president he had a life-long career in the British nuclear industry: he started working in 1975 at the Health Physics and Safety Department at the Sellafield site of *British Nuclear Fuels plc (*BNFL) and did so for over 30 years, "holding radiation protection roles covering operations, environmental protection and emergency planning. His responsibilities broadened to encompass nuclear safety, together with conventional safety and environmental issues. He completed his industry career as Director of Environment, Health and Safety for both BNFL and its British Nuclear Group subsidiary." Over the years, BNFL has had to face up to quite some issues in the field of safety and was the subject of a "damning report into the falsification of safety data at the Sellafield reprocessing plant" at the start of this century.

This year, on its website, IRPA published the first new safety guidelines of ICNIRP since 1998, of which ICNIRP-chair Van Rongen said, as we mentioned earlier: " The new guidelines provide better and more detailed exposure guidance in particular for the higher frequency range, above 6 GHz, which is of importance to 5G and future technologies using these higher frequencies. The most important thing for people to remember is that 5G technologies will not be able to cause harm when these new guidelines are adhered to."

Self-declared legitimacy

Since the signing of IRPA-charter in 1992, ICNIRP is based in Munich, Germany and registered as a self-governed NGO (non-governmental organisation) that was formally recognized as "an official collaborating non-state actor by the World Health Organization (WHO) and the International Labour Organization (ILO)." ICNIRP is consulted by the European Commission and is linked to many organizations engaged in NIR protection worldwide through diverse collaborative projects.

As mentioned in the introduction of this report, extensive reporting by *Investigate Europe*, in March 2019 (updated on June 10th 2020), showed that there are many close links between ICNIRP and other leading organisations in the field of health protection. Many ICNIRP-members are, or were, also members of one of these three scientific bodies (from which most radiation safety authorities in Europe and governments, seek their advice) and it is important to mention them again, because these are the bodies that guide government policies in most countries:

- The EU Scientific Committee on Health, Environment and Emerging Risk, SCENIHR / SCHEER.
- The World Health Organization (WHO) International EMF Project (IEMFP).
- The WHO Cancer Unit IARC, International Agency for Research on Cancer.

It is worth underlining, however, that IARC does not really fit into this "gang of four" because it has a much more critical and independent approach. IARC published a report in May 2011 which concluded that radiofrequency (RF) radiation is "possibly carcinogenic" to humans.

The IARC cancer classification includes all sources of RF radiation, of which the long-term exposure can come from mobile phone base stations, Wi-Fi access points, smart phones, laptops and tablets.

However, IARC may now have a solid reputation as independent scientific body, some years ago, IARC also got into trouble. Anders Ahlbom, senior professor of Epidemiology at the Karolinska Institute in Stockholm, and a long standing, influential member of ICNIRP (Commission Member and ICNIRP SCI working group (Epidemiology)), and ICNIRP Chairman from 1996 until 2008, was also part of the IARC panel of experts in 2011. Ahlbom was, until very recently, doing assessments of environmental health risks as chair of the Swedish Radiation Safety Authority's (SSM), the scientific council on electromagnetic fields, as a member of ICNIRP and of the EU advisory body SCENHIR.

But he was asked to step down from IARC after a journalist exposed him as being on the board of his brother's consulting firm in Brussels, which helps clients on telecoms issues. He had not made IARC aware of this. As the Swedish investigative reporter, Mona Nielsson, wrote: "Furthermore, Anders Ahlbom's brother, Gunnar Ahlbom, was for a long time a lobbyist for Swedish telecom giant Telia (previously TeliaSonera) in Brussels. At the same time Anders Ahlbom served as an "independent expert" on several important expert panels, in Sweden as well as at the WHO and EU. At a meeting organized by the European Commission in cooperation with GSM Association and Mobile Manufacturers Forum in Brussels in 2004, Anders Ahlbom was an invited expert to speak on health effects, while his brother Gunnar Ahlbom sat in the audience representing TeliaSonera."

There was, and is, more controversy and division on this topic within the WHO. In a 2017 article, "A hard nut to crack", professor Lennart Hardell draws attention to a Fact Sheet issued by WHO in June 2011, only two months after the IARC's report adapting the cancer classification of RF radiation, which stated that "to date, no adverse health effects have been established as being caused by mobile phone use". According to Hardell, this statement was "not based on scientific evidence at that time on a carcinogenic effect from RF radiation. And it was certainly a remarkable conclusion by WHO since IARC is a part of WHO, although seemingly independent". And he goes on to conclude: "Considering the WHO statement of 'no adverse health effects' the aim might have been to undermine the IARC decision and give the telecom industry a 'clean bill' of health."

One of the main reasons for this schizophrenic approach within the WHO is to be found in the figure of ICNIRP-founder, Mike Repacholi, and the WHO's International EMF Project, IEMFP) (see more below). At least four ICNIRP-members were, or are, also members of the WHO-EMF Group.

In January 2019, in the German newspaper Der Tagesspiegel, investigative journalists described ICNIRP as "a Cartel", that systematically refutes all studies that show possible harm: "And no radiation protection agency, no EU commissioner and no minister, contradicts this. For European governments and their authorities, the 13 members of the self-appointed Commission act as a kind of force majeure. But why? Why are all the warners, even prominent figures like the panel of experts for the US Health and Safety Executive, not heard?"

The Investigative journalists describe an “astonishing phenomenon: the members of ICNIRP are simultaneously active in all the relevant institutions and thus have control over the official discourse.” They then go on to note that, legally speaking, ICNIRP is an association that auto-controls itself and thus avoids dissenting opinions, but in the first instance, the connection with the German state begins with the chosen address of ICNIRP which is the same as the German Federal Office for Radiation Protection (BfS).

Is it just a strange coincidence that ICNIRP’s secretariat is located in the building of the BfS in Munich. The scientific coordination for/of/within? ICNIRP has, for the last few years, been the responsibility of a BfS official: Gunde Ziegelberger. “Her predecessor even chaired the club until 2016. At the same time, the German government supports the NGO of scientists with about 100,000 euro a year. The spokesperson rejects the impression that the private organization is almost part of the German authority as "not applicable". The office only supports the international network of research, she said. Moreover, the ICNIRP is officially recognised by the WHO, which gives it legitimacy.”

We have asked Mrs Ziegelberger via email if she would agree to answer our questions on ICNIRP in writing, but we have, to this date, received no response (the ten questions can be found in Annex I)

This self-declared sense of legitimacy was carefully created by the Australian scientist, Michael Repacholi, who co-founded ICNIRP and also, a few years later, in 1996, the EMF Project of the WHO (officially the WHO’s International EMF Project, IEMFP) of which he became the head. The WHO’s International EMF Project (IEMFP) basically based itself on ICNIRP’s guidelines and by doing so gave itself a “quality label”.

ICNIRP under Michael Repacholi’s chairmanship

Since 1978, the Australian biophysicist, Repacholi, has been a member of the International Non-Ionizing Radiation Committee (INIRC), a part of the International Radiation Protection Association (IRPA), and between 1988—1992 he was chairman of INIRC, which then became into ICNIRP. Between 1996 and 2006, Repacholi called the shots at the WHO by creating, and then leading, the WHO EMF Project, to study the health effects of electric- and magnetic-field radiation (EMF).

So, almost simultaneously with his leadership of ICNIRP, Repacholi was able to set up the EMF Project of the WHO (officially the WHO’s International EMF Project, IEMFP) in 1996, and became its head (see more below) until 2006. From the very beginning, the WHO EMF Project and ICNIRP have been intertwined, as Louis Slesin wrote in *Microwave News*. Given the central role of Repacholi, it might explain why, from very early on, ICNIRP was officially recognized by the WHO. From 1996 until today, Repacholi has been “Member Emeritus” of ICNIRP and today, still has access to the organisation he founded.

As early as 1992, ICNIRP adopted Repacholi’s 1984 IRPA proposal that the only health issue to address in standard setting was the short-term effects due to the absorption of RF/MW energy of sufficient power to be converted to heat, based on the IEEE’s (Institute for Electrical and Electronic Engineers) Radiofrequency standard philosophy. Since then it seems to be carved in stone that ICNIRP only recognises the ‘thermal effects’ of radiation as a serious concern. This is a crucial element to understand the position of ICNIRP, it was built on the logics and thinking of electrical and electronic engineers and completely lacking biomedical expertise.

In 1998, ICNIRP published its first “Guidelines on limits of exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)”, still largely produced under the chairmanship of Repacholi.

A fierce and long-standing critic of the first ICNIRP guidelines was Dr Neil Cherry, Associate Professor of Environmental Health. In November 1999, Dr Cherry was invited by the Ministry of Health/Ministry for the Environment of New Zealand to carry out a peer-review of the proposal to adopt the ICNIRP guidelines for cell sites in New Zealand.

Cherry: “The ICNIRP guidelines were covered by a published assessment in 1998. This review shows that the assessment had ignored all published studies showing chromosome damage. It was highly selective, biased and very dismissive of the genotoxic evidence and the epidemiological evidence of cancer effects and reproductive effects. The assessment gives the strong impression of being predetermined in the belief that the only effects were from high exposures that cause electric shocks and acute exposures that cause tissue heating. For, example, they cite two studies saying that they do not show any significant increased effects of Brain/CNS cancer from microwave exposures when the actual published papers, Grayson (1996) and Beall et al. (1996), both do show significant increases of Brain/CNS cancer.”

In September 2000, he presented evidence of Health Effects of Electromagnetic Radiation to the Australian Senate Inquiry into Electromagnetic Radiation. The Inquiry Chairperson, Senator Lyn Allison, described Cherry’s evidence as the only independent professional evidence with no relation to industry. The conclusions from this evidence are strongly contrasted with the position of Dr Michael Repacholi, the WHO, ICNIRP, the Australian Radiation Laboratory and many other organisations around the world.

Twenty years ago, Cherry said: “This issue has been so politicized. There are two major casualties, the truth and public health. On these matters, I have no respect for the position of ICNIRP, nor that of the WHO. The WHO position is taken solely by Dr Repacholi. ICNIRP is a small self-appointed, self-promoted group that claims standing by having WHO recognition. In other words, a body formed in part and led by Dr Repacholi, claims its standing by being recognized by Dr Repacholi.”

Cherry used harsh words for INCIRP under Repacholi's chairmanship. “They consistently misquote and misrepresent the published research results. They reject all epidemiological evidence because every single epidemiological study occurs with mean exposure levels and orders of magnitude below their thermally-based standard. They are highly selective, using only a small proportion of the available studies in order to construct and defend their own case. They prefer author's conclusions that there are no effects, even when the data and analysis in the paper clash with this and contradict it. They dismiss large, reliable and well-defined studies as ill-defined and unreliable. They state that studies don't show significant increases in CNS cancers when they actually do, even when the papers include significant dose-response relationships. Both the WHO and ICNIRP, under Dr Repacholi's leadership, have maintained the thermal view to the present, despite the large and ever-growing body of scientific research that firmly and conclusively challenges this.”

He also accused Repacholi of maintaining close links with industry. "He not only appeared in New Zealand in two court cases for industrial clients, in Vienna he was taken to an industry sponsored press conference where he stated that there was no evidence that GSM cell phones were hazardous to health. At the conference, he presented his paper on the Telstra (**Telstra** is Australia's largest mobile network operator and telecom company) funded project that showed that GSM cell phone radiation at quite low non-thermal levels, doubled the cancer in mice. When challenged by the conference chairman, Dr Michael Kundi, Dr Repacholi said that a study is not evidence until it is replicated. The conference rejected this. A study is evidence. Replication provides confirmation and establishment."

The fact is that Repacholi has followed a remarkable career path, from member of IRPA and working in an Australian hospital, to holding a dominant position in the international debate on EMF risks. He also developed as a scientist, from publishing a study in 1997 on lymphoma incidence in mice exposed to RF radiation, to becoming a consultant for telecom and power companies ten years later.

In 2017, he published 'A History of the International Commission on Non-Ionizing Radiation Protection (ICNIRP)' in the scientific review *Health Physics*, in which he stated: "ICNIRP's guidelines have been incorporated into legislation or adopted as standards in many countries. While ICNIRP has been subjected to criticism and close scrutiny by the public, media, and activists, it has continued to issue well-received, independent, science-based protection advice. This paper summarizes events leading to the formation of ICNIRP, its key activities up to 2017, ICNIRP's 25th anniversary year, and its future challenges."

It is quite revealing that Repacholi writes, "ICNIRP has been subjected to criticism and close scrutiny by the public, media, and activists", and yet, forgets to mention, *and also by scientists*. Because, since the first publication of guidelines by ICNIRP in 1998, there has been a never-ending stream of critical academics publishing harsh analysis on the scientific work of ICNIRP. The issue is that Repacholi has not only been a dominant figure, but also a very divisive figure, in the international EMF-debate and he has been able to make sure that independent scientists who do not agree with the ICNIRP-dogma of 'thermal effects only" have not become part of ICNIRP nor of the WHO EMF Project.

The fact that, in his article for the 25th anniversary of ICNIRP, Repacholi makes no mention of the criticism and close scrutiny by scientists is quite telling. Because basically, the story of ICNIRP and the ongoing controversy and ever deeper divisions within the scientific community in the EMF-debate, started around the persona of Michael Repacholi himself.

'Good science' and the EMF Project (IEMFP)

As we have stated above, Repacholi was not only ICNIRP chairman, but also the leader of the WHO EMF Project. In his own words: "The WHO established the International EMF Project to provide a mechanism for resolving the many and complex issues related to possible health effects of EMF exposure. The Project assesses health and environmental effects of exposure to static and time varying electric and magnetic fields in the frequency range 0 - 300 GHz, with a view to the development of international guidelines on exposure limits."

In 1999, Repacholi published the Proceedings of an International Seminar on EMF Risk Perception and Communication that took place in Canada. The event was not only sponsored by the WHO, some government ministries and the Faculty of Medicine at the University of Ottawa, but also by the Cellular Telephone Industry Association, the Canadian Wireless Telecommunications Association and some electricity companies. The almost 300-page document published by Repacholi's "International EMF Project" (part of the WHO's Department of Protection of the Human Environment) kicks off with this statement: "Possible health effects of exposure to electromagnetic fields (EMF) have led to concerns among the general public and workers that appear to go well beyond those that are attributed to well-established risks. It is necessary to understand why this occurs and to deal with it through an effective communications programme. People have the right to access reliable, credible and accurate information about any health risks from EMF exposure."

In his review, "A hard nut to crack", professor Hardell writes: "Michael Repacholi immediately set up a close collaboration between WHO and ICNIRP (being head of both organizations) inviting the electric, telecom and military industries to meetings. He also arranged for large part of the WHO EMF project to be financed by the telecommunication industry's lobbying organisations; GSM Association and Mobile Manufacturers Forum, now called Mobile & Wireless Forum (MWF)." Hardell states that Repacholi acted like "a representative for the telecom industry while responsible for the EMF health effects department at the WHO"

An investigative article in US magazine, *The Nation*, stated: "Although Repacholi claimed on disclosure forms that he was "independent" of corporate influence, in fact Motorola had funded his research: While Repacholi was director of the WHO's EMF program, Motorola paid $50,000 a year to his former employer, the Royal Adelaide Hospital, which then transferred the money to the WHO program. When journalists exposed the payments, Repacholi denied that there was anything untoward about them because Motorola had not paid him personally."

According to *The Nation*, "eventually, Motorola's payments were bundled with other industry contributions and funnelled through the Mobile and Wireless Forum, a trade association that gave the WHO's program $150,000 annually. In 1999, Repacholi helped engineer a WHO statement that "EMF exposures below the limits recommended in international guidelines do not appear to have any known consequence on health."

In a *Microwave News* article, Repacholi claims that he always followed the WHO rules on funding and that, "NO funds were EVER sent to me." But the article's author, Louis Slesin goes on to say that "this is financial *legerdemain*. As *Microwave News* has previously reported, Repacholi arranged for the industry money to be sent to the Royal Adelaide Hospital in Australia, where he used to work. The funds were then transferred to the WHO. Seven years ago, Norm Sandler, a Motorola spokesman, told us that, "This is the process for all the supporters of the WHO program." At the time, Motorola was sending Repacholi $50,000 each year. That money is now bundled with other industry contributions and sent to Australia by the Mobile Manufacturers Forum (MMF), which gives the project $150,000 a year."

A scientist who is very critical about the activities of Repacholi is American Professor Andrew A. Marino (who used to work at the departments of Orthopedic Surgery, Neurology, and

Cellular Biology & Anatomy at the LSU Medical School in Louisiana) wrote: "In 1996 the World Health Organization began what it said was a program to assess the scientific evidence of possible health effects of EMFs. But the project was corrupted from the start because it was controlled by the power- and cell-phone companies in the industrialized countries. The companies designated Michael Repacholi as the project head. He had long been a consultant and spokesman for power companies, so it was unrealistic to expect him to conduct an open and honest inquiry, but his performance in office was even more miserable than could have been anticipated based on his known conflict-of-interest."

Marino: "While heading the EMF program at WHO, Repacholi dealt almost exclusively with experts on the payroll of cell-phone and power companies. Scientists who disagreed with the viewpoint of the EMF companies were excluded from the EMF evaluation process. The public was also excluded from participation even though it was a major stakeholder in the EMF debate. Only pro-industry spokesmen were heard in Repacholi's star-chamber processes, which ultimately resulted in reports and evaluations that exonerated the companies from any responsibility for human disease produced by their EMFs."

Marino saw Repacholi at the Annual Meeting of the Bioelectromagnetics Society (BEMS) in Cancun, Mexico, in June, 2006: "The Mobile Manufacturers Forum, a consortium of the world's major cell-phone companies, were "Gold Sponsors" of the BEMS meeting, and the leaders of BEMS, had invited Repacholi to give a talk entitled "Results from 10 Years of WHO's International EMF Project," which he delivered at a plenary session of the meeting. Unsurprisingly, his talk was a paean to his EMF activities at WHO. He was proud of having successfully stemmed the tide of concern regarding the link between environmental EMFs and other human diseases, and of having defended the principle that man-made environmental EMFs were harmless. He touted model legislation that he had drafted, and said that he hoped it would be enacted by various governments so that the fact that environmental fields were safe would be enshrined in law."

In 2006 Repacholi stepped down as director of WHO's EMF Project.

Not much later *Microwave News* announced: "It's Official: Mike Repacholi Is an Industry Consultant And He's Already in Hot Water": "Just months after leaving his post as the head of the EMF project at the World Health Organization (WHO), Mike Repacholi is now in business as an industry consultant. The Connecticut Light and Power Co. (CL&P), a subsidiary of Northeast Utilities, and the United Illuminating Co. (UI) have hired Repacholi to help steer the Connecticut Siting Council away from a strict EMF exposure standard."

To strengthen his testimony on behalf of the two electric utilities, Repacholi cited the findings of an unfinished WHO report —Environmental Health Criteria (EHC)— on EMF risks. Twenty invited experts drafted this report at a meeting in Geneva in October 2019. The final version was expected to be made public months ago but it's still being edited by the WHO staff.

According to Chris Portier, who chaired the expert EHC panel for the WHO, Repacholi has misrepresented the group's conclusions: "The paraphrasing sometimes has gone a bit far and may be misleading". Portier is the associate director for risk assessment at the National Institute of Environmental Health Sciences (NIEHS)." (see below).

Portier cites a couple of examples. For example, in a summary of the WHO report, Repacholi states that the EHC panel concluded that "The epidemiological evidence cannot be used as a basis for standards (exposure limits)”. Portier retorts, “Such a statement is absurd, since they obviously can be used."

Repacholi has since also been involved in an industry propaganda video and interviews with GSM Association and Hydro Quebec where he clearly speaks in favour of the telecommunications and the power industries, respectively.

A year later, in 2007, *Microwave News* reported that “Mike Repacholi has now revealed that up to half of the funds raised for his EMF Project came from industry. This admission was made in an interview with *Resource Strategies Inc*. in an effort, he states, to “set the record straight.” While Repacholi has acknowledged in the past that he raised funds from industry, the extent of the industry support is much greater than anyone has previously suspected. Repacholi has never disclosed how much money he received nor from whom. He insists that the EMF Project was not “influenced by industry.”

According to an e-mail seen by *Microwave News*, Repacholi touts the interview as an example of “where the press finally got it right”: “*Resource Strategies*, however, can hardly be considered "the press" in the usual meaning of the term. *Resource Strategies* is a corporate consulting firm that prepares briefing papers for clients, which are almost exclusively in the wireless and electric utility businesses. Among them are *EPRI, FGF, GSM Association* and *MMF*. All of these industry groups supported the EMF Project during Repacholi’s tenure. And to bring it all full circle, the WHO is also on *Resource Strategies*’ client list.”

Some current ICNIRP members, such as the new chair, Rodney Croft, also declare doing work for EPRI.

Researcher Don Maisch wrote that Repacholi harmed the credibility of the WHO: “It is acknowledged that in an ever increasingly globalized world the reliance on international organisations to set standards to protect public health is an irrefutable fact of modern life. It is also a fact that international organizations charged with this task need to be “eternally vigilant” to ensure that their organisations are not co-opted by vested interest groups – as exampled by Big Tobacco and WHO. However, when it comes to non-ionizing radiation issues (in this case for power frequency health risk assessment) the evidence is clear that Michael Repacholi has used his standing in both WHO and ICNIRP to stack the WHO’s Environmental Health Criteria Task Group for power frequency exposures with representatives of the power industry in contravention of WHO policy.”

Maybe one of the most telling episodes in the professional life of Repacholi is his open fight with his former boss, Gro Harlem Brundtland, who was director-general of the WHO. In interviews and a speech, Brundtland admitted that she is ‘electrically sensitive’: “I never place a mobile phone next to my head because in one second I would develop a bad headache.” Repacholi was not amused. In 2012, several Norwegian newspapers reported that the “Former head of WHO’s EMF project and ICNIRP chairman says that Brundtland has created “fear of mobiles” in the population”. He offered to examine her, as if she had a psychological problem.

Very seldom were critical voices heard within the WHO. From the minutes of the Sixth International Advisory Committee meeting in May 2001, we read that Russian professor Yuori Grigoriev (the one from the ‘angry letter’ mentioned below) tabled a document outlining EMF activities in Russia, and the difficulties with standards harmonization “particularly because of the inadequate consideration of non-thermal effects by ICNIRP and other national authorities”.

Dr Paolo Vecchia, of the National Institute of Health in Italy, and later ICNIRP chair, reacted to this by saying that “it is important to be able to recognize what good science is. WHO should be a reference point or clearinghouse for good science and good scientific review. It is important to recognize that science and legal measures follow the technology – it is not possible to do a mobile phone epidemiological study before the introduction of the technology! Given the pace of new technological development it is not possible, even now, to envisage the complete set of new research that will be needed.”

Vecchia also claimed to be personally very concerned about ‘defensive science’, speaking of over-cautiousness and an over-emphasis on uncertainties. “Scientists should be more confident ‘about the state of art’”. He is now doing consultancy work and speaks at Telecom-conferences.

IEEE/ ICES

In 2008, Vecchia wrote: “Guidelines for safe exposure to electromagnetic fields have also been developed by other international organizations, in particular the Institute of Electrical and Electronics Engineers (IEEE). Apart from some differences in terminology and numerical values of the limits, these guidelines are based on the same methodological approach, the same structure, and the same scientific database as ICNIRP.”

In his thesis on “an examination of the manipulation of telecommunications standards by political, military, and industrial vested interests at the expense of public health protection” ORSAA-member and scientist, Don Maisch, compares the ICNIRP and IEMFP with the American based IEEE. It is interesting because while ICNIRP claims to be free from the influence of private interests, IEEE/ICES has always openly had members of the military and of the telecom industry among its ranks.

Maisch writes: “On the part of both IEMFP and ICNIRP, a disregard for their own stated principles on independence from industry and following questionable criteria for evaluating science, suggests an agenda to cut off the scientific controversy over EMF human health hazards by less than scientific means. It could be argued that IEEE’s openly industry and military dominated standard-setting process is at least more honest than WHO / ICNIRP masquerading as independent scientific voices free of vested interest machinations.”

Dariusz Leszczynski, Adjunct Professor at the University of Helsinki, writes about conflicts of interest concerning ICES: “ICES, equivalent of ICNIRP, prepares safety recommendations for the exposures of users by radiation emitted by cell phones. Unlike ICNIRP, anyone can apply for membership of ICES and all members of ICES participate in the decision-making process. Sounds nice… Not a “private club” as ICNIRP where participation is by invitation only and the invitees have to have the same opinion on radiation safety – this helps in reaching unanimous decisions… But ICES has another problem that caused me, member of ICES for a couple of years, to resign my membership in 2009. The problem is that the ICES membership is clearly dominated by scientists working or consulting for telecoms."

And in another blogpost Leszczynski wrote: "The membership of the IEEE-ICES-TC95 consists predominantly of the industrial scientists and the committee is chaired by C.K. Chou since the time he was employed by Motorola. This means that all safety standards being developed by IEEE-ICES-TC95 are, in practice, developed by the industry scientists for the use by the industry they are employed by. The industry scientists have the majority on the committee and upper-hand in any process involving democratic voting. To me this is clear Conflict of Interests".

In the portraits of ICNIRP chair, Croft, and co-chair, Van Rongen, we describe (from page 50) how they worked on establishing closer relations between ICNIRP and ICES.

From the minutes of a meeting by the IEEE/ICES TC95 working groups at a Motorola headquarters, a few interesting things got clear: In 2017 Repacholi was still a member of the "ICES literature systematic review working group". And ICES-chair Faraone Antonio from 'Motorola Solutions' proudly announced that "ICNIRP has delayed finalizing their conclusions to give full consideration of ICES's recommendations".

Former Motorola employee Chou stated at the same meeting on the interaction with World Health Organization (WHO EMF Project) that "in response to C-K Chou, the WHO has agreed to encourage international harmonization of RF Safety Limits, especially between ICNIRP and ICES"

And concerning the WHO EMF Project, Hardell describes how Repacholi recruited Emilie Van Deventer to the WHO EMF Project in 2000, and to this day, she remains project manager at WHO for the EMF project: "She has been a long time member of the industry dominated organization Institute of Electrical and Electronics Engineers (IEEE). IEEE has prioritized international lobbying efforts for decades especially aimed at the WHO." Hardell states that Van Deventer is an electrical engineer and has no formal or earlier knowledge in medicine, epidemiology or biology, so it is surprising that she was selected for such an important position at the WHO. Hardell: "The very same year she was recruited to the WHO EMF Project, Toronto University Magazine wrote about Emilie van Deventer's work, stating that it was 'invaluable' to industry: 'The software modelling done by teams like van Deventer's is invaluable.' 'The industrial community is very interested in our research capabilities,' says Van Deventer. 'It always needs to be working on the next generation of products, so it turns to universities to get the research done'."

The importance of this work is reflected in the research funding van Deventer and her team received from the Natural Sciences & Engineering Research Council of Canada (NSERC), Communications & Information Technology Ontario (CITO), and their major industrial partner, Nortel. "We are fulfilling a very real need in the industry today, which will only increase as technology creates more opportunity. In the process, consumers will continue to enjoy faster computers, lighter cell phones, smaller electronic organizers and the vast array of other electronic gadgets the high-tech world has to offer."

In 2016, during a seminar at the SSI, concerning health effects of EMF, former Swedish investigative journalist, Mona Nilsson, asked both Emilie van Deventer, Head of the WHO

EMF Project, and Eric van Rongen, the then chair of the ICNIRP, "whom the citizens should believe: them or the opinion of 220 scientists who signed an Appeal submitted to the United Nations and the WHO?". Both Van Rongen and Van Deventer answered the question without defending their position. Apparently, neither Van Rongen or van Deventer are willing to fully defend the reliability of the evaluation of science by ICNIRP, because as Leszczynski points out, neither of them said that ICNIRP evaluation of science is reliable and that the Appeal's conclusions are unreliable. "This clearly demonstrates that there is no scientific consensus on the health effects of radiation emitted by wireless communication devices. This situation should be taken into consideration when the WHO selects expert group for preparation of the final version of the Environmental Health Criteria for RF-EMF. Scientists with diverse scientific opinions should and must be appointed in order to facilitate an unbiased scientific debate."

We have sent questions to Van Deventer, but have, to date, received no answer.

Angry Russian letter

Although ICNIRP was recognised as "an official collaborating non-state actor by the World Health Organization (WHO) and the International Labour Organization (ILO)", from the early days, ICNIRP has also been criticized for industry-bias and indisputable situations of conflict of interest.

Hardell notes that the Ethical Board at the Karolinska Institute in Stockholm, Sweden, concluded, already in 2008, that "being a member of ICNIRP may be a conflict of interest that should be stated officially whenever a member from ICNIRP makes opinions on health risks from EMF."

Nevertheless, for the WHO, this does not appear to pose a problem. After the IARC publication in 2011, the WHO announced a new 'formal risk assessment' in 2012, which was launched in 2014 and was then open for public consultation until the end of 2014.

The WHO stated "the drawing of conclusions from the literature and the drafting of these chapters is the remit of a formal Task Group that will be convened by WHO at a later stage in the process."

Hardell disclosed that "it turned out that of the six members in the WHO Core Group, four are active members of ICNIRP and one is a former member." Indeed, in a research paper from 2016, Sarah J Starkey concludes that "the anticipated WHO Environmental Health Criteria Monograph on Radiofrequency Fields, due in 2017, is being prepared by a core group and additional experts, with 50% of those named, being, or having been, members of AGNIR or ICNIRP (Table 2)."

In another research paper, from 2017, Hardell notes: "It is striking how ICNIRP has infiltrated the WHO Monograph core group, making it less likely that the conclusions in that Monograph will differ from ICNIRP's conclusions." And according to him, only one person seems to be independent of ICNIRP and "several persons also have affiliation(s) to other advisory groups, authorities and/or committees. Six of the 20 additional experts are affiliated with ICNIRP".

In March 2017, professor Oleg A. Grigoriev, Chairman and Head of the Scientific Department of Non-Ionizing Radiation, Federal Medical Biophysical Centre of Federal Medical Biological Agency (RNCNIRP) of Russia wrote an angry letter to Maria Neira, Director of Public Health and Environment at the WHO, in which he openly attacks ICNIRP: "It has just come to our attention that the WHO RF Working group consists mainly from present and past ICNIRP members. In general, the WG is not balanced and does not represent the point of view of the majority of the scientific community studying effects of RF. In particular, the private self-elected organization, ICNIRP, similar as majority of the current WHO RF WG members, does not recognize the non-thermal RF effects, which represent the main concern of widespread exposure to mobile communication and upholding guidelines from 1996, which are based on RF thermal effects only."

The Russian scientist concludes that "the guidelines of ICNIRP are irrelevant to the present situation when majority of population over the world is chronically exposed to non-thermal RF from mobile communication. Based on multiple Russian studies and emerging number of studies coming from other countries, the Russian equivalent of ICNIRP has consistently warned against possible health effects from mobile communication. This point of view of RNCNIRP (Russian radiation protection agency) is supported by hundreds of new publications including well known recent RF studies in human and animals."

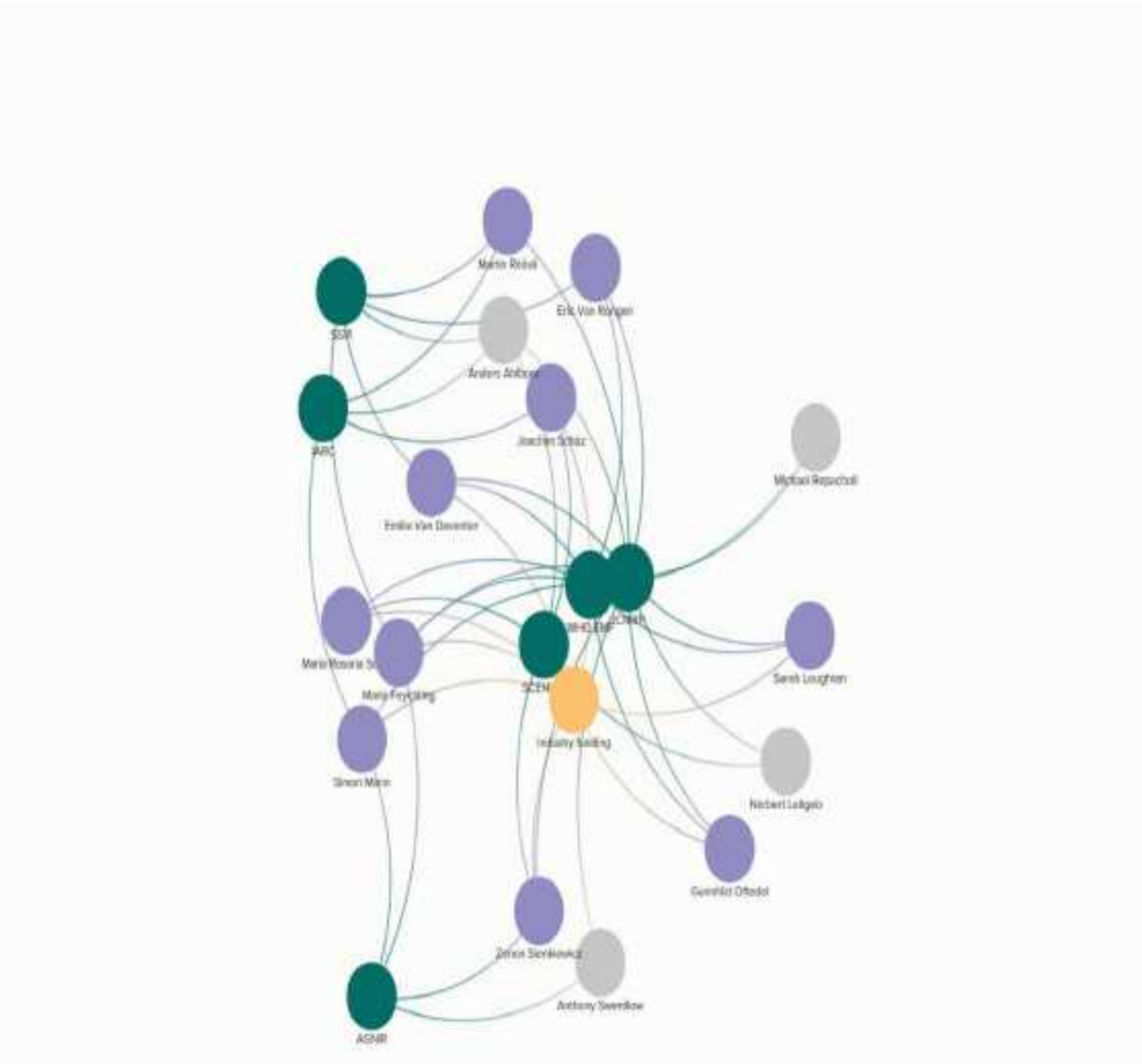
Apparently, this angry Russian letter, in addition to other outcries, did have some effect on the WHO, because it relaunched a Call for Expressions of Interest for systematic reviews (2020) for an 'Environmental Health Criteria Monograph': "The World Health Organization's (WHO) Radiation Programme has an ongoing project to assess potential health effects of exposure to radiofrequency electromagnetic fields in the general and working population. To prioritize potential adverse health outcomes, WHO conducted a broad international survey in 2018. Ten major topics were identified for which WHO will now commission systematic reviews to analyse and synthesize the available evidence."

We wonder if this time the WHO will try to avoid conflicts of interests and whether, for example, there will also be Russian experts and other non-ICNIRP affiliated scientists on the panels of experts.

Investigate Europe wrote that the conflicts in EMF research run deep: "Historically, science in this field has been associated with the telecom sector and the military. ICNIRP's safety limits primarily take into account the needs of the telecom industry, claims Dariusz Leszczynski, former long-time researcher at the Finnish radiation protection agency. In 2011, he sat on the committee of IARC, the cancer body of the World Health Organisation, when it decided that EMF is "possibly carcinogenic" to humans. ICNIRP's goal is to set safety limits that do not kill people, while technology works – so something in between", says Leszczynski."

Dariusz Leszczynski, has written about this many times on his blog and has often referred to an unbalanced expert composition: "ICNIRP can, and should, be considered as a "private club" where, members of the new Main Commission are selected by the members of the outgoing Main Commission. It is a self-perpetuating and self-promoting German NGO that is not accountable for its actions at all. Nobody controls it. Nobody supervises it. Nobody checks it for conflicts of interests. Nobody checks it for the scientific accuracy. In all what and how ICNIRP does, we, the general public, must rely on the self-assurances, from the

ICNIRP, that all is in order. One may ask whether such self-assurances are sufficient when ICNIRP is preparing advisories "enforced" world-wide by the WHO and applied by the numerous governments and by the multi-billion industry."



The following Graphic – made by *Investigate Europe* shows the interlinkages between renowned ICNIRP-members and other scientific bodies. These groups, are to a large extent staffed by the same experts. "Of 13 ICNIRP scientists, six are members of at least one other committee. In the WHO group, this applies for six out of seven," *Investigate Europe* writes.

III - Discussion & Controversies

An observation one could make based on what has been discussed above, is that ICNIRP is simultaneously one of the most powerful and one of the least-known non-governmental organisations (NGO's) in the world. Powerful, because for almost three decades, ICNIRP has enjoyed a monopoly in the regulation of exposure to EMFs through their guidelines thanks to the stamp of approval of the WHO. For the past 30 years, and currently, this advice and these guidelines, are to a large extent followed by governments all over the world. In every annual report, by any major telecom company, you will find references to ICNIRP in any discussion or statement on the safety of their mobile phones. ICNIRP garners huge influence worldwide, functioning on a modest yearly budget of around 140.000 euro, and yet ICNIRP is largely unknown by the general public.

ICNIRP presents itself, and is described by the European Commission and in the media, as an independent commission that gives advice based on scientific evidence. Our research shows that there are several reasons to question this (self)-image.

Biased composition

The composition of ICNIRP is very one sided. As one can read in the portraits of the members of the ICNIRP commission and of the Scientific Expert Group (SEG), they all share the same position on the safety issues: non-ionising radiation only poses a health threat at thermal levels.

Prominent ICNIRP-members therefore denounce the findings of the U.S. National Toxicology Program (NTP) that showed rats and mice contracted cancer when exposed to telephone radiation. In a scientific publication, Van Rongen and co-authors state, as we laid out in the portrait of the former chair of the ICNIRP-commission, that "substantial limitations (of the NTP-study) preclude conclusions being drawn concerning RF EMFs and carcinogenesis."

Professor Hans Kromhout of Utrecht University, who is leading a long-term study into the effects of mobile phone use on human health, and who is chairman of a special committee on Electromagnetic Fields of the leading Dutch Health Council, regrets the way INCIRP minimalizes the conclusions of the NTP study. "You can see that certain groups are trying to reason that away. But they are well-executed studies", he said in a Dutch newspaper.

According to Kromhout, a deep controversy divides the scientific community that researches EMF: "Two camps have arisen in science, with the two groups shouting at each other from their trenches. It has become impossible to conduct a normal conversation." This observation is also made by ORSAA-scientists.

And one of these two camps, is not represented at all inside ICNIRP. "It would seem that the Commission is composed only of 'non-believers," Kromhout wrote in an email to us. In the Dutch newspaper, he had earlier stated: "It's a bit of an opaque club. How candidates are elected is not clear. Call it self-indulgent. In that sense, it doesn't really have an independent status."

In more recent exchanges with us, he re-iterates that the use of the word “self-indulgent” is justified. He refers to the sentence in the ICNIRP Charter: “The election of the members of the Commission shall be made by the Commission from current members of the Commission and from nominations submitted by the Commission itself, the Executive Council of IRPA and the IRPA Associate Societies, with regard to an appropriate balance of expertise. Attention shall be paid to geographical representation.” The first part – that it is the members of the Commission who elect its new members – puts the Commission at risk of remaining a closed circle made up only like-minded scientists.[3]

The unbalanced composition of ICNIRP is further demonstrated by the lack of expert-members with training and experience in medical and/or biological sciences. As one researcher pointed out, of the outgoing ICNIRP commission only one member was trained in medicine, and only three in biological sciences. Furthermore, the sole medical professional, Adele Green, was not an expert researcher in RF-EMR (with a single original research article back in 2005), but was specialised in UV-radiation and skin cancer. She also left ICNIRP in May 2020. It seems a good thing she has been replaced by Dutch scientist, Anke Huss, assistant professor at the Institute for Risk Assessment Sciences (IRAS) at Utrecht University (NL), who seems to be rather critical. Tania Cestari has replaced Adele Green ICNIRP in May 2020, although, like Green that she has collaborated with, her expertise seems to be on UV radiation in dermatology. Interestingly, a search on the PubMed database showed that she has no publications for radiofrequency or other EMFs so she is not an expert on wireless radiation.

The system of cooptation of ICNIRP and the resulting excessively homogeneous composition clearly favors such biases. In 2013, in his article "Not Entirely Reliable : Private Scientific Organizations and Risk Regulation - The case of Electromagnetic Fields", Gabriel Domenech Pascual, Professor Administrative Law at the University of Valencia, states in his conclusions : "That lack of plurality tends to reduce both the quantity and the quality of the available information that serves the basis of their judgments, to stifle critical dialogue, to exacerbate the common biases and positions of their members and to produce extreme outcomes, polarized in the direction of those biases and points of view."

We can safely say that ICNIRP has been, and is still lacking people with a relevant medical background and over represented by physical scientists, which may not be the wisest composition when your remit is to offer advice on human health and safety to governments around the world.

Dr. Chris Portier, former director of the National Center for Environmental Health and international expert in the design, analysis, and interpretation of environmental health data with a focus on carcinogenicity, writes to us that the ICNIRP Council and SEG “appear to have a very wide balance of experience”. However, what they are lacking, according to Portier, “is representation by scientists who have a history of working in risk assessment for chemicals. This leads to their having different risk assessment approaches than the rest of the area.”

[3] For a better understanding of IRPA and functioning of ICNIRP, we refer you to the historical section of this report

Portier argues that risk assessment for chemicals is “well-established and has been used for many, many years”. This standard of assessing risks of chemical substances, governs how to judge the quality of various types of scientific studies and how to incorporate them into the final risk assessment decisions.

Portier: “I have long felt that experts from EMF-research have been incorrectly arguing that this exposure is different and must be handled separately. But ionizing radiation is handled the same was as chemicals in risk assessment, why not EMF?” Portier states that ICNIRP could “expand their expertise in epidemiology and toxicology and experts who understand the challenges of biomedical study design and interpretation in a general sense.

And Portier states that “it would also be good to have a few scientists who are more outspoken about potential risks.” Portier writes that these improvements “would” challenge ICNIRP to “be exact about their dismissal of some of the positive findings” in research on health effect of EMF, that do exist.

The composition of ICNIRP is also one sided in another sense: there is a lack of representatives from the Middle East, Russia, China and India who have outstanding research contributions in the RF research and also (in many cases) have more stringent standards.

For Gabriel Domenech Pascual "this lack of plurality is not fortuitous at all, but caused by the system used to elect the members of the ICNIRP. As everybody knows, cooptation tends to produce homogeneous, conservative, immobile and not sufficiently innovative groups."

"This stands in sharp contrast with the principles underlying current European Union Law", Domenech Pascual adds. "As stated in the Communication from the Commission on the collection and use of expertise, pluralism is a determinant of the quality of the scientific advice. Therefore, “wherever possible, a diversity of viewpoints should be assembled. This diversity may result from differences in scientific approach, different types of expertise, different institutional affiliations, or contrasting opinions over the fundamental assumptions underlying the issue. Depending on the issue and the stage in the policy cycle, pluralism also entails taking account of multi-disciplinary and multi-sectorial expertise, minority and non-conformist views".

Various EMF-experts have pointed out on many occasions in the past years that ICNIRP is wrongfully dismissing certain scientific studies showing adverse health effects and sticking, in an almost dogmatic way, to the conviction that “non-ionising radiation poses no health threats and the only effects it has are “thermal”. Two leading experts, Kromhout and Portier confirm to us that ICNIRP is a closed, non-accountable and one-sided organisation. As concluded earlier, “a closed circle of like-minded scientists” has turned ICNIRP into a self-indulgent science club, with a lack of biomedical expertise as well as a lack of scientific expertise in risk assessment and risk management philosophies (similar to those used for ionizing radiation and for chemicals), which might lead to “tunnel-vision”.

Will world safety standards really be safe?

Several ICNIRP-members are, or were, also members of the International Committee on Electromagnetic Safety (ICES) of the IEEE. This is an organisation in which many people from the media and telecom industry and from the military are actively and openly involved. The former chair of the ICNIRP-commission was a member of an ICES-committee. As we mentioned in his portrait, ICES thanked Van Rongen for improving the relationship between ICES and ICNIRP and for his willingness to discuss the harmonisation of ICNIRP-guidelines and IEEE-exposure limits. In its latest published annual report (2016), ICES states: "ICES will maintain its collaborative relationship with ICNIRP with the goal of setting internationally harmonized safety limits for exposure to electromagnetic fields at frequencies below 300 GHz. This interaction with ICNIRP is considered a major step forward."

In 2016 Van Rongen invited members of ICES to give their comment on the new guidelines for HF Fields. And ICNIRP took these comments very seriously. In 2017 during the annual meeting of ICES it was stated that "ICNIRP has delayed finalizing their conclusions to give full consideration of ICES's recommendations".

The new chair of the ICNIRP-commission Croft was also member of ICES until December 2015. Seven other ICNIRP-scientists - Guglielmo d'Inzeo, Akimasa Hirata, Jose Gomez-Tames, Ilkka Laakso, Kensuke Sasaki, John Tattersall and Tongning Wu – were or are also members of an ICES-committee.

This clearly shows that ICNIRP has been working very closely with IEEE/ICES on the creation of the new RF safety guidelines that were published this year. And this implies that large telecom-companies as Motorola and others, as well as US military, had a direct influence on the ICNIRP guidelines, which are still the basis for EU-policies in this domain.

Kromhout comments that he was unaware of the fact that several ICNIRP-members also participate in ICES/IEEE. ICES/IEEE is not one of the organisations that is mentioned as a collaboration partner on the ICNIRP-website. On the subject of the IEEE, the Dutch professor writes that "this is not really an independent organisation when it comes to electromagnetic fields and health."

Portier sees the membership of ICES as a potential conflict of interest. He indicates as an example that the declarations of interests of some ICNIRP-members mention membership in ICES, but no mention of the travel costs associated with that membership being covered by ICES: "This has two consequences. Travel cost reimbursement is a perk and it could be removed if the member fails to give the right answer, hence a potential Conflict of Interests. Secondly, being a member in ICES gives industry access to the ICNIRP member which would not be available to the general public and can thus bias opinions."

A membership of and close cooperation of ICNIRP-members with ICES, which for several years held its annual meetings at a Motorola's branch, can be considered as a possible conflict of interest. As described, during the current leadership of ICNIRP, these ties got even closer "with the goal of setting internationally harmonized safety limits for exposure to electromagnetic fields".

Ties that bind

A lot of ICNIRP-scientists have also participated in research work that was funded, or partly funded, by the telecom industry.

The International Agency for Research on Cancer (IARC) has a strict policy when it comes to inviting scientists to assist it in the writing of the famous monographs – like the one from 2011, that classified radiofrequency electromagnetic fields as, "possibly carcinogenic to humans (Group2B), based on an increased risk for glioma, a malignant type of brain cancer associated with wireless phone use." In the final Monograph 2012 report, it is stated that each scientist must disclose pertinent research, employment, and financial interests during the past 3 years, unless that a grant from for example a company does not exceed more than 5% of total research budget: "All grants that support the expert's research or position and all consulting or speaking on behalf of an interested party on matters before a court or government agency are listed as significant pertinent interests."

In our introduction, we wrote that the European Food and Safety Authority (EFSA) has slightly less stringent member-selection criteria: "Research funding from the private sector benefiting EFSA's experts should not exceed 25% of their total research budget."

It seems that this percentage is not exceeded by most of the members of the ICNIRP-commission and Scientific Expert Group, insofar as we can trust their Declarations of Personal Interest. But these declarations are often not complete. Anssi Auvinen, for example, mentions that he received € 100,000 from the Mobile Manufacturers Forum for the Finnish section of the COSMOS-study. But he does not mention what percentage of his total research budget that amount constitutes. And Maria Feychting, former vice-chair of the ICNIRP-commission, did not mention any research support received from commercial entities in her Declaration of Personal interest, although a lot of her research actually was, as we showed in her portrait, funded by industry. Some of the member's DOI's are also somewhat out of date. For example, the last DOI available for Isabelle Lagroye, published on the ICNIRP-website, is dated October 2015.

The majority of ICNIRP-scientists did perform research partly funded by industry. But is this important information? As we argue in the introduction, we believe it is. Scientific publications, co-authored by two ICNIRP-scientists – Anke Huss and Martin Röösli, confirm the importance of funding. In 2006 and 2009 they did a systematic review of the effect of the source of funding in experimental studies of mobile phone use on health, and their conclusion was that, "industry-sponsored studies were least likely to report results suggesting (adverse health) effects".

And theirs is not the only study that showed this kind of bias. Portier agrees in writing to us that this is a problem: "There have been numerous studies of the differences in reporting from industry-funded research versus publicly-funded research that suggest a strong bias."

David O. Carpenter, professor of Environmental Health Sciences at the University at Albany, explains the mechanism behind this claim in the preface of the book Corporate Ties That Bind - An Examination of Corporate Manipulation and Vested Interest in Public Health: "One of the greatest problems in scientific discovery," he writes, "is the perversion that can result due to conflicts of interest. While there are other possible bases for conflicts of interest, most are financial. Individual scientists may have financial conflicts of interest that influence the design of the studies they perform so that they obtain a result similar to that which they, or their funders, want. When funding for scientists comes from an organization or corporation with desires to present a clean bill of health to the public, there is strong motivation to give the funder what they want, if only to continue receipt of funding."

The Australian researcher, Don Maisch, claimed in his PhD-thesis, *The Procrustean Approach: Setting Exposure Standards for Telecommunications Frequency Electromagnetic Radiation* (2010), that the dismissal by ICNIRP of all studies that show health effects of non-ionizing radiation shows the influence industry exercises on ICNIRP: "Such dismissal may, on the surface, appear to be objective expert opinion, but an examination of ICNIRP's risk assessment processes finds, however, that power industry influence is endemic to the process. This influence appears to be aimed at ensuring economic protection for the industry against the need to spend enormous amounts of money on upgrading distribution networks as well as the risks of litigation if more restrictive limits were ever put in force.**"**

According to Maisch, the essence is that the thermal limitations of the IEEE standards and the ICNIRP RF Guidelines "can be said to be little more than an outdated artefact from a half-century ago, maintained by a scientific elite who have long staked their scientific credibility on maintaining that viewpoint. From their perspective, to retreat from that paradigm would be to admit that they had it wrong after all."

Ten years after Maisch' publication and many other similar criticisms, ICNIRP still adheres to the paradigm that the only proven effects are thermal. "ICNIRP appears to take into account only the warming of tissue and uncontrolled muscle contractions, although they claim in the most recent advice, that they also evaluated other mechanisms", writes Kromhout.

As many scientists and critical observers have pointed out, it seems as if ICNIRP members are either oblivious or ignoring scientific studies that find possible adverse health effects where there is an absence of heating. Even when some ICNIRP-members themselves acknowledge that industry-funding of scientific research tends to have less positive findings, and publicly funded studies – like the NTP-study – does find significant links between EMF and adverse health effects, this does not seem to influence one iota the views of ICNIRP-members.

A mixed bag of responsibilities

In an e-mail we received from Lloyd Morgan, Senior Research Fellow of the Environmental Health Trust and Director of the Central Brain Tumor Registry of the United States, is very critical of both ICNIRP and governments: "Who are ICNIRP? The International Committee on Non-Ionising Radiation Protection (ICNIRP) are a private, self-appointed body or NGO who together with the Advisory Group on Non-ionising Radiation (AGNIR) and Public Health England (PHE), have somehow ended up effectively setting microwave radiation exposure 'safety' standards for the populations of large parts of the world since the 1990s," he writes. "What amazes me, and simultaneously sickens me, is how did ICNIRP convince a large number of "independent" nations to adopt ICNIRP's so called "standards"?

Morgan suspects that high-level persons in the government's administration was "able to have the legislation passed because almost no-one in the government understood what was happening."

ICNIRP only publishes guidelines. It is then up to national governments to decide if they pass these guidelines into law. According to Lloyd Morgan, "that places the burden on each national government, should its citizens file a lawsuit".

Clearly, the Telecom sector as a whole, and the auctioning off of bandwidth and selling of Telecommunication licenses, are an important source of cash income for governments. The analogy with the Tobacco sector has often been made by scholars who study 'regulatory capture', but there is also an important similarity between the tobacco and telecom sectors in terms of their importance for State budgets.

The auctioning off of Radio frequency spectrums brings in billions of euros for European countries. Telecom companies also earn billions of euros thanks to these spectrum acquisitions, since 'owning the right' to use a specific radio frequency spectrum is an essential resource for telecommunication services such as mobile telephones, TV and radio broadcasting, satellite and broadband communications.

The *European 5G Observatory* notes that, "Germany's Federal Network Agency announced that the 5G auction, which started in March 2019, ended with 6.55 billion euros offered in total by the four bidders. *Deutsche Telekom* and *Vodafone* Germany criticized high prices of the country's auction". In the 5G Action Plan as adopted by the EU in 2016 it says:, "from September 2016, member states will be required to authorise the 700 MHz-band by 2020, unless there are justified reasons for delaying it until mid-2022 at the latest", reports the *European 5G Observatory*. The Observatory also stated, in April 2020, that "exceptional circumstances caused by the Covid-19 epidemic have forced some countries in Europe to postpone 5G auctions scheduled in the first months of 2020. Four EU countries, Austria, France, Spain and Portugal have postponed spectrum auctions for 5G due to the Covid-19 epidemic so far."

The European Commission selected the consultancy firm, Idate-digiworld to carry out the *European 5G Observatory,* to monitor the rolling out of the 5 G Action Plan. IDATE-DIGIWORLD is a smart-looking consultancy company and self-declared "European think-tank for members, policy-makers and players of the digital transformation", with some of the largest telecom operators and producers as its clients.

One of those clients, isn't a Telecom giant, but a governmental regulator, Ofcom in the UK. *European 5G Observatory* reports that 'Ofcom opened a consultation on human exposure to Electromagnetic Field Emissions (EMF) in the UK. The consultation started on February 21th 2020 and ended on May 15th 2020: "The regulator proposes to include a specific condition in telecom licences requiring licensees to comply with ICNIRP guidelines. {…) At the same time, Ofcom released the results collected close to 16 5G base stations in 10 cities across the UK and to 60 GHz fixed wireless equipment in Liverpool. In all cases, the measured EMF levels from 5G base stations were far below the ICNIRP Guidelines (the highest level was approximately 1.5% of the relevant level); the 5G share of the total emissions level observed was currently very low."

To the question, "Is ICNIRP responsible?", Paolo Vecchia, former Chairman for ICNIRP (2004-2012) answered very clearly at a conference in September 2008 that "the ICNIRP guidelines are neither mandatory prescriptions for safety, the "last word" on the issue, nor are they defensive walls for Industry or others." This statement makes it clear that the decision to adopt these guidelines into national legislation as "sufficient to protect public health" is political. The possible misuse by governments of ICNIRP and its guidelines seems to be another key question, that still needs looking into and answering.

On the other hand, ICNIRP presents itself as the provider of scientific truth. For example, in a report for the Irish government, under the heading, "Recommendations International Guidelines" it states that "there should be strict compliance with ICNIRP guidelines: The ICNIRP guidelines on exposure limits have been recommended by the European Commission to its Member States, and they provide science-based exposure limits that are applicable to both public and occupational exposure from RF and ELF fields. They also provide sound guidance on limiting exposure from mobile phones and masts, as well as for power-line fields. The ICNIRP guidelines provide adequate protection for the public from any EMF sources. While the guidelines were published in 1998, they are constantly under review and still have appropriately protective limits. The guidelines are based on a weight of evidence review from all peer-reviewed scientific literature and not on the conclusions of any single scientific paper."

Even as ICNIRP has been positioning itself during the last 25 years as the sole scientific truth when it comes to possible relation between EMF and adverse health effects, it would not be correct to hold this scientific NGO accountable if one day it would be undisputed that EMF causes health problems. National governments have their own responsibility to protect their citizens, just as the European Commission has, which after all is the 'Guardian of the Treaty' and therefore should also take the legally binding 'precautionary principle' into account.

The telecommunication industry applauds ICNIRP

In most policy fields, industry keeps reiterating that the limits scientific advisory committees propose are too strict. But in the case of the exposure limits for non-ionizing radiation the telecom industry seems very content with the norms ICNIRP proposes. In many reports over the past twenty years, the Telecoms lobby in Europe has always referred to the safety assurances published by ICNIRP.

In its Environmental Report of 2005, the European Telecommunications Networks Operators' Association (ETNO) wrote: "Concerning the European Union's legislative and policy framework on EMF, ETNO has been in direct contact with EU institutions. The association has provided a steady stream of facts and advice to legislative bodies in order for the EU to base its Directive concerning 'minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)' on a sound scientific basis as provided by the International Commission on Non-Ionising Radiation Protection (ICNIRP)."

Thirteen years later, the Boston Consulting Group, in a report with the ominous title, 'A playbook for accelerating 5G in Europe', pleads for the harmonized limits ICNIRP (and also IRPA and the WHO EMF project) proposes, and criticizes governments that apply stricter limits. Exactly the same point was made by ETNO in a public consultation by the European Commission. ETNO was in favour of the "harmonised ICNIRP limits".

The same word, *harmonised*, comes back in a plea for "a harmonised EU approach to 5G security" that ETNO launched on 29 January 2020. "We therefore welcome today's publication of the "5G Security Toolbox", presented by EU Member States with ENISA and the European Commission. Europe's decision-making on 5G should continue being based on facts, it should be proportionate to threats and build on a solid understanding of technology reality. In this context, we invite National Governments to avoid disproportionate actions that negatively impact the investment climate, and which could in turn harm both Europe's competitiveness and its strategic position in 5G development."

ETNO argues that rules and regulations should not hamper but support European investment and innovation, because "regulatory pressure still risks holding back European investment and innovation on many fronts"…"The speed of 5G rollout is significantly slowed by excessive spectrum prices and challenging license conditions."

ETNO continues to explain the policy-wish list: "The opportunity of fully unleashing fibre deployment awaits a pro-investment implementation of the European Electronic Communications Code. Regulatory asymmetries, especially in the field of data, still hold back European innovation. Market fragmentation still affects Europe's full potential in network investment. European institutions and national governments both have a major role to play in removing such barriers."

Yet again, ETNO does not lobby for lowering the ICNIRP standards, these are not seen as part of the "regulatory pressure" that hampers technological development. On the contrary: the norms ICNIRP proposes are the "harmonised limits" that ETNO welcomes.

All in all, the telecom-sector seems to be quite pleased with ICNIRP's positioning. This is deviating from the standard procedure in EU-policy making where a specific industry concerned will on essential aspects always try to influence laws and regulations in their favour through various ways of lobbying. Apparently in case of ICNIRP there is simply no need to do so.

The Telecom Lobby

In order to promote a continuation of favourable policy-making, European telecom companies have many lobby-meetings with the European Commission, and no doubt also at national political levels. According to the EU transparency Register, ETNO has a budget of over one million euros for lobbying and representing Europe's telecom companies. With at least seven registered lobbyists, ETNO had 70 registered lobby meetings with the European Commission (EC) in 2019. "ETNO's primary purpose is to develop top-level policy papers and support members in promoting a positive policy environment allowing the EU telecommunications sector to deliver best quality services to consumers and businesses. We also organize some of the main European events for discussing telecom and digital policy."

But of course, the individual telecom companies also have lobbying budgets and lobbyists representing them at the European institutions in Brussels. Ericsson had a lobby budget of 700.000 euros and five accredited lobbyist in 2019, Telefonica had a lobbying budget of 1,8 million euros and 6 lobbyists who covered no less than 83 meetings with the EC, Deutsche Telekom had a 1,5 million lobbying budget, with 5 lobbyists and a total of 110 lobby meetings with the EC.

In early December 2019, a large delegation of CEOs from ETNO met with Margrethe Vestager, Executive Vice-President of the European Commission responsible for "Europe fit for the Digital Age". The delegation included: Tim Hoettges from *Deutsche Telekom*, Stephane Richard from *Orange*; Thomas Arnolder from *Telekom Austria*, Salvatore Rossi from *TIM*, Alexandre Fonseca from *Altice Portugal*, as well as the Chairman of ETNO, Steven Tas, the Director General of ETNO, Lise Fuhr, and senior representatives from *Telefonica* and *Telenor*.

At the end of January 2020, an important event was held, the European 5G conference. It welcomed more than 250 delegates, who discussed "the necessary next steps to ensure the success of 5G in Europe". Eric Van Rongen, at the time still ICNIRP-Chair, was among the speakers who provided "the audience with insightful views on their areas of expertise." The purpose, apparently, was not to discuss the sagacity and safety of rolling out 5G, but rather to ensure the success of 5G deployment.

It is important to note that the efforts of the telecom industry to influence regulatory agencies often take illegal forms. Telecommunications companies are high on the list of the companies that were penalised in the U.S. for corrupt practices. European companies like *Ericsson, Alstom* and *Telia* are in the top ten.

Also significant, is the fact that more and more world leading insurance companies are backtracking from insuring telecom companies concerning the risks around EMF. In March 2019, in its "SONAR Emerging risk insights" report, one of the world's largest insurance companies, *Swiss Reinsurance Company* (Swiss Re), classified "unforeseen consequences of electromagnetic fields" into the highest risk class, together with endocrine disrupting chemicals. "The ubiquity of electromagnetic fields (EMF) raises concerns about potential implications for human health, in particular with regard to the use of mobile phones, power lines or antennas for broadcasting. Over the last decade, the spread of wireless devices has accelerated enormously. The convergence of mobile phones with computer technology has led to the proliferation of new and emerging technologies. This development has increased exposure to electromagnetic fields, the health impacts of which remain unknown."

The lobby power of the telecom-industry in Brussels, the decision-making heart of the EU, is enormous. Yet the corporations involved do not have to lobby the guidelines and health advice related to their technology, because ICNIRP has been providing the "safety certification" for over 25 years. At the same time the insurance sector is not very assured and does not want to pay possible litigation costs once telecom companies would get sued, which is happening more and more frequently.

The call for more independent scientific assessment in this area

Almost ten years ago, in May 2011, the Council of Europe adopted a report from Mr Jean Huss on "The potential dangers of electromagnetic fields and their effect on the environment". It stated that the findings of scientific research on the possible risks of electromagnetic fields were inconclusive and contradictory. In the light of the correlation between origin of funding and the findings it called for "genuine independence on the part of the expert appraisal agencies and for independent, multidisciplinary and properly balanced expert input. There must no longer be situations where whistle blowers are discriminated against and renowned scientists with critical opinions are excluded when experts are selected to sit on expert committees or no longer receive funding for their research."

In the meantime, not a lot seems to have changed. In a letter, published this year in *Bioelectromagnetics,* three researchers - Steven Weller , Victor Leach and Murray May - of the Australian "Oceania Radiofrequency Scientific Advisory Association" (ORSAA) write: "Half a century of scientific research into the safety of EMFs (from static to 300GHz) has not resulted in any substantial policy advice changes. The question that we believe needs to be asked is as follows: Is the continuing unchanged policy advice on EMFs occurring because those who are trying to advocate change have no voice in the process and because the process is dominated by groups with self-interests in maintaining the status quo?"

The three researchers point to the fact that radiofrequency electromagnetic radiation is "a booming multi-trillion-dollar industry globally, and changing current prescribed safety levels to more stringent standards would bring about unfavourable financial consequences and affect industrial and military functions. In some countries, such as Australia, the regulator, which has a health protection responsibility, also sells RF spectrum licenses, which represents a clear conflict of interest. The very same agencies with responsibility for providing safety advice to the public are also considered by some to have been captured by the industry."

The huge financial weight and power of the telecom companies is something the industry itself also stresses. In its report from January 2020, 'The State of Digital Communications 2020', ETNO boasts that "its Telecom members are thriving and business is booming: Telecom is Europe's major technology business, with a €136.9 billion per year value added and training on the rise. (…) Of the 17 Europe-based companies figured in the 2019 Forbes Digital 100 index, 11 are either telecoms operators or telecoms equipment vendors, and more than half of them are ETNO members."

Whether or not ICNIRP is 'captured by industry', a remarkable fact is that the organisation that appears to be the world's most important body responsible for advice on non-ionizing radiation is a private organisation, not a public authority.

"To me it seems wiser if the EU and national governments stop relying only on the advice of ICNIRP. A committee of its own is not an unnecessary luxury," Hans Kromhout writes. When we ask him if it would seem to him more logical that it be a public organisation giving advice on non-ionizing radiation, he answers: "I completely agree."

But this is not what is happening in the heart of the European Union. According to ICNIRP's website there is a contractual partnership between the European Commission, which is the Guardian of the Treaty, and thus also of the legally enshrined precautionary principle. It states: "The European Commission and ICNIRP collaboration over the years, relies on annual or specific contracts, such as the Concerted Action within FP5 - Life Quality, Key action Environment and Heath. ICNIRP also takes part, in consultation together with other stakeholders, on the development of directives and liaises, upon request, with different EC entities, such as the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Support to ICNIRP is provided by the European Commission through its Directorate General Health and Safety at Work as part of an EC grant agreement, as laid down in the ICNIRP reports."

Given the experience with ICNIRP of the past 25 years, the growing body of evidence that there are serious concerns on adverse effects of EMF on public health and the huge economic interests involved, it seems not very wise for the European Commission and national governments to base their policies solely on the ICNIRP guidelines and advice.

Chris Portier agrees by saying that “governments have no say in the governance or membership of ICNIRP. In addition, without their own review committees, governments do not have their own experts to advise them about these topics. I believe it would be best if such an entity was run by a trusted organization that has some form of government oversight.”

Portiers adds in writing to us: “I have been in the position of managing, running, chairing and/or being a member of dozens of national and international committees. These were always government committees or WHO-related entities. When run properly, governments can get excellent advice on issues. There is usually a place for interested parties (industry, concerned citizens) to express their opinions to these committee members at public forums. And there are legal consequences to providing false information on Conflict of Interest forms, etc. All of these reasons lead one to believe a government managed Commission would be better.”

We think that the call for more independent scientific assessment in this area is, for all the arguments mentioned in the above, fully justified.

IV - Conclusion

ICNIRP presents itself, and is described by the European Commission and in the media, as an independent international commission that gives advice based on scientific evidence. We believe that there are various reasons to question this (self)-image.

The composition of ICNIRP is very one sided. With only one medically qualified person (but not an expert in wireless radiation) out of a total of 14 scientists in the ICNIRP Commission and also a small minority of members with medical qualifications in the Scientific Expert Group, we can safely say that ICNIRP has been, and is still, dominated by physical scientists. This may not be the wisest composition when your remit is to offer advice on human health and safety to governments around the world.

As one can read in the 45 portraits of the members of the ICNIRP commission and of the Scientific Expert Group (SEG), they all share the same position on the safety issues: non-ionising radiation poses no health threats and the only effects it has are thermal. ICNIRP says "non-ionising radiation poses no health threats if it does not heat the tissue by more than 1 °C", by which it admits that there are possible health effects, but only if exposure levels to strong radiation are too high".

Over the past years, and on many platforms, various EMF-experts have stated that ICNIRP is wrong to continue dismissing certain scientific studies showing adverse health effects – like the American NTP-study - and is mistaken in its almost dogmatic conviction that "non-ionising radiation poses no health threats and the only possible health effects it has are thermal in case of strong radiation".

Even after much criticism from members of the global scientific community, ICNIRP still adheres to the paradigm that the only proven effects (on health) are thermal. "ICNIRP appears to take into account only the warming of tissue and uncontrolled muscle contractions, although they claim in the most recent advice, that they also evaluated other mechanisms", writes Dutch Professor Hans Kromhout, who is currently leading a long-term study (in the Netherlands) into the effects of mobile phone use on human health, and who is chairman of a special committee on Electromagnetic Fields of the leading Dutch Health Council, which advises the Dutch government.

It seems that "a closed circle of like-minded scientists" has turned ICNIRP into a self-indulgent science club, with a lack of bio-medical expertise, as well as a lack of scientific expertise in specific risk assessments. Thereby, creating a situation which might easily lead to "tunnel-vision" in the organisation's scope. Two leading experts, Hans Kromhout and Chris Portier, confirmed to us that ICNIRP is a closed, non-accountable and one-sided organisation.

As many scientists and critical observers have pointed out, it seems that ICNIRP members are either oblivious to, or are ignoring, scientific studies that find possible adverse health effects in the absence of heating. Even though some ICNIRP-members have themselves acknowledged that industry-funded scientific research tends to produce less findings showing adverse health effects of EMF, whereas publicly funded studies – like the NTP-study – do find significant links between EMF and adverse health effects, this does not seem to influence one iota the views of ICNIRP-members.

The majority of ICNIRP-scientists have done, or are doing, research partly funded by industry. Is this important? As we argue in the introduction, we believe it is. Scientific publications, co-authored by two ICNIRP-scientists – Anke Huss and Martin Röösli, confirm the importance of funding. In 2006 and 2009 they did a systematic review of the effects of the source of funding in experimental studies of mobile phone use on health, and their conclusion was that, “industry-sponsored studies were least likely to report results suggesting (adverse health) effects”. And theirs is not the only study that showed this, as there have been numerous studies of the differences in reporting from industry-funded research versus publicly-funded research that suggest a strong funding bias on the results.

In addition to the fact that certain members of ICNIRP, are simultaneously members of the International Committee on Electromagnetic Safety (ICES) of the US-registered Institute of Electrical and Electronics Engineers (IEEE), we have seen further evidence of a close cooperation between ICNIRP and ICES, an organisation in which many people from the media and telecom industries, as well as from the military, are actively and structurally involved. During the current leadership of ICNIRP, these ties have become even closer “with the goal of setting internationally harmonized safety limits for exposure to electromagnetic fields”. This must surely be considered as a situation in which conflicts of interest are a real possibility.

It is clear from ICES minutes that ICNIRP worked very closely with IEEE/ICES on the creation of the new RF safety guidelines that were published in March 2020. And this implies that large telecom-companies such as Motorola and others, as well as US military, had a direct influence on the ICNIRP guidelines, which are still the basis for EU-policies in this domain.

Although there is a lot of lobby-power by the telecom sector in the European Union (both in Brussels and in the member states), the European Telecommunications Networks Operators' Association (ETNO) does not lobby for lowering the ICNIRP standards, as these are not seen as part of the “regulatory pressure” that hampers technological development. On the contrary: the norms ICNIRP proposes are the “harmonised limits” that ETNO welcomes. All in all, the telecom-sector seems to be quite pleased with ICNIRP's positioning. This deviates from the standard procedure in EU-policy making, where a specific industry concerned will, on essential aspects, always try to influence laws and regulations in its favour through various lobbying strategies. Apparently, in the case of ICNIRP, there is simply no need to do so. At the same time, the insurance sector does not, at present, seem very reassured and does not want to be put in a situation of having to pay potential litigation costs, if and when telecom companies get sued, something that is happening more and more often.

Despite ICNIRP positioning itself, during the last 25 years, as the sole purveyor of scientific truth when it comes to possible relation between EMF and adverse health effects, it would not be right to hold this scientific NGO solely accountable if, one day, it were to become undisputed that EMF do cause health problems. National governments, as well as the European Commission, which is, after all, the ‘Guardian of the Treaty’, have a duty of care and protection of their citizens, and therefore should also take the legally binding ‘precautionary principle’ into account.

We think that the call for more independent scientific assessment in this area is, for all the arguments mentioned above and in what follows, fully justified.

That is the most important conclusion of this report: for really independent scientific advice we cannot rely on ICNIRP. The European Commission and national governments, from countries like Germany, should stop funding ICNIRP. It is high time that the European Commission creates a new, public and fully independent advisory council on non-ionizing radiation. The funds currently allocated to ICNIRP could be used to set up this new organisation. And given the overall rise in R&D funding via Horizon Europe, with a foreseen budget (for 2021-2027) of between 75 and 100 billion euros, funding should in no way constitute an insurmountable hurdle to setting up this new, truly independent, body.

V - PORTRAITS OF THE ICNIRP-MEMBERS

ICNIRP COMMISSION:

Gunde Ziegelberger (Scientific Secretary)

Biography

On ICNIRP's website we read that Gunde Ziegelberger holds a PhD in Biology and after a career at the Max-Planck-Institute, she joined the Federal Office for Radiation Protection (BfS) in 2002, where she works on "Non-Ionizing Radiation". Since 2004 she also worked as Scientific Secretary for ICNIRP- she replaced Rüdiger Matthes, who became a commission member - and in that function, she is also a member of the ICNIRP Board together with the Chair (see Croft) and Vice Chair (see Van Rongen). ICNIRP's website clarifies: "The three Board members represents ICNIRP externally and mostly in its relations with the international and national partners and the press. The Scientific Secretariat is in charge with some specific scientific projects mostly related to workshops and with all administrative and operational tasks."

Position

In February 2019 Dr Ziegelberger gave a short interview in which she stated that when the limit values are respected so far scientific findings show that human beings don't run any risk from electromagnetic radiation.

Ziegelberger functions as Scientific Secretary of ICNIRP, she co-authors many scientific publications with ICNIRP-members. In September 2016 for example Ziegelberger was co-author of a publication 'A Closer Look at the Thresholds of Thermal Damage: Workshop Report by an ICNIRP Task Group'. The article concludes the workshop – co-organsied by the WHO and financed by the European Commission, the Turkish Ministry of Health, the International Radiation Protection Association (IRPA), the German Federal Ministry for the Environment (BMUB), and the Finnish Radiation and Nuclear Safety Authority (STUK). The conclusion shows that the workshop "will provide valuable input into the revision of the guidelines being formulated by ICNIRP for limiting human exposure to RF fields." It was also clear that only thermal (adverse) effects were discussed as was the case in the new ICNIRP guidelines from 2020.

She co-authored as BfS -researcher a study within the ARIMMORA risk assessment which concluded that "the relationship between exposure to the agent ELF-MF and risk of childhood leukaemia is considered consistent with "IARC Group 2B" classification of possibly carcinogenic to humans (Fig. 1). This category is the result of limited evidence of carcinogenicity in humans and inadequate evidence of carcinogenicity in experimental animals."

Possible conflicts of interest.

Although Ziegelberger plays an important role for ICNIRP, given her position in the board and the fact that she works in an important department for radiation protection (BfS) of the German government, we could not find any DOI.

Rodney Croft (chair as of May 2020)

Biography

Rodney Croft is a psychology researcher. He works as professor of Health Psychology at the School of Psychology, University of Wollongong, Australia.

He joined the ICNIRP Biology Standing Committee in 2008 and the Main Commission in 2012, to become chair in May 2020.

ICNIRP's website states that his research focuses on the delineation of human brain function, as well as psychiatry more generally. He participates in a variety of national and international scientific and government committees, was Executive Director of the Australian Centre for Radiofrequency Bioeffects Research ((ACRBR 2004-2011) and is currently Director of the Australian Centre for Electromagnetic Bioeffects Research.

In June 2011, Rodney Croft as Executive Director of ACRBR announced that the organisation would cease operations because "it had been unable to secure further funding to continue its research activities". But many of the ACRBR Directors would be able to continue their Rf research but under the banner of the Bioelectromagnetics Research Group, part of the Brain and Psychological Sciences Research Centre (BPsyC) at the Swinburne University of Technology, which has for many years very close ties to Telstra, Australia's biggest Telecom company.

In August 2012 Croft received new funding when Australian Minister for Health, Tanya Plibersek, announced the establishment of a new $2.5 million NHMRC Centre of Excellence: the Australian Centre for Electromagnetic Bioeffects Research (ACEBR) to be based at the University of Wollongong and led by Professor Croft. One of the central university partners of the ACEBR research Swinburne University.

Position

Croft is a typical ICNIRP member and has been defending for years and from different positions the point of view that there are no dangers associated with the use of mobile phones. On the ABC Lateline program (April 4, 2009) Dr. Rodney Croft, then Director of ACRBR, stated: "There really has been a lot of research done to date and the research has very clearly shown that there aren't any effects. With children, I really don't think there is any evidence suggesting that this might be a problem. There isn't anything to suggest that we may have to be a little bit more cautious."

Much earlier in 2003 the Australasian College of Nutritional and Environmental Medicine (ACNEM) published a paper by Don Maisch "that detailed reasons why extra precautions needed to be taken for children and cell phone use. The paper included a number of statements of concern specific to this issue from scientific and medical organizations internationally and concluded with the question: “Is it worth the risk” to continue to allow unrestricted cell phone use by children.”

In 2008 the Russian National Committee on Non-Ionising Radiation Protection (RNCNIRP) issued official advice that the “health of the present generation of children and future generations is under danger” from cell phone use and therefore the committee has recommended that cell phone use be restricted for people under 18 years of age.

Croft said in 2011: “With children, I really don’t think there is any evidence suggesting that this might be a problem. There isn’t anything to suggest that we may have to be a little bit more cautious” And to visually back up ACRBR’s on children and cell phone use on the ACRBR web site published “an animated image that included images of children happily using cell phones”.

In 2009 a scientific review paper with Van Rongen and Croft as first and second authors respectively stated. “Subjective symptoms over a wide range, including headaches and migraine, fatigue, and skin itches, have been attributed to various RF sources both at home and at work. However, in provocation studies a causal relation between EMF exposure and symptoms has not been demonstrated, suggesting that psychological factors such as the conscious expectation of effect may play an important role in this condition.” The article mentions that “all authors are either current or former members of the Standing Committee on Biology of the ICNIRP” but does not mention anything on funding of the study.

During an International Workshop on RF Measurements, Research Studies & Standards Development in 2018 Croft downplays scientific research that shows effect from EMF by saying that “Counterbalancing is necessary to enable appropriate interpretation of data” and “Conclusions must be based on the scientific literature, not just a data set”.

In 2019, Croft and a researcher (expert in antipsychotics) were awarded 1.2 Million$ for a project entitled "Exposures of mobile phone radiofrequency electromagnetic energy in juveniles: effects on brain development and behaviours." Neither of the two researchers are experts in the area of brain development, developmental psychology or juvenile behaviour.

Within ICNIRP, Rodney Croft was the chair of the Project Group that was tasked with preparing the new ICNIRP Guidelines, published early 2020. According to critics, ICNIRP still dismisses completely: the existence and significance of non-thermal effects, existence of the risk of cancer in long term avid users of mobile phones, IARC’s classification of RF as a possible human carcinogen (the IARC monograph review of science was not included in list of science reviews used by ICNIRP in preparation of the new guidelines).

Possible conflicts of interest

Just like his predecessor Van Rongen, Rodney Croft provides unpaid services to the IEEE ICES SC/4 Standards committees, a US version of ICNIRP, with a broad number of representatives from both military and telecom industry; ICES boasted that they had “at least two members of ICES as members of the new 13 person ICNIRP Project Group (PG) on HF guidelines (up to 300 GHz), of which the PG Chairman (Croft), is now very willing to work with ICES to develop science based safety standards. This will enhance the possibility of harmonizing international RF safety standards."

Croft also advises the EMF reference group, and a community group managed by the Australian Government organization, ARPANSA. He receives funding from the Electric Power Research Institute EPRI for a project investigating RF effects on EEG and thermoregulation.

To possibly answer this question a brief examination of ACEBR's Science & Wireless 2013 seminar "Health & Future RF Technologies" is an indication. In the seminar acknowledgements, the following was stated: "The ACEBR gratefully acknowledges the financial support of the National Health & Medical Research Council of Australia and Telstra Corporation, which has enabled SW2013 to run".

In Rodney Croft's introduction to the presentation by Mr. Mike Wood from the Australian Mobile Telecommunications Association (AMTA) on "4G telecommunications technologies", he said the following, in part: "Clearly what we see here is a whole lot of new technologies which are going to come about. How do we know what's going to be most relevant to us? Well, in the short term I think that our industry representatives are going to give the best indicator of this"

Croft was appointed in 2014 an Associate Editor of the BEMS journal of the Bioelectromagnetics Society (BEMS); The annual meetings of BEMS are a heavily industry sponsored event. The annual meeting celebrating the Bioelectromagnetics Society (BEMS) and the European Bioelectromagnetics Association (EBEA) was in 2015 in California (USA), had sponsors including companies such as, the Electric Power Research Institute (EPRI), Mobile Manufacturers Forum (MMF), Korean Institute of Electromagnetic Engineering Society (Mobile EMF Consortium) and, GSM-ATM5.

Croft also held talks and expert opinion on behalf of industry and for the Mobile Manufacturers Forum, a consortium of the world's major cell-phone companies. At a 5G Conference in Dubai In December 20, 2019, Croft held a lecture on behalf of ICNIRP alongside ICES Chairman Jafar Keshvari and TC95 Chairman C-K. Chou.

He joined the conference organized by the Telecommunication Regulatory Authority (TRA) of the United Arab Emirates held on December 8-9, 2019 in Dubai. Three presentations were on RF exposure safety limits: "5G RF safety concerns: New IEEE StdC95.1TM-2019" by C-K. Chou; "Scientific Basis of 5G Exposure Limits IEEE C95.1:2019 Standard" by Jafar Keshvari, and "Ensuring 5G Safety with the New ICNIRP Guidelines (100 kHz to 300 GHz)" by Rodney Croft of ICNIRP.

Croft has also actively collaborated in research with Ray McKenzie, who is a manager at the Mobile Carriers Forum (MCF) which is a special division of the Australian Mobile Telecommunications Association (AMTA) dealing with the policy, regulatory, public communications and health and safety aspects of the deployment of mobile networks in Australia.

On his website Croft's disclosure statement says: Rodney Croft has consulted to a range of organisations such as Shelharbour City Council, Department of Defence, Comcare and Optus. According to his ICNIRP declaration of interests he received personal remuneration for providing data analysis services to Heptares Therapeutics Ltd, a pharmaceutical company. And Croft received personal remuneration for providing advice to Australian Bureau of Statistics (ABS) on effects of RF devices used by field staff on field staff, resulting from a contract between University of Wollongong and ABS. He also received personal remuneration for “providing advice to Victorian Government on conducting bioelectromagnetics research, resulting from a contract between University of Wollongong and Victorian Government”.

As explained before in this report the Australian government receives billions from issuing spectrum licences to Telecom operators. In Australia, this licensing is carried out by industry regulator ACMA, the Australian Media Communications Authority. ACMA also collects a separate levy or tax from the wireless industry, money that is earmarked for scientific research on RF-EMR. ACMA then diverts $300,000 to the other government institution ARPANSA (Australian Radiation Protection & Nuclear Safety Agency) for its public information campaign) and $700,000 to the National Health & Medical Research Council (NHMRC).

According to the Australian research group ORSAA “the money that the Australian NHMRC receives in order to provide grants for medical research has mostly gone to industry-friendly researchers who have direct links with the wireless industry. For example, the largest recipient of this NHMRC research funds is Prof. Rodney Croft. He has essentially been the head of RF-EMR health research in Australia, despite his questionable qualifications for this health research role. Prof. Croft has received ample direct industry funding in addition to his lucrative NHMRC grants, which should be termed indirect industry funding.” Croft was the only Australian who played a part in determining what NHMRC research on EMR and health should be funded.

He used his international contacts at the WHO to get more Australian funding. This is how it worked behind the scenes: Croft was invited from Australia to the WHO for an expert consultation to determine which areas of medical research was needed; The Australian NHMRC research on EMR then looked to the WHO guidelines (co-influenced by Croft and ICNIRP or hi-jacked as some critics say) in order to decide their funding priorities (the 2010 WHO RF Research Agenda is the basis of funding for NHMRC research grants). Croft's laboratory then received the funding and has continued to get most of the research money over many years.

Croft had good relations with an influential industry man, Dr K. Joyner. Which researchers or research groups have been granted the NHMRC funds has been influenced to a large extent by Joyner, who was Motorola’s Director of “Global EME Strategy and Regulatory Affairs” and also represented the Australian Mobile Telecommunications Association, an industry group, on the telecommunications standards committee and the Mobile Manufacturers Forum ; Notwithstanding these ties Joyner was a longstanding member of the Standards Australia TE/7 Committee: Human Exposure to Electromagnetic Fields, and later on he was on the ARPANSA committee that set the current Australian Radiofrequency/Microwave human exposure standard. He was regarded by the cell phone companies as Australia's foremost authority on the industry's position on health issues with EMR and has represented Motorola and the Australian cell phone industry on several international standards-setting bodies. Joyner also had connections with Burson Marsteller, the PR firm representing the cell phone industry in Australia.

In October 2003 Ken Joyner, the key Motorola representative gave a presentation at the Annual Conference of the Australian Radiation Protection Society called: “A Review of RF Bioeffects Studies Relevant to the Use of Mobile Phones by Children”. Don Maisch writes in an article Motorola’s Micky Mouse Review: “The Motorola review’s conclusions as to a lack of scientific evidence of possible harm to children using mobile phones ignores a large body of expert opinion calling for a precautionary approach when it comes to children and mobile phone use.”

As reported in Microwave News (1999) in Europe there was some discontent with scientists with Motorola’s involvement with the EC research and telling European scientists how to spend research funds. As Don Maisch writes in ‘Corporate ties that bind: An Examination of Corporate Manipulation and Vested Interest in Public Health’ (2017): “In January 2009, Dr. Joyner announced that he was leaving his Director position at Motorola after 12 years and was "looking for new opportunities to work in the telecommunications industry". In that same year, Dr. Joyner was listed on the NHMRC's Peer Review Honour Roll which acknowledged its many peer reviewers and external assessors who had exhibited "excellent track records and wide-ranging expertise in Australian and international health and medical research fields". However, under the section "Administering Institution/Employer" he was listed as simply "consultant" and nothing about possible conflicts of interests. He later was appointed as the sole non-radiation expert on the 14-member Victorian government's Health department's Radiation advisory committee.

ORSAA calls this “pure corruption at a huge cost to public health everywhere. This system of funding and promoting an in-club of industry friendly researchers has kept a small number of people in powerful positions within the WHO, ICNIRP, ARPANSA etc., influencing decision making for most of the world.”

Eric van Rongen (Vice Chair ICNIRP-commission, until May 2020 chair)

Biography

Eric Van Rongen is a biologist. He is a staff member of the Dutch Health Council since 1992, where he focuses on non-ionizing radiation.

Van Rongen is a member of ICNIRP since May 2001. In 2016, he became the chair of the ICNIRP-commission. Since the beginning May 2020 he is no longer chair but vice-chair.

He also a member of the International Advisory Committee WHO EMF Project since 1995.

Van Rongen did not publish original research studies on EMF himself, only opinions or review articles.

Position

Van Rongen systematically, in scientific publications and in press articles, defends for more than twenty years the point of view that there are no dangers associated with the use of mobile phones. According to him, even for children there are no reasons to apply the precautionary principle. In 2004 for example he published an article in which he stated: 'The Health Council therefore sees no reason to recommend limiting the use of mobile phones by children.'

He systematically criticizes all studies that seem to show that non-ionizing radiation poses a problem. Recently the National Toxicologic Program (NTP) study on Cell Phone Radio Frequency concluded that there was clear evidence of tumors in the hearts of male rats But in an ICNIRP-publication Van Rongen and others stated that 'substantial limitations (of the NTP-study) preclude conclusions being drawn concerning RF EMFs and carcinogenesis.'

Possible conflicts of interest

The WHO EMF project was severely criticized in 2007 for being for a large part financed by the telecom industry, for example by the Mobile Manufacturers Forum (now Mobile & Wireless Forum), a lobby organisation of the industry.

Since 2000 Van Rongen is a member of the International Committee on Electromagnetic Safety (ICES) of the IEEE. This committee is dominated by people from industry and military. The ICES chairman Jafar Keshvari works at Intel, the chairman of one of the main committees C.K Chou at Motorola. ICES clearly is an industry lobby and standard setting organisation. Maybe Van Rongen decided for that reason to become a 'non active member' according to his declaration of personal interests 2019.

In previous years there was some competition between ICNIRP and ICES/ IEEE – at the time when the chair of ICES was still Dr. Ralf Bodemann, topshot of Siemens and Dr. B Jon Klauenberg from US Air Force Research Laboratory was the chair of ICES working group TC95. (Klauenberg was the US counterpart of former ICNIRP-chair Repacholi to lead the very start of the WHO EMF in the 90'ies.) According to an annual report of ICES it was thanks to the arrival in 2016 of Van Rongen as chair of ICNIRP that the relations with ICES improved significantly, as they were not so cordial before: "In May 2016, there was a change of leadership and some members of ICNIRP. The new ICNIRP Chairman and one of the new members of the 14-member committee are also ICES members and ICNIRP is now willing to discuss harmonization of the exposure limits found in IEEE Stds C95.1 TM -2005 and C95.6 TM -2002 and the ICNIRP Guidelines."

The ICES annual report further mentions that thanks to the invitation to do so by Van Rongen, ICES has been able to comment on the proposed new guidelines by ICNIRP. ICES workgroup TC95 formed a 19-member task group to draft a document to comment on the ICNIRP proposed guidelines on time. "ICES will maintain its collaborative relationship with ICNIRP with the goal of setting internationally harmonized safety limits for exposure to electromagnetic fields at frequencies below 300 GHz. This interaction with ICNIRP is considered a major step forward."

A year later during the annual meeting of ICES in 2017 it was stated that "ICNIRP has delayed finalizing their conclusions to give full consideration of ICES's recommendations". And Van Rongen gave a presentation saying that there is "No evidence that HF-EMF causes such diseases as cancer, no evidence that HF-EMF impairs health beyond effects that are due to established mechanisms of interaction."

Scientist Dariusz Leszczynski was a member of TC95, but resigned. He explained why on his blog: "My problem was that the membership of the IEEE-ICES-TC95 consists predominantly of the industrial scientists and the committee is chaired by C.K. Chou since the time he was employed by the Motorola. This means that all safety standards being developed by IEEE-ICES-TC95 are, in practice, developed by the industry scientists for the use by the industry they are employed by." According to Leszczynski this is a clear conflict of interests.

The latest minutes of TC95 that ICES published on its website (August 2019) show that the committee is still dominated by industry scientists.

In October 2019 Van Rongen spoke at the GSMA Europe EMF Forum. The GSM Association is a lobby organisation that defends the interests of mobile operators worldwide. In 2018, he also was a guest at the Forum. Then he defended ideas that GSMA received with pleasure: "The ICNIRP limits provide a high level of protection for all people against known adverse health effects. Dr van Rongen explained that there is no scientifically substantiated evidence that radio signals cause diseases such as cancer and that ICNIRP had considered studies such as that of the American National Toxicology Program."

In November 2019 Van Rongen presented the "ICNIRP RF guidelines revision" at 23rd GLORE (Global Coordination of Research and Health Policy on RF Electromagnetic Fields) conference held on 4th – 6rth of November in Lima, Peru. GLORE is an initiative to coordinate research and policy initiated by Japan and Korea in 1997 and joined by Europe and then by USA, Australia and Canada. Main speakers were also his ICES-colleagues Jafar Keshvari and TC95 Chairman C-K. Chou.

Van Rongen recently assured the Dutch press that there are no conflicts of interest inside ICNIRP right now. He stated: 'In the past certain members maybe received co-funding from the private sector, but currently no member has ties with the telecom sector.'

Of course, it depends on what you consider as a 'tie with industry', but his own involvement in ICES is already shows that it is not true that 'currently no member had ties with the telecom sector'. He also published articles together with researchers who did receive industry funding, for example with Bernard Veyret, who is 'a member of the Scientific Council of the French mobile operator Bouygues Telecom. His laboratory has received research funds from the same operator.' This information can be found in the footnotes of this article.

Tania Cestari

Biography

Tania Cestari received her medical degree from the University of Rio Grande do Sul and completed her medical Residency in Dermatology in Porto Alegre, Brazil and since 1995 she works as Professor of Dermatology at the same university, where she studies predominantly on clinical aspects and skin response. Dr Cestari has authored 112 scientific peer-reviewed publications, 42 book chapters and joined the ICNIRP Commission in May 2020.

Position

Dr Cestari has been doing mainly research into skin allergies and dermatological problems; We could not find any publication linked to EMF.

Possible conflicts of interest

In her 'Declaration of Interests' it is mentioned that she received research grants via the Medical Foundation of her hospital from Pfizer, Abbvie Pharmaceutical and Vichy Laboratoires for drug research.

Nigel Cridland

Biography

Nigel Cridland is Senior Group Leader at Public Health England. He joined what was to become the Public Health England (PHE) already in 1990, where he specialised in non-ionising radiation. He was member of the project team that wrote the European Commission guide to implementation of the Artificial Optical Radiation Directive (2006) and leader of the project team that developed the guide to implementation of the EMF Directive (2013).

He was Scientific Co-ordinator Mobile Telecommunications and Health Research (MTHR) Programme 2001 - 2012. Cridland was a member of the Independent Expert Group on Mobile Phones (2000). On LinkedIn he states that he was also member of the management committee of the European COST 281 action Potential Health Implications from Mobile Communications Systems.

Position

The 2000-report of the Independent Expert Group on Mobile Phones stated that 'the balance of evidence to date suggests that exposures to RF radiation below NRPB and ICNIRP guidelines do not cause adverse health effects to the general population'. But at the same time, it said: "the gaps in knowledge are sufficient to justify a precautionary approach".

The MTHR-programme (2001-2012) of which he was the Scientific Co-ordinator concluded that no association between cancer and mobile phone use was found. We can now be, said professor David Coggon, the chairman of the MTHR-programme, ‘be much more confident about the safety of modern telecommunications systems.’ Curiously enough the authors stated that: ‘We see no need for need for further research in any of the areas addressed by the research that is summarised in this report.’

Possible conflicts of interest

The MTHR-programme was funded by government and industry together, both for half of it. The final report states that to ensure that any of the funding organisation could not influence the outcome of the Programme an independent Programme Management Committee was set up. But there can be doubts about the independence of its members. From 2001 until 2007 Mike Repacholi (ICNIRP-founder, see the chapter on the history of ICNIRP) was for example member of the committee.

Guglielmo d'Inzeo

Biography

On ICNIRP’s website it reads that Guglielmo d'Inzeo is a Professor of "Bioelectromagnetic Interaction" at "La Sapienza" University of Rome since 1990. He researched active and passive microwave component design and bioelectromagnetism, mainly the interaction of electromagnetic fields with biological tissues, the effects of microwaves and ELF fields on biological samples and humans. He is author or co-author of more than seventy papers in international refereed journals and books.

He became a member of the European Bioelectromagnetics Association EBEA in 1989, and then President from 1993 to 1998. From 1992 to 2000 he was an Italian representative for the COST 244 and 244Bis projects on "Biomedical Effects of Electromagnetic Fields". From 1998 to 2004 he chaired the Italian ICEmB (Inter-University Centre Electromagnetic Fields and Biosystems). From 2001 to 2006 he was an Italian National representative in COST 281 project “Potential Health Effects from Emerging Wireless Communication Systems” and from 2007 in COST BM0704 related project.

Position

He has been active in the IEEE since the 80’ies, served as secretary–treasurer of ‘the IEEE Middle and South chapters’ and was from 2004 to 2009, also a member of the Technical Committee 95 (TC95) of IEEE International Committee on Electromagnetic Safety (ICES), of which Eric Van Rongen and Rodney Croft are also members. He published in the past 20 years a number of studies in IEEE Transactions on Biomedical Engineering and other IEEE publications, in which several times ICNIRP-founder Mike Repacholi was heartily thanked for his help.

In 2005 he was responsible for the Italian chapter of the report “European Information System on Electromagnetic Fields Exposure and Health Impacts” published on behalf of DG SANCO (European Commission), which was coordinated by the Joint research Centre (JRC of the EU); Alongside this project the “JRC developed during 2003-2004 the EIS-EMF project on behalf of DG SANCO with the overall objective of promoting cooperation among policy makers on public health and EMF risk communication issues in the EU”. What these projects basically reflect is the idea that concerns about possible health effect occur because people do not understand the issue well enough and that the concerns can be taken away by better communication.

Possible conflicts of interest

As we stated before (see Van Rongen and Croft), ICES is dominated by people from industry and military.

His declaration of personal interest 2019 is signed but only partly completed. d'Inzeo did some paid consultancy for an Italian legal office called Trifirò & Partners and for a Environmental Measurement Report Managers & Partners - Actuarial Services S.p.A in Rome. His DOI from 2016 mentions that he has been doing work for the "Marconi Foundation". The Guglielmo Marconi Foundation states to "promote research in the field of telecommunications and carries out activities devoted to the knowledge and diffusion of Guglielmo Marconi's scientific activity". The Marconi Foundation further states that "professional training and teaching play a major role" in its activities and that "their research focuses on two major fields: 1) mobile and personal communication systems, with a special focus on radio access and propagation; and 2) the computer-assisted design of non-linear microwave devices".

What is not declared in his DOI is that d'Inzeo, is a director of the scientific committee of Elettra 2000, a consortium of Marconi and other foundations. The self-declared aim of Elettra 2000 is to "spread knowledge of Bioelectromagnetics and start a dialogue between science, politics, industry and citizens, involving young people and schools." And "Elettra 2000 promotes researches and studies related to specific areas of interest. In particular, the consortium co-finances a number of national and international projects devoted to the study of the effects of electromagnetic fields on human health, in order to provide an authoritative scientific answer, fair and independent to the problem."

Elettra 2000 provides "advice to enterprises" and "owns a modern fleet of instruments for measuring electromagnetic fields in both low and high frequency" which "are available to both institutional and private entities in order to promote the improvement of standards of protection and safety of people and environment."

This paper from 2008 (The Italian national electromagnetic field monitoring network) is an example of the kind of research projects that is financing. The conclusions reads: "The monitoring campaign, combined with the travelling communication campaign contributed to create a different and more constructive approach to the problem by the citizens. This is demonstrated by the analysis of the data press that shows criticality and greater negative involvement in those areas where the monitoring campaign has been less efficient or less intense".

Furthermore, in 2019 an Italian journalist of Investigative Europe wrote the following in *Il Fatto*: "He has done multiplied scientific opinions for companies such as Vodafone, participated in European projects - all funded by industry, such as Interphone, Cosmos, Cefalo, and since the late 90s participates in the Efhran portal, where among the financiers are Deutsche Telecom and the European Association of GSM producers."

Akimasa Hirata

Biography

Akimasa Hirata is professor of Electrical and Electronic Engineering at the Nagoya Institute of Technology and Director of Center of Biomedical Physics and Information Technology.

He also is an Administrative Committee Member and Subcommittee Chairperson (SC6 EMF Dosimetry Modelling) in IEEE International Committee on Electromagnetic Safety (ICES). The latest committee (also called TC95) is the one of which Eric Van Rongen and Rodney Croft were also members.

Position

In November 2019 TC95 once again came to conclusion that the IEEE standards are safe. The authors, among which Hirata, wrote:

“a) The weight-of-evidence provides no credible indication of adverse effects caused by chronic exposures below levels specified in IEEE Std C95.1TM-2019.

b) No biophysical mechanisms have been scientifically validated that would link chronic exposures below levels specified in IEEE Std C95.1TM-2019 to adverse health effects.”

Possible conflicts of interest

As we stated before (see Van Rongen and Croft), ICES is dominated by people from industry and military.

Hirata conducted research published in *IEEE Transaction* in 2010 partly funded by KDDI Foundation. KDDI Corporation is a Japanese telecommunications operator.

But according to a recent publication Hirata himself judges that he has no conflicting interests.

Anke Huss

Biography

ICNIRP’s website states that Anke Huss is an assistant professor at the Institute for Risk Assessment Sciences (IRAS) at Utrecht University, the Netherlands. “Her research focuses on environmental and occupational exposure assessment to environmental factors including electromagnetic fields and their health”.

Huss is also involved in the GERoNiMO project, cancer and neurodegenerative diseases such as Parkinson’s disease, Alzheimer’s or ALS in the NOCCA (Nordic Occupational Cancer Study) and SNC (Swiss National Cohort) studies and on electromagnetic hypersensitivity. She is a member of the Dutch Health council, and the Scientific Council for Electromagnetic fields of the Swedish Radiation Safety Authority (SSM).

Position

She is one of the rare members of ICNIRP who seems to be aware of an industry-bias; In the book "Overpowered: The Dangers of Electromagnetic Radiation (EMF) and What You Can do about it" by Martin Blank, Anke Huss is quoted on Industry bias in research to the possible health risks of EMF.

In a scientific paper Huss writes that 82% of the research funded by public agencies or governments and 71% of the research jointly funded by industry and public sources, report health effects from RF exposure. When the research is solely funded by industry only 33% finds such a link.

Later Huss published another study in which she and colleagues examined whether the source of funding of 59 studies of the effects of low-level RF radiation has an effect on the results of studies. "Of these 59 studies, 12 (20%) were funded exclusively by the telecommunications industry, 11 (19%) were funded by public agencies or charities, 14 (24%) had mixed funding (including industry), and in 22 (37%) the source of funding was not reported." Huss et all conclude that "there is widespread concern regarding the possible health effects associated with the use of cellular phones, mobile telephone base stations, or broadcasting transmitters. Most (68%) of the studies assessed here reported biologic effects. At present, it is unclear whether these biologic effects translate into relevant health hazards. Reports from national and international bodies have recently concluded that further research efforts are needed, and dedicated research programs have been set up in the United States, Germany, Denmark, Hungary, Switzerland, and Japan. Our study indicates that the interpretation of the results from existing and future studies of the health effects of radiofrequency radiation should take sponsorship into account."

In 2010, she published a follow up study which confirmed the previous findings: "Of 75 additional studies 12% were industry-funded, 44% had public and 19% mixed funding; funding was unclear in 25%. Previous findings were confirmed: industry-sponsored studies were least likely to report results suggesting effects.

She also published in 2018 a meta-analysis based on among others epidemiologic studies "to examine associations of occupational exposure to extremely-low frequency magnetic fields (ELF-MF)" with amyotrophic lateral sclerosis (ALS).

Possible conflicts of Interests

Her DOI says she gets funding from US based EPRI for a study called TransExpo on leukaemia in children. Ironically, she states that the contract does not mention complete independence from the funder, but she explains clearly why the data will be analysed independently and "that there is no way that the funders can have an influence on what we report to them."

Ken Karipidis

Biography

Ken Karipidis has been working as a scientist at the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) since 2000. He is, states ICNIRP, 'currently the assistant director of the Assessment and Advice Section at ARPANSA where he is heavily involved in the scientific and regulatory aspects of radiation protection from electromagnetic radiation sources.'

He is member of the Scientific Expert Group since August 2015. In May 2020, he became member of the ICNIRP Commission.

Position

In 2017 Karipidis published an article with the conclusion that the exposure to radiofrequency radiation due to Wi-Fi in schools was very low. In a letter to the editor three scientists criticized the study as 'of little practical use' and 'misleading'.

Karapidis and Rodney Croft were part of a subcommittee established by ARPANSA to look at EHS and the research in 2016/17. According to an ORSAA member present in these meetings both Karipidis and Croft ignored clinical/medical evidence "in favour of poorly conducted provocation studies performed by psychologists, some of whom were funded by industry".

At the end of 2018 Karipidis together with among others Rodney Croft published a study that claimed to proof that in Australia there has been no increase in any brain tumour that can be attributed to mobile phones. That study received a lot of criticism because it excluded the group of people above sixty, which is the largest segment of the population with brain tumours.

In August 2019 Karipidis advised 40,000 Australian doctors or general practitioners via an article on the website of Royal Australian College of General Practitioners (RACGP) in which he wanted "GPs and their patients to know there is no evidence to support the concern that 5G technology, which uses radio waves and emits low-level radiofrequency (RF) electromagnetic energy (EME), will cause harms to the public". He stated: "There's been a lot of research into whether radio waves cause adverse health effects, and the only established health effects of radio waves are very high-power levels, where they raise temperature. An everyday example of that is your microwave oven at home; inside the microwave is very powerful radio waves which make the water molecules in the food bounce very fast, heating them up."

Possible conflicts of interest

In the introductory chapter, we wrote about the financial relationship between ARPANSA and the telecom industry. ARPANSA every year has a meeting with the Australian Telecommunications Association (AMTA), a lobby-organisation of the telecom industry. Minutes of this meeting made public after a Freedom of Information Request show that the funding of research was also on the agenda. 'Industry remains supportive of continued funding,' it says.

Carmela Marino

Biography

Carmela Marino studied Biological sciences in Faculty of Sciences of "La Sapienza" University of Rome. According to ICNIRP she is currently Head of the Unit of Radiation Biology and Human Health, at Casaccia Research Center of Italian Agency for New Technologies, Energy and Sustainable Economic Development (ENEA).

On behalf of ENEA she coordinated the research activity Subprogram 3 *Interaction between sources and biosystems* (MURST/ENEA-CNR Italian National Program *"Human and Environmental Protection from Electromagnetic Emissions")* and was involved in *several projects of the 5° and 6°FP, as member of steering Committee and Coordinator of research unit.*

Position

On the one hand Marino seems to agree with the official ICNIRP position; On the other hand In May 2012, during ICNIRP's 7th International NIR Workshop in Edinburgh, Marino held a lecture on the advantages, challenges and limits of experimental studies, in which she said that there is a "large number of studies but with controversial results and also a limited number of studies in relation to particular endpoints." Marino asked her fellow ICNIRP members the rhetorical question, whether these studies "really able to give conclusive information?" ICNIRP's answer to that question was and is no.

Possible conflicts of interest

Her Declaration of Personal Interests does not mention anything. Notaby, not that since April 2020 her university holds a patent based on her research, not mentioned in her DOI 2019, although the worldwide application for this patent was filed years ago.

Sharon Miller

Biography

Sharon Miller works at the Food and Drug Administration (FDA) as optical engineer since 1981. According to ICNIRP she served on numerous committees of the International Commission on Illumination (CIE) and the International Organisation for Standardization (ISO).

Position

Miller publications are mainly in the field of ultraviolet radiation and optical issues. It is difficult to find scientific publications or public statements in which she says anything about the safety of non-ionizing radiation.

Possible conflicts of interest

In her Declaration of Personal Interest Miller does not state any possible conflict of interest and we did not find any.

Gunnhild Oftedal

Biography

Gunnhild Oftedal is associate professor at the Norwegian University of Science and Technology (NTNU). According to ICNIRP she is currently, working as Research Co-ordinator at the Faculty of Information Technology and Electrical Engineering, NTNU. “From the early 1990s, she has been involved in research on health effects of EMF in the ELF and the RF ranges, mainly with experimental human studies and observational studies.

She is member of international organisations in the field of non-ionising radiation and participates in the work of WHO (Environmental Health Criteria project) on the health risk assessment on RF fields.”

She was one of the experts on a government-commissioned study, published in 2012, of possible health risks with radiation from mobile phones, base stations and wireless networks in Norway.

Position

In 2004 she answered on the questions if electromagnetic radiation from mobile phones may well affect us in other ways, too “that scientists are skating on thin ice when discussing these issues. They know little about the cause-and-effect mechanisms involved, and hence cannot eliminate the possibility that the effect of electromagnetic fields, however weak in mobile phones, may cause health problems”.

But she sticks with the official ICNIRP position and in a study for the Norwegian government she suggests that this approach is the right one: “Only effects for which there was reliable scientific evidence were used (by ICNIRP) as the basis for the exposure restrictions.”

In another recent study she concludes that “overall, the evidence points towards no effect of exposure. If physical effects exist, previous findings suggest that they must be very weak or affect only few individuals with IEI-EMF. Given the evidence that the nocebo effect or medical/mental disorders may explain the symptoms in many individuals with IEI-EMF, additional research is required to identify the various factors that may be important for developing IEI-EMF and for provoking the symptoms.”

As writes Leszczynski the ‘nocebo’ hypothesis argues that people first become aware, e.g. from news and social media, of the possible health risks of EMF-emitting devices and then worries about the possible health risk lead to develop symptoms, which they attribute to EMF exposures.

Oftedal denies in an article by IE that the health debate is polarised: ”In our field it is easy to put people in two camps, but the landscape is much more nuanced”. Also, the closed culture at ICNIRP is being denied: “People who demonstrate that they are skilled are asked to contribute.”

Possible conflicts of interest

In the study on “Mobile phone headache: a double blind, sham-controlled provocation study” co-financed by The Research Council of Norway, Norwegian Post and Telecommunication Authority, Statnett, Telenor, Norsk tele- og informasjonsbrukerforening (NORTIB), Netcom. The study found no effects.

She is member of Bioelectromagnetics society (BEMS) according to the DOI and also of the European Bioelectromagnetics Association (EBEA)

Tsutomu Okuno

Biography

Tsutomu Okuno worked for the National Institute of Occupational Safety and Health, Japan from 1980 to 2015.

He became a member of the Scientific Expert Group in 2013 and is a member of the ICNIRP Commission since 2016.

Position

Okuno was one of the authors of the ICNIRP note that criticized the NTP-study that showed carcinogenicity in rats. For the rest, his work seems mainly to be on ultraviolet radiation, not on radiofrequency radiation.

Possible conflicts of interest

In his Declaration of Personal Interest there do not seem to be sources of possible conflicts of interest and we did not find information that contradicts this.

Martin Röösli

Martin Röösli is Professor for environmental epidemiology at the Swiss Tropical- and Public Health Institute in Basel and leads the Environmental Exposures and Health Unit. His background is situated in atmospheric physics and environmental epidemiology.

In the field of non-ionizing radiation Röösli did several exposure assessments and epidemiological studies on the health effects of electromagnetic fields “including population based studies dealing with cancer, neurodegenerative diseases and non-specific symptoms of ill health”.

He is the chair of BERENIS, a Swiss expert group advising the government on electromagnetic fields and non-ionising radiation. He is a member of the advisory group of Cohort Study of Mobile Phone Use and Health (COSMOS) and between 2015 and 2018 of the the Scientific

Council of the IARC, specifically SC52. Since 2013 he is also a Member of the Editorial Board of Bioelectromagnetics.

He is still a member of the Expert Group for the Swedish Radiation Safety Authority (SSM), for which he gets 3000 Swiss francs yearly.

Relevant to this report Röösli was part of the Working Group of the IARC Monographs on the Evaluation of Carcinogenic Risks to Humans Volume 102: Non-Ionizing Radiation, Part II: Radiofrequency Electromagnetic Fields.

Position

Röösli has contributed to a study (see portrait of Anke Huss) which show that the funding of scientific research into EMF can influence the findings. Nevertheless, he confirms the general position of ICNIRP that no adverse health effects are proven.

In a study from 2010 ("Systematic review on the health effects of exposure to radiofrequency electromagnetic fields from mobile phone base stations") Röösli concludes: "Our review does not indicate an association between any health outcome and radiofrequency electromagnetic field exposure from MPBSs at levels typically encountered in people's everyday environment."

In a recent 5G report for the Swiss government Röösli et all conclude that "No health effect has been consistently proven," which he repeated in an interview.

In an annual report prepared for the Swedish Radiation Safety Authority (April 2020) by a nine-member panel of experts of which, ICNIRP vice-chair Eric Van Rongen and Röösli, which according to *MicroWave News* is published each year "as an annual update with the past year's most important scientific developments on the health effects of EMFs and RF radiation" states very bluntly that "no new established causal relationships between EMF exposure and health risks have been identified." The annual report simply does not mention the NTP report. "The two ICNIRP members and their seven colleagues made believe that the NTP report does not exist. It's not mentioned, there is no citation. Nothing at all. For the record, the NTP final report was released on November 1, 2018."

Louis Slesin of *MicroWave News* wrote: "There is a discussion of the NTP findings in last year's Swedish update. But that was based on an earlier NTP draft where the staff had opted for a weaker designation, "some evidence" of cancer. Later, after an in-depth public peer review, the NTP strengthened the conclusion to "clear evidence" of cancer. That was the headline news of 2018. "Clear evidence" was a game changer; leaving it out of the annual update is a sure sign of bias. The NTP conclusion was now qualitatively different from the earlier draft —it could well have been the title of the panel's 2018 update. But van Rongen, Röösli and the others ignored it."

On January 7, 2020 prof. Lennart Hardell and supported by 22 scientists researching EMF wrote a remarkably critical, open letter to Mrs. Simonetta Sommaruga, President of the Swiss Confederation, in which they conclude: "It is imperative that the chair and other experts evaluating scientific evidence and assessing health risks from RF radiation do not have such clear conflicts of interests or bias as Martin Röösli has. Indeed, being a member of ICNIRP and being funded by industry directly or through an industry funded foundation, constitutes clear conflicts of interest. Furthermore, it is recommended that the interpretation of results from studies of health effects of radiofrequency radiation should take sponsorship from telecom industry into account."

The group of scientists also point out to a strange contradiction in the positioning of Röösli: "Surprisingly the IARC classification from 2011 of RF-EMF exposure as class 2B, 'possibly' carcinogenic to humans, was ignored in the background material to the new ICNIRP draft on guidelines. Remarkably one of the ICNIRP commission members, Martin Röösli, was also one of the IARC experts evaluating the scientific RF carcinogenicity in May 2011. Röösli did not abstain from the IARC Group 2B classification and should be well aware of that decision, but seems now to neglect that fact being an ICNIRP member. That may be due to the fact that the IARC classification contradicts the scientific basis for the ICNIRP guidelines."

Hardell et al. suggest to the Swiss government that Mr. Martin Röösli should be released from his duties as a scientist who is not objective and has substantial conflicts of interest. On the letter Röösli reacted by saying: "It's not a scientific letter. It sounds like activists who do not use scientific facts but who just attack people. It would be much more compelling if Lennart responded to my criticism of him in a scientific way instead of derailing the debate".

A recent publication of the COSMOS (October 2019) on the outcomes states reassuringly that "using mobile phones most extensively for making or receiving calls at baseline reported weekly headaches slightly more frequently at follow-up than other users, but this finding largely disappeared after adjustment for confounders and was not related to call-time in GSM with higher RF-EMF exposure. (See also the portrait of Anissi Auvinen)

Possible conflicts of interests

Röösli does "unpaid work" for the COSMOS study, which received considerable funding from telecom companies. In the 2019-publication on this study for example, Nokia and mobile network providers TeliaSonera and Elisa are mentioned in the category 'funding'.

According to his DOI he gets 70,000 Swiss francs a year for the Berenis work, from the Federal Office for the Environment.

He also received 16,000 francs for assisting in the Working Group Mobile Phone and Radiation the Federal Office for the Environment of the Swiss government.

The Swiss Tropical and Public Health Institute in which he plays a leading role, has a lot of corporate clients of which Swisscom, the biggest telecom company in Switzerland, of which the Swiss government holds 51% of the shares. In the annual Report 2019 the institute states that of the total budget of roughly 90 million Swiss francs, 78. 6 % was "competitively acquired" and 21.4 % came from "Core contributions".

Studies selected or self-directed by Röösli, were directly funded by the (Research Foundation for Electricity and Mobile Communication)

of which Martin Röösli is a member since 2011, according to his CV on the website of the Swiss Tropical and Public Health Institute. FSM is "a non-profit-making foundation with the purpose of promoting scientific research into the chances and risks of radio and electric power technologies that produce and use electromagnetic fields". The five founders of the FSM are:

ETH Zurich, Swisscom, Salt, Sunrise, 3G Mobile (liquidated in 2011) and the current main sponsors are Swisscom and Swissgrid. The sponsors are also represented in the FSM Foundation Board with one delegate out of seven.

Soichi Watanabe

Biography

Watanabe is currently Director of the Electromagnetic Compatibility Laboratory of the "National Institute of Information and Communications Technology (NICT).

He was a member of ICNIRP Standing Committee III since 2004 and is a member of the Commission since 2012.

He is a guest lecturer of several universities and at the Central Research Institute of Electric Power Industry.

Position

All publications to which Watanabe contributed as author point in the same direction: no effect. For example, this article about tumorgenenis in rats.

In 2019, he was co-author of an article which stated: 'To date, no adverse health effects of the EMF, linked to these applications, have been established.'

Possible conflicts of interest

As a guest lecturer at the Central Research Institute of Electric Power Industry he receives a small amount (about € 450 for each lecture, 1 or 2 a year).

He was co-author of the article with commission-member Hirata on the research funded partly by KDDI Foundation.

MEMBERS WHO HAVE LEFT THE ICNIRP COMMISSION IN MAY 2020

Maria Feychting

Biography

Maria Feychting is a Professor of Epidemiology at the Institute of Environmental Medicine, Karolinska Institutet, Stockholm, Sweden.

She joined the Commission in 2008 and was elected vice chair in 2012. She left the Commission in May 2020.

Position

Feychting was in charge of the Swedish part of the Interphone study which concluded that there was no link between brain tumours and mobile phone use.

Feychting also conducted the Swedish part of the COSMOS-study, which in 2011 came to the conclusion that there was no increase in glioma in the Nordic countries that could be attributed to the use of mobile phones.

She recently repeated this point of view in the media in an article on the risks of 5G, which were none according to her.

According to this source she criticized the NTP-study on false grounds.

Possible conflicts of interest.

In a 2019 study in the context of COSMOS, she declared a declaration of interest as "vice chairman of the ICNIRP".

The telecom industry contributed € 5.5 billion to the funding (total € 19.2 billion) of the Interphone Study.

A 2016 publication on the Interphone Study once again mentioned industry funding by among other the Mobile Manufacturers Forum.

The Swedish part of the COSMOS-study was partly funded by the telecom industry: TeliaSonera, Telenor and Ericsson. In her Declaration of Interests for 2015 she declares that her Institute received a grant from industry sources which constituted "no more than 4% of her unit of epidemiology total income."

A 2011 study was partly funded by the Swiss Research Foundation on Mobile Communication, an organisation which is founded and funded by the telecom industry.

A 2012 study was funded by the Electric Power Research Institute (EPRI), an organisation funded by industry.

She did not mention these sources of funding in her Declarations of Personal Interest.

Adèle Green

Biography

Green is an Australian epidemiological scientist at the Queensland Institute of Medical Research, Australia and is the institute's Head of Cancer and Population Studies Group. She specialised in UV and skin cancer causation, harmful effects of UVR exposure in childhood and the prevention of melanoma. Apart from various Australian research bodies, she was also member of many committees at the International Agency for Research on Cancer (IARC) and contributed to the IARC monograph that led to classification in

Position

Although she focussed mostly on UV radiation, Green seemed to agree with her ICNIRP colleagues on the ICNIRP position, for example in this study from 2005 where Green was first author the research did not find any consistent or biologically relevant effect of specific radiation on cells. And another study from 2009 Epidemiologic Evidence on Mobile Phones and Tumor Risk, concludes by saying that “In the last few years, the epidemiologic evidence on mobile phone use and risk of brain and other tumors of the head has grown considerably. In our opinion, overall the studies published to date do not demonstrate a raised risk within approximately 10 years of use for any tumor of the brain or any other head tumor.” And despite certain methodologic shortcomings and limited data on long-term use, “the available data do not suggest a causal association between mobile phone use and fast-growing tumors such as malignant glioma in adults, at least those tumors with short induction periods.”

Conflicts of Interests

The declarations of interests of Dr Green have disappeared from the ICNIRP’s website. The IARC Monograph mentions that Dr Green received “research funds (not exceeding 5% of total research support) from L’Oréal which makes products intended to reduce the dose from solar radiation.”

Zenon Sienkiewicz

Biography

Sienkiewicz worked until his retirement in 2018 for Public Health England. There he led a research group that investigates the effects of ionizing and non-ionizing radiation. Since 2011 he has been a member of ICNIRP. He was also external expert for the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) report on ‘Potential health effects of exposure to electromagnetic fields (EMF)’, adopted in January 2015.

Position

Sienkiewicz systematically defends the position that there is no proof for any harm caused by non-ionizing radiation. In 2002, he said in the media: "The bottom line is there are no known mechanisms by which mobile phone radiation can increase the risk of cancer." Fifteen years later he still holds exactly the same position. In a 2017-article he stated that all the extensive research done has ‘not identified any public health risks with any degree of certainty.’ Moreover, it concluded that ‘animal studies investigating the carcinogenic potential of exposure to multiple RF frequencies should not be given a high priority for research at this time.’

Possible conflicts of interest

A remarkable fact in his latest Declaration of Personal Interests is that he has shares in telecommunications multinational BT Group, one of the largest telecommunications companies in the world from 2003 to the present day. The gain is very little: about 100 pounds a year. But still: if you want to avoid the impression of conflicts of interest buying shares in a telecom company doesn't seem to be a wise decision.

He himself acknowledges this is a potential conflict of interest. Under an article published in 2017 the 'Statement on the Conflict of Interest' is: The authors declare that this work was conducted in the absence of any commercial or financial relationships that could be constructed as a potential conflict of interest, *except Sienkiewicz declares that he has owned 440 ordinary shares in BT Group, a communication services company.*'

In his 2015 Declarations of Interests he declares to have done since 2012 "Provision of research and scientific advice to UK government and other stakeholders". It is not specified who those other stakeholders were, but it can be assumed those were not civil society groups.

Also since 2009, he has been a consultant to the Rapid Response Group at the Japan EMF Information Center, which is funded by "Japan Electrical Safety & Environment Technology Laboratories, where he conducts reviews and analyses of recently published scientific studies

He was between 2001 and 2012 member of the Mobile Telecommunications Health Research (MTHR)-programme. The programme did not find any association between exposure to mobile telephone communication and an increased risk of developing cancer. In the final report of the programme we read that that the core funding was provided in approximately equal share by government and industry. He systematically defends the point of view that there are no health risks associated with non-ionizing radiation. He was co-author of the 2019 article which criticized the NTP-study.

SCIENTIFIC EXPERT GROUP

Jacques Abramowicz

Biography

Jacques Abramowicz is Professor of Obstetrics and Gynecology and the Director of the Ultrasound Services at the University of Chicago.

He is a member of the Scientific Expert Group since May 2016.

Position

Abramowicz is, says his personal page at Chicago University, "an expert in the use of ultrasound for prenatal diagnosis of foetal anomalies and screening for early detection of ovarian cancer."

As far as we could find out, he did not perform research into the health effects of mobile phone radiation.

Possible Conflicts of Interest

In his declaration of personal interests Abramowicz doesn't mention possible conflicts of interest and we did not find information that contradicts this.

Anssi Auvinen

Biography

Auvinen is currently a professor of Epidemiology at the School of Health Sciences, University of Tampere in Finland. He is a member of ICNIRP's Scientific Expert Group since 2013. He was also external expert for the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) report on 'Potential health effects of exposure to electromagnetic fields (EMF)', adopted in January 2015.

Position

In harmony with all ICNIRP-members Auvinen criticizes research that seems to show an association between health problems and mobile phone use. Although there have been individual reports of associations between MP-use and tumours, this research is not consistent and on balance does not provide evidence of an association,' he and his co-authors wrote in 2008. His own research systematically shows no association between health problems and non-ionizing radiation.

Auvinen participated in the Finish Cohort Study of Mobile Phone Use and Health (COSMOS). A recent publication (October 2019) on the outcomes states reassuringly that "using mobile phones most extensively for making or receiving calls at baseline reported weekly headaches slightly more frequently at follow-up than other users, but this finding largely disappeared after adjustment for confounders and was not related to call-time in GSM with higher RF-EMF exposure. Tinnitus and hearing loss were not associated with amount of call-time." In another publication on the COSMOS-outcomes (April 2020) an association between sleep quality and mobile phone use is also not found.

Possible conflicts of interest

In his Declaration of Interests he submitted to ICNIRP he states that he in 2014 and 2015 received research € 100,000 funding from the Mobile Manufacturers Forum, an international organization founded in 1998 by leading manufacturers of mobile phones and radio equipment, such as Alcatel, Ericsson, Mitsubishi Electric, Motorola, Nokia, Panasonic, Philips, Sagem, Samsung, Siemens and Sony Ericsson.

The funding was for the COSMOS-study. In the 2019-publication on this study Nokia and mobile network providers TeliaSonera and Elisa are mentioned in the category 'funding'.

Another recent article states that Auvinen received 'consulting fees from Epid Research Inc.' According to his Declaration of Interest he received a fee of € 1000 in 2015 and 2017. Not in his declaration of interest is that he received lecture fees from pharmaceutical companies Glaxo Smith Kline and MSD. Maybe one can argue that these companies do not operate in the field of non-ionizing radiation. But to avoid conflicts of interests it seems wise to be transparent about all fees and funding received from industry.

Christian Cajochen

Biography

ICNIRP's website states that Cajochen studied natural sciences followed by a 3-y postdoctoral stay at the Harvard Medical School in Boston, USA. He leads the Centre for Chronobiology at the University of Basel and focusses on the influence of light on human cognition, circadian rhythms and sleep, circadian related disturbances in psychiatric disorders, and age-related changes in the circadian regulation of sleep and neurobehavioral performance.

He serves as associate editor for established sleep-related scientific journals and is editor in chief for “Clocks&Sleep”.

He started as a member of the Scientific Expert Group (SEG) in May 2018.

Position

As stated Cajochen focusses on the influence of lights and far as we could find out, he did not perform research into the health effects of mobile phone radiation.

Possible conflicts of interest

In his DOI it is stated that he studies the “effects of day LED on human performance, melatonin and sleep. Research studies in healthy human volunteers partially sponsored by Toshiba Materials.” In the period from 2014-2018 that accounts for 120.000 (we assume euro), whereby Toshiba has the right “to request (i) revisions to the publication, so that no Confidential Information is inadvertently disclosed or a delay of not more than 60 days to allow for protection of any potentially patentable subject matter by filing of a patent application.”

Toshiba does not focus on telecommunications, but rather on mainly infrastructure energy and Electronic Devices.

Jose Gomez-Tames

Biography

Gomez-Tames is Research Associate Professor in Nagoya Institute of Technology.

He is also Working Group Chair of the Subcommittee on EMF Dosimetry Modelling of the IEEE International Committee on Electromagnetic Safety from 2017.

Gomez-Tames is member of the Scientific Expert Group since 2018.

Position

Gomez-Tames work is more on the modelling of non-ionizing radiation than on the health effects.

Possible conflicts of interest

See Van Rongen and others on the role of IEEE/ICES.

In his Declaration of Personal Interest Gomez-Tames doesn't mention other sources of possible conflicts of interest and we did not find information that contradicts this.

Penny Gowland

Penny Gowland worked at the University of Nottingham School of Physics and Astronomy until 2016 and is now retired. She did a PhD in Magnetic Resonance Imaging from the Institute of Cancer Research in 1990.

According to ICNIRP's website "her work at high field and on foetal development as led her to take a strong interest in the interactions of EMF with the human body, and safety aspects of MRI."

Penny Gowland is a member of the ICNIRP Scientific Expert Group (SEG) since March 2013.

Position

She declared in her DOI that her "research interests are in MRI: but I am also academically and professionally interested in any biological effects of EMFs."

As stated Gowland focussed mainly on MRI and far as we could find out, she did not perform research into the health effects of mobile phone radiation.

Possible conflicts of interest

According to the organisation AVAATE her previous Declaration of Interests, she reported that she has held many research contracts with Phillips Electronics but without any money involved. Gowland has been part of the MR safety working group of British Institute of Radiology. According to the British Institute of Radiology website, Phillips and Siemens are platinum sponsors.

In 2015 AVAATE also stated that the European Society for Magnetic Resonance in Medicine and Biology (ESMRMB), organization mentions that Gowland was a member of several committees, including the Committee on Security, and has received financial support from companies like Hitachi, Philips, Siemens, Toshiba and General Electric.

John Hanifin

Biography

John Hanifin is laboratory director of the Light Research Program at Thomas Jefferson University.

He is a member of the Scientific Expert Group since May 2018.

Position

Hanifin is specialized in the effects of light. A recent publication he contributed to is for example is about the effect on nurse and patient experience of the overnight use of blue depleted illumination. He did not conduct research on the health effects of mobile communications technologies.

Possible conflicts of interest

The Light Research Program received industry support from among others OSRAM, Philips Lighting and Panasonic.

His PhD-thesis (2015) was also party funded by industry, by Philips Lighting, Apollo Lighting and OSRAM.

Hanifin's Declaration of Personal Interest shows that his laboratory earns about 5% of its yearly income by conducting clinical research for Bios Lighting. It mentions that his laboratory is obliged to submit a manuscript to the sponsor before publication for review and comment, 'however Sponsor shall not exercise editorial control over the publication'. The fact that the sponsor can review and comment the manuscript does not seem to be a strong guarantee of independence.

Jukka Juutilainen

Biography

He is a retired professor emeritus of Radiation Biology and Radiation Epidemiology, and Department Head of the Department of Environmental Science at the University of Eastern Finland. Juutilainen teaches generic courses on environmental health and risk assessment, as well as specific courses on non-ionizing and ionizing radiation

He is an Associate Editor of *Bioelectromagnetics*, effective immediately for which he was nominated by the European Bioelectromagnetics Association (EBEA) a non-profit scientific association with many current and former ICNIRP-members.

He was a member of the ICNIRP Standing Committee on Biology from 2004 until 2012 and became a member of the Scientific Expert Group (SEG) in March 2013.

Position

In 2007, *Microwave News* reported positively about a study published by Juutilainen: “Every now and then a new paper comes along that gives hope that one day we'll make sense of the conflicting results that have become the hallmark of EMF research.” The study was financed partly by the cell phone industry —the MMF and the GSMA and although Juutilainen suggested that needed a follow-up it never got one.

Another study from 2007 concluded that “the data did not show any effects of radiofrequency electromagnetic fields on micronucleus frequency in erythrocytes. The findings were consistent in two mouse strains (and in a transgenic variant of the second strain), after 52 or 78 weeks of irradiation, at three SAR levels relevant to human exposure from mobile phones, and for three different mobile phone signals.” The study was co-funded by Nokia, Elisa Communications Corporation, Finland Benefon, Finland Sonera.

Juutilainen published this study in 2009, together with Croft and Van Rongen, on the ‘Effects of Radiofrequency Electromagnetic Fields on the Human Nervous System’. The conclusion was that “However, in provocation studies a causal relation between EMF exposure and symptoms has never been demonstrated. There are clear indications, however, that psychological factors such as the conscious expectation of effect may play an important role in this condition.”

Possible conflicts of interest

In his past ICNIRP Declaration of Interests, he stated that he has received research funding from government organizations and foundations.

In his last non-signed DOI he indicates “The Department of Environmental and Biological Sciences of the University of Eastern Finland (UEF) has received funding from the Electric Power Research Institute (EPRI). Although EPRI is an independent, non-profit research organization (and therefore not reported above in research support received from commercial entities), this funding might be perceived as affecting my independence (Period: 2015-2019).”

According to AVAATE he had “numerous research programs funded by Nokia, Benefon, Sonera, Elisa, FINNET, the GSM Association and the Mobile Manufacturer Forum.” For example, the national research programme on possible health effects of mobile phones in Finland (from 1998 to 2003) which was coordinated by Juutilainen was mainly funded by TEKES, National Technology Agency a governmental organisation, and also supported by Nokia, Benefon, Sonera, Elisa, Radiolinja, Finnish 2G, Mobile Manufacturers Forum and the GSM Association.

He has participated in conferences and publications funded in part by organizations with interests in the telecommunications sector.

Masami Kojima

Biography

Masami Kojima is a professor of Kanazawa Medical University. He is specialized in ocular damage due to microwaves.

In the period 2001-2004 he was a consulting member for ICNIRP, since november 2014 he is a member of the Scientific Expert Group.

Position

Kojima's research is mainly on the effects of microwaves on the eye, often of rabbits. In his publications, we found no direct statements about possible effects on the eye within the ICNIRP-norms.

Possible conflicts of interest

He was co-author of the 2010 article partly funded by KDDI Foundation (see Hirata and Watanabe).

His Declaration of Personal Interest does not mention other sources of possible conflicts of interest and we did not find any.

Ilkka Laakso

Biography

He is Professor of Electromagnetics in Health Technologies at Aalto University, Finland and focuses on theoretical and computational bioelectromagnetics at both extremely low and radio frequencies. Laakso has been "combining computational electromagnetics with medical image processing and biological neuron modelling." The purpose of this research is to offer the medical and electrical engineering community new computational methods for individual physical modelling of the human body.

According to ICNIRP's website he is the "secretary of Subcommittee of EMF Dosimetry Modeling (SC6) of the IEEE International Committee on Electromagnetic Safety and a working group chairman since 2015."

Laakso became a member of the Scientific Expert Group (SEG) in 2016.

Position

A study from 2009 (Assessment of the Computational Uncertainty of Temperature Rise and SAR in the Eyes and Brain Under Far-Field Exposure From 1 to 10 GHz') about the specific absorption rate (SAR) seems to suggest that the 'reference levels by ICNIRP and maximum permissible exposure limits by IEEE seemed to be conservative in the sense that at the reference levels the temperature rise in the eyes and brain was always less than 1◦C."

Possible conflicts of interest

For IEEE/ICES see Van Rongen and others.

According to his DOI for ICNIRP he owns stocks of and is a board member of 'Fieldsim Oy', a consulting company in Finland that does computer simulations of electromagnetic fields, including electromagnetic field exposure.

Isabelle Lagroye

Biography

Isabelle Lagroye is a director of studies at the Ecole Pratique des Hautes Etudes (EPHE) and works at Bordeaux University. Her research, states a recent publication, 'deals mainly with the biological and toxicological effects of non-invasive electromagnetic fields.' She is currently member of the Bruxelles-Capitale expert committee on non-ionising radiations.

She was member of an ICNIRP committee in the period 2009-2012 and was elected member of the Scientific Expert Group in March 2013.

Position

In 2018 Lagroye together with two other scientists published an article in *European Scientist* in which she concluded that the NTP-study "consolidates current knowledge and reinforces the fact that when effects of mobile radiofrequency fields can be observed, it is at exposure levels that far exceeds the maximum permissible exposure values. In practice, these limits cannot be reached with commonly used wireless communication technologies (relay antennas, mobile phones, Wi-Fi …)."

This statement seems to be in contradiction with findings from her own research. A recent publication of which Lagroye was co-author concludes: 'However, we found that exposure to GSM-modulated 1800 MHz signals at 2 W/kg decreased the PMA maximal efficacy to activate both RAS and ERK kinases' activity.' So, it influences the signaling between proteins.

This is an effect at 2 W/kg, while according to the new ICNIRP-norms health effects in head and torso are only above 20W/kg and the norm is, with a safety factor of ten, 2W/kg.

Lagroye was also co-author of the final report of the Geronimo-project. In this report, we do find indications for health effects. It says:

"Results suggest that increased RF dose to the brain and longer mobile phone call time may be associated with risk of hyperactivity and conduct problems."

And: "a meta-analysis among four birth cohorts (n=55,507) indicated that maternal cell phone use during pregnancy may be associated with shorter pregnancy duration and increased risk for preterm birth (Tsarna et al., 2019, accepted Am J Epidemiol)."

Interesting is also that research conducted by Lagroye seems to suggest non-thermal effects, while ICNIRP states that thermal effects are the only ones for which there is scientific evidence. In this article the authors write: "Altogether, our experimental findings provide evidence for dose-dependent effects of RF signals on the bursting rate of neuronal cultures and suggest that part of the mechanism is non-thermal."

In 2009, she co-authored a scientific paper with Van Rongen and Croft which stated on the 'effects of radiofrequency electromagnetic fields on the human nervous system' that "there are clear indications, however, that psychological factors such as the conscious expectation of effect may play an important role in this condition."

Possible conflicts of interest

The latest Declaration of Personal Interest of Lagroye that can be found on the ICNIRP-site dates from 19 October 2015, almost five years ago. At that moment, she stated that she got 2,35% of the income of her research unit from a commercial partner, the Réseau de Transport d'Électricité (RTE).

A study published in 2010 which suggested that exposure to WiFi did not damage the brains of young rats was funded by France Telecom and La Fondation Santé et Radiofréquences, an organisation that is for the half funded by industry.

This organisation also partly funded several other studies to which she contributed, like this one published in 2011 and this one published in 2012.

Another 2012 publication was partly funded by Bouygues Telecom.

Sarah Loughran

Biography

ICNIRP's website states that Loughran is currently a researcher at the University of Wollongong in the Australian Centre for Electromagnetic Bioeffects Research (ACEBR) human neurophysiology research group, an NHMRC Centre of Research. She studied physiology and psychology and got a PhD in cognitive neuroscience/psychophysiology at Swinburne University of Technology, investigating the effects of electromagnetic fields on human sleep, the electroencephalogram (EEG), and melatonin.

To this centre (ACEBR) also ICNIRP-chair Rodney Croft and ICNIRP-member Andrew Wood are connected. Swinburne university and in particular the Radiofrequency Dosimetry Laboratory is part of the ACEBR which has a very close relationship with and is co-funded by Telstra, the biggest Telecom company in Australia. (See also portraits on Woods and Croft)

Loughran is also a member of the current World Health Organisation (WHO) RF Environmental Health Criterion evaluation committee, and is on the board of directors for the Bioelectromagnetics Society (BEMS). She is a member of the ICNIRP Scientific Expert Group (SEG) since March 2013.

Position

A 2005 study by Loughran and Woods on the effects of EMF on human sleep demonstrated that "a short exposure to mobile phone-type radiation has an effect on subsequent sleep EEG, although no conclusions can be made regarding adverse health consequences as the mechanisms of the effects are still unknown."

In 2007 Microwave News reports that "the ability of mobile phone radiation to affect sleep is emerging as a robust low-level effect. A team led by Bengt Arnetz has reported that a three-hour exposure to GSM radiation at 1.4W/Kg an hour before bed can disrupt sleep." This study supported earlier findings of Peter Achermann of the University of Zurich and Loughran at the time working at the Brain Sciences Institute at Swinburne University.

Because later findings of other studies got quite some media attention, Loughran, Peter Achermann & Niels Kuster published a statement to temper the seriousness of the findings.

Loughran worked for some years in Switzerland, where several scientists like Kuster do research on EMF and sleep. *The Nation* reported that Niels Kuster, a Swiss engineer co-authored in *The Lancet Oncology* a summary of the WHO's findings of the Interphone study which was launched by the WHO's International Agency for Cancer Research in 2000 (and to which two wireless trade associations contributed $4.7 million or 20 percent of the $24 million budget). Kuster had filed a conflict-of-interest statement affirming that his research group had taken money from "various governments, scientific institutions and corporations." But after his publication The Lancet "issued a correction expanding on Kuster's conflict-of-interest statement, noting payments from the Mobile Manufacturers Forum, Motorola, Ericsson, Nokia, Samsung, Sony, GSMA, and Deutsche Telekom. Nevertheless, Kuster participated in the entire 10 days of WHO-deliberations."

In general, Loughran (ACEBR) is in agreement with Croft. In an interview with Computerworld: "*There are people that are suffering and yes, it's **not due** to electromagnetic energy exposure, it's more of a **psychosomatic** condition*…"

According to a 2017 study "IEI-EMF provocation case studies: A novel approach to testing sensitive individuals" of which Loughran is the second author "*the present experiment failed to show a relationship between RF-EMF exposure and an IEI-EMF individual's symptoms*". The information on Electro hypersensitivity from the WHO's EMF Project (see also History chapter in this report) to which Loughran is connected has not been updated since 2005.

Possible conflicts of interest

In her DOI she declares for 2015 having received almost 16.000$ from EPRI funding a*nd NPF research Institute, which accounted "approximately for 5% of her lab's income".*

In a 2016 EPRI workshop "Loughran provided an overview of the current state of knowledge in the field of human laboratory studies, an assessment of the critical gaps in knowledge, and recommendations for research priorities. Loughran and the session rapporteur, Rodney Croft, University of Wollongong, led the workshop participants in a discussion of human laboratory studies".

See also portraits on Croft and Wood.

Jack Lund

Biography

Jack Lund was research physicist with the US Army Medical Research Command. There he studied the effect of laser radiation on ocular tissue and the visual system. He retired in 2018.

He was an ICNIRP Consulting Expert from 2002 to 2012. He joined the Scientific Expert Group in 2018.

Position

Jack Lund is an expert in laser safety issues. He did not publish article about the health effects of mobile communication technologies and did not make, as far as we could find out, make public statements about it.

Possible conflicts of interest

Lunds '[Declaration of personal interest]' is completely empty. We did not find other information about possible conflicts of interest.

Simon Mann

Biography

According ICNIRP's website Simon Mann is a chartered electrical engineer and heads the Physical Dosimetry Department at Public Health England's Centre for Radiation, Chemical and Environmental Hazards. Man is responsible for programmes of scientific work to develop health-related advice on exposures to electromagnetic fields (EMFs) and optical radiation across the UK.

He was secretary to the independent Advisory Group on Non-ionising Radiation (AGNIR), and member of the IARC Working Group that evaluated the carcinogenic potential of radiofrequency EMFs in 2011. He currently works with WHO EMF Project (see also history part) to develop its Environmental Health Criteria monograph on radiofrequency fields.

He is also active in technical standardisation and is a UK delegate to the CENELEC TC106X Committee.

During [a meeting of the WHO EMF Project] in 2013 Lindsay Martin from ARPANSA – (Australia) and Simon Mann (PHE - UK) were elected chair and vice chair respectively. In the meeting J. Keshvari from International Committee on Electromagnetic Safety (ICES)and the International Electrotechnical Commission (IEC) TC 106 said that "Maintenance work is in hand on several EMF exposure Standards. Harmonisation and avoiding duplication of effort, between CENELEC, IEEE and ITU is encouraged where possible." Keshvari also mentioned that IEEE/ICES "has been developing an RF safety Standard for NATO".

He is a member of the ICNIRP Scientific Expert Group since 2015.

Position

Mann is part of the close network of ICNIRP and WHO EMF scientists that claim there are no real immediate health effects from EMF. For more on the WHO Project and EMF IEEE/ICES, see the history part of this report and the portrait of Croft and Van Rongen.

Possible conflicts of interest

We could not find a recent DOI on ICNIRP's website: the link to Mann's DOI on ICNIRP's website is not functioning.

However, he did not mention in his former Declaration of Interests statement submitted to ICNIRP, that he has received research funding from the GSM association, the Mobile Manufacturer Forum and the UK's Mobile Telecommunication and Health Research Program (MTHR), on which he still plays a leading role. According to AVAATE MTHR in the past received funding from the Vodafone, a wireless company.

Since 2009 he has been a member of BEMS and the EBEA22.

Rüdiger Matthes

Biography

Rüdiger Matthes was from 1989 until his retirement in 2016 Head of the group "Non-Ionizing Radiation (Dosimetry)" at the German Federal Office for Radiation Protection. He became the Scientific Secretary of ICNIRP in 1993. He was Chairman of the Standing Committee on Physics and Engineering (SCIII) from 2004 to 2008. He became Vice-Chair in 2008, and Chair again in 2012. Since 2016 he is a member of the Scientific Expert Group.

Position

Matthes defends the position that there are no studies that prove the existence of non-thermal health effects of non-ionizing radiation and that no plausible mechanism has been described whereby these effects could take place. There is no evidence for a link between cancer and the use of mobile phones, he said in 2010.

Matthes was one of the authors of a recent ICNIRP-publication in which ICNIRP explains the principles for health protection on which its guidelines are based.

Possible conflicts of interest

In his Declaration of Personal Interests Matthes does not mention any possible conflict of interest and we did not find any information that contradicts this.

During a meeting of the WHO EMF Project in 2013 Matthes spoke on behalf of both BfS and ICNIRP by stating that: “Exposure recommendations have been developed by several organisations such as ICNIRP and IEEE/ICES, and there is good harmonisation between these on fundamental limits.”

John *O'Hagan*

Biography

On ICNIRP’s website it says that John O’Hagan heads the Laser and Optical Radiation Dosimetry Group at Public Health England. This research group covers all aspects of optical radiation dosimetry, including both the beneficial and detrimental effects of optical radiation on people.

He is Vice-President Standard of the International Commission on Illumination (CIE), Convenor of the International Electrotechnical Commission Technical Committee 76 “Optical Radiation Safety and Laser Equipment” Working Group 9 “Non-coherent sources”, Chairman of the British Standards Committee EPL/76 “Optical Radiation Safety and Laser Equipment” and is a member of a number of other national and international committees.

According to his DOI he was also a member of EU SCENHIR/SCHEER Working Group on Potential risks to human health of Light Emitting Diodes (2016-2018) and is a Member of WHO Core Group on NIR Basic Safety Recommendations.

He joined the ICNIRP Scientific Expert Group (SEG) in March 2013.

Position

In 2017 O’Hagan co-wrote a chapter in Clay's Handbook of Environmental Health in which the general line of ICNIRP, SCENHIR and WHO EMF Project is repeated: no adverse health effects.

Possible conflicts of interest

In his DOI he states under activities “Provision of scientific support and advice to government and other stakeholders”, but fails to mention which stakeholders.

In his statement, he says that he is the President of the Committee EPL/76 Optical radiation safety and laser equipment, of BSI Standards Development (BSI is a company that sets rules to help organizations worldwide achieve excellence). Organizations that work with this committee include the Association of Industrial Laser Users, the Association of Manufacturers of Domestic Appliances, GAMBICA Association Limited (a UK national organisation representing the interests of companies in the instrumentation, control, automation and laboratory technology industry) the Institute of Physics, the Institution of Engineering and Technology, the Institution of Mechanical Engineers, and the Lighting Industry Association.

He also reports that he is the Vice President of the CIE-UK National Illumination Committee of Great Britain. This committee was established by the Illuminating Engineering Society of

Great Britain, the Institute of Electronic and Electrical Engineers, the Institute of Gas Engineers, and the NPL, in collaboration with industry and professional associations, government departments and lighting technicians.

Chiyoji Ohkubo

Biography

Chiyoji Ohkubo is Director of the Japan EMF Information Center (JEIC). This organisation was established in July 2008 'to facilitate communication on EMF issues among government agencies, industry, the media and the general public.'

In the period 2005-2007 he worked for the EMF WHO-project.

He is a member of Scientific Expert Group since March 2013.

Position

All his publications seem to fit into the same category: no effect. See for example this study in which the exposure of rats to RF EMF radiation did not alter their cerebral microcirculation.

Possible conflicts of interest

For criticism of the WHO EMF Project see among others Van Rongen.

The Japan EMF Information Center, writes Okhubo himself, 'has been financed from donations by stakeholders and governmental funds.' An information leaflet of the organisation says: 'The JEIC is founded to present in a neutral way the positions of industry, science and society, and to discuss the risk analysis.' It seems to be no coincidence that industry is mentioned first.

Ohkubo did research funded by the Association of Radio Industries and Businesses (ARIB), Japan.

Margarethus Paulides

Biography

Margarethus ('Maarten') Paulides obtained his MSc in Electrical Engineering at Eindhoven University in 2002 and his PhD in Medical Electromagnetics

He works as Associate Professor, Department of Electrical Engineering, Electromagnetics, at the university of Eindhoven as well as Associate Professor, Erasmus Medical Centre in Rotterdam.

The outcome of his research were novel devices, patient-specific simulation technology and pioneering data and knowledge for improving EMF exposure guidelines.

Since 2015 he is board member of the Dutch National Antenna Research Framework (NARF). From 2017, he serves in the Electromagnetics Committee of the Dutch Health Council that advises the relevant ministers in the Netherlands on EMF related subjects. He also is a Management Committee member and Workgroup leader in COST action CA17115.

He is a Member of the ICNIRP Scientific Expert Group (SEG) since 2017.

Position

Most of his research is focussed on applications in health monitoring, disease diagnosis and therapy. We did not find much research on the health effects of radiofrequency radiation.

He did some research on thermal effects on tissue which resulted in this 2018 study in which the authors basically state that the protection levels of ICNIRP and IEEE are conservative and safe: “To protect against any potential adverse effects to human health from localised exposure to radio frequency (100 kHz-3 GHz) electromagnetic fields (RF EMF), international health organisations have defined basic restrictions on specific absorption rate (SAR) in tissues. These exposure restrictions incorporate safety factors which are generally conservative so that exposures that exceed the basic restrictions are not necessarily harmful.”

Possible conflicts of interest

According to the ICNIRP website he “also acts as advisor of start-up companies aimed at providing solutions for computer simulation and image guided interventions”.

His DOI further states that he does paid consultancy for a company Sensius.biz, which in fact he co-founded, for an amount of 5000€. He also owns 4,9% in stocks of this company.

The same amount he got from a German company Sennewald Medizin Technic.

He received a 45.000€ research Grant form General Electric Research Centre in Germany.

For the contracting company Phillips he received a STW research grant of 10.000€ in cash and 66.300€ in kind.

Kensuke Sasaki

Biography

Kensuke Sasaki is a Researcher of the National Institute of Information and Communications Technology, Japan.

He is a member of Subcommittee of EMF Dosimetry Modelling of IEEE International Committee on Electromagnetic Safety. He is also an expert for a committee of the International Electrotechnical Commission.

He joined the Scientific Expert Group in November 2018.

Position

Most publications of Sasaki are about how to measure the effects of non-ionizing radiation and about the thermal effects of it on for example the eye. We did not find direct statements about the health effects.

Possible conflicts of interest

For information about IEEE/ICES see Van Rongen.

Together with Hirata and Watanabe (see above) he conducted research published in *IEEE Transaction* in 2010 partly funded by KDDI Foundation.

David Savitz

Biography

Savitz is currently Professor of Epidemiology and Obstetrics and Gynecology, at the American Brown University.

His teachings and research is focussed mainly on epidemiologic methods and, reproductive, environmental, and cancer epidemiology and he authored a book entitled “Interpreting Epidemiologic Evidence”.

He was a member of the ICNIRP Standing Committee on Epidemiology from 1997 until 2012 and then became a member of the ICNIRP Scientific Expert Group (SEG) in 2013.

Position

Given the fact that he has been connected to ICNIRP for 23 years we can safely assume that he agrees with the position of this NGO on health effects of EMF.

Possible conflicts of interest

His Declaration of Interests statement to ICNIRP, says that he does paid consultancy but “non-relevant to ICNIRP”.

According to AVAATE this is not really true: “He gave expert witness testimony on behalf of the defendants in a January 2012 lawsuit in Federal District court in Portland, Oregon.”

A company AHM Wireless sued the Portland Public School System, because it called for the removal of a Wi-Fi system in the schools. The testimony of Savitz was requested to assess the expertise of plaintiffs' claims that the implementation of wireless devices and wireless systems in the schools could possibly cause cancer or other adverse health effects.

In court, he states that the purpose of his contract with Battelle was to investigate relationships between environmental agents and human health and that he had a variety of sponsors, including some federal government agencies and other groups that he does not recall at this time.

Remarkably when he is asked about his ICNIRP membership he said that doesn´t consider himself to be really an active member and that he contributed all those years to just four reports, together with Anders Ahlbom, who coordinated their advice work for ICNIRP and whom had also recruited Savitz to join ICNIRP (in 2011 was asked to step down from IARC panel after he was exposed to be on the board of his brother's consulting firm, which telecom clients). Savitz: "My understanding of the organization is really actually quite limited. My role in it has been much narrower to participate in the evaluation of evidence and the reporting of the results of that evaluation. I have not been involved in what's done with that evaluation."

When the lawyer of the public school asks "So the organization, though, it's involved with the protection of human beings from non-ionizing radiation; is that correct?" Savitz answers: "Again, my understanding is not much deeper than as you described it based on the name of the organization. My understanding is that they evaluate evidence and make recommendations that are intended to be protective of health."

When asked if he is paid to be part of scientific committees, he says that he remembers only travel expenses being reimbursed by ICNIRP. He says he doesn´t even remember how many scientific committees he belongs to. He wasn´t involved with what ICNIRP does in making decisions after it receives the results of the evaluation carried out by the Standing Committee on Epidemiology. He says that he has never read the ICNIRP Statutes, its mission, etc. He maintains that he is hired to help evaluate a particular line of research. Also, when asked if there was any relationship between ICNIRP and the WHO for the work in which he contributed to, he said he did not know.

It almost seems as if Savitz does not want to be remembered too much about ICNIRP and tries to distance himself from the NGO and its position. When the lawyer of the public schools asks "you would agree then that we need protection from non-ionizing radiation; is that correct?", Savitz answers: "Well, that's not something that I get involved in the technical judgment of the sort of guidelines or regulations or decision-making. If you're asking, obviously there are levels of exposure that I'm aware that can be harmful, so that I can understand in a general way that it makes sense that there be consideration of regulation."

AVAATE notes that "when asked whether he has been paid out of funds acquired from companies and/or telecom consultants and law firms that represent these companies, he replied that there are a few cases where he has done research funded by the electric utility industry. However, he emphasized that the funders tried to isolate his work from the source of funding. He says he once had done a study before realizing where the money came from."

Savitz also stated that he has done work sponsored by EPRI, as many ICNIRP members, which is funded by the electrical power industry.

There is no record of these kind of data in the Declaration of interests that he submitted to ICNIRP.

Karl Schulmeister

Biography

Karl Schulmeister is since 1994 head of the Laser, LED and Lamp Safety group at Seibersdorf Laboratories in Austria. On his LinkedIn profile he describes himself as 'Consultant on Laser and Optical Radiation Safety'.

He was a member of the ICNIRP Standing Committee on Optical Radiation in the period 2008-2012 and joined the Scientific Expert Group in March 2013.

Position

Karl Schulmeister is specialized in optical radiation. He did not perform research on the health effects of radiofrequency radiation.

Possible conflicts of interest

Seibersdorf Laboratories is a firm, not an academic institution. Schulmeister's group derives, according to his Declaration of Interest, about 10% of its income from paid consultancy.

Research for an article published in 2015 and a white paper published in 2016 received both the support of the Laser Illuminated Projector Association, which presents itself as "a single industry voice in rationalizing laser regulations".

David H. Sliney

Biography

Sliney serves as chair of the IES Photobiology Committee and holds a Ph.D. in biophysics and medical physics from the University of London, Institute of Ophthalmology. He worked for the US Army Public Health Center for 42 years, serving as Program Manager, Laser/Optical Radiation Program, until retiring in 2007.

Het still acts as Safety Director, American Society for Lasers in Medicine and Surgery; And he remains an associate faculty member of the Johns Hopkins School of Public Health, Department of Environmental Science and Engineering, Baltimore, MD.

He served as member, advisor and chairman of numerous committees that are active in the establishment of safety standards for protection against non-ionizing radiation (ANSI, ISO, ACGIH, IEC, WHO, NCRP).

He has been an ICNIRP Commission Member from the very start in1992 until 2004 and as Chairman of ICNIRP SCIV (optical radiation) from 1998 until 2004. He is a member of the ICNIRP Scientific Expert Group (SEG) since November 2017.

Position

Sliney has been mainly focussing on safety and health issues of laser lights, UV light or other sources, important for safety for medical staff who work with laser application in surgery and medicine. Also, scientists and military staff are risk groups for laser damage to the eye. We could not find research on the health effects of radiofrequency radiation.

Which does not mean that he is not involved in the scientific debate. In 2013 for example he participated in a webinar by the American Conference of Governmental Industrial Hygienists (ACGIH) on electromagnetic radiation.

In an article from 2017 on the history of of ICNIRP founder Mike Repacholi explicitly gives a special thanks to long-term INIRC and ICNIRP member David Sliney for his help with reviewing the article.

In a book from 2000 in 'the NATO Science Series' by B.Jon Klauenberg (US Air Force Research Laboratory) and also NATO-liaison, Sliney is described as "Dr Dave Sliney and army employee who serves on the ICNIRP". Klauenberg who in the first years led the WHO EMF Project together with Repacholi, is a prominent figure from the US Department of Defense (DOD) and describes it as follows: "Because the US military services operates globally and with many different national partners, uniformity of the RFR exposure standards is a desirable goal." He then describe the various ways that the DOD contributes to "worldwide standards harmonisation". So, the DOD participates in the WHO EMF project for example "through active engagement of US Air Force Research Laboratory as well as US army personnel providing service on the IEEE". And Sliney thus seems to be the US army representative in ICNIRP.

Possible conflicts of interest

His DOI is signed in 2019 but does not mention much.

Rianne Stam

Biography

Rianne Stam is senior scientist at the National Institute for Public Health and the Environment (Bilthoven, the Netherlands) since 2007. There she performs risk assessments and policy research on the biological effects and possible health risks of electromagnetic fields (EMF).

She is a member of the Scientific Expert Group since March 2013.

Position

Stamm made in 2015 and 2019 overview reports of the long term effects of electromagnetic fields on the health of workers. The conclusion: 'Scientific research has not yet proven any links between the exposure of workers and the occurrence of cancer, disorders of the nervous system or other illnesses in the long term.'

Possible conflicts of interest

According to her ‘Declaration of Personal Interest’ Stam has no possible conflicts of interest and we did not find any information that contradicts this.

Bruce Stuck

Biography

Bruce E. Stuck He is now retired. He was from 1992-2010, the Director of the U.S. Army Medical Research Detachment of the Walter Reed Army Institute of Research, where he had responsibilities for the Army Medical Department’s laser and radio frequency radiation biological effects research program. Until 2013 he was the Director of the Ocular Trauma Research Division at the U.S. Army Institute of Surgical Research in San Antonio, Texas.

Since 2012 Stuck is a part-time independent consultant on non-ionizing radiation bioeffects.

He has been a member of ICNIRP SC IV since 1999 and of the Commission from 2004 until 2016. Stuck is now supporting the work of the Project Group as a SEG member.

Position

His research focussed on laser and radio frequency radiation biological effects and “establishes protection strategies (e.g. exposure limits or physical protection products) and develops triage and treatment approaches for ocular injury from non-ionizing radiation and shock wave exposures from blast”. During his 32 years-experience in laser hazards research experience he was author/co-author of numerous papers on ocular and cutaneous effects of laser and radio frequency radiation. His primary interests are in the biological effects of visible and infrared laser radiation on the retina and cornea and the assessment of laser-induced eye injuries and their treatment.

Possible conflicts of interest

His DOI states that he is “a consultant to Perfect Lens, LLC on a proprietary project under a signed confidentiality agreement to provide advice and written assessment on biological exposure limits as applied to their repetitively pulsed fem to second laser application for use in medical application in the eye”. He delivered oral and written reports on the device hazard assessments. Income was less than 1% of personal income from his retirement annuity in 2018 tax year.

John Tattersall

Biography

John Tattersall **i**s scientist in the Defence Science and Technology Laboratory, a government Agency which provides research and advice for the UK Ministry of Defence and other government departments. He also is Honorary Senior Lecturer in Clinical Neurosciences at the University of Southampton.

He was a member of the IEEE International Committee on Electromagnetic Standards from 2012 until 2017.

He joined the Scientific Expert Group in March 2013.

Position

Twenty years ago, Tattersall did research that showed effects of RF Radiation on the brain of rats. *New Scientist* wrote: "Last year, fears about mobiles affecting brain function received fresh impetus thanks to work by John Tattersall and his colleagues at the Defence Evaluation and Research Agency's labs at Porton Down in Wiltshire. Tattersall exposed slices of rat brain to microwave radiation. He found that it blunted their electrical activity and weakened their responses to stimulation. Because the brain slices were taken from the hippocampus, a structure with a role in learning, the results were seized upon as further evidence that mobile phones could scramble human memories."

But according to later research these effects were artificial, "may be explained by localised heating produced by interaction of the RF fields with the recording and stimulating electrodes".

Tattersall was involved in the new guidelines that were published in 2020.

Possible conflicts of interest

For IEEE/ICES see Van Rongen and others.

Tim Toivo

Biography

Tim Toivo works as senior inspector for the Radiation and Nuclear Safety Authority STUK in Helsinki, Finland. He is mainly involved in regulatory, research and expert work in the area of safety issues of electromagnetic fields (EMF) and ultrasound.

He studied biomedical engineering at Tampere University of Technology 1996. And started his work at STUK–Radiation and Nuclear Safety Authority in 1998 as a scientist in the unit of non-ionizing radiation.

Part of his work is to inform users of EM fields and communicate with the general public about safety issues. He participated in the preparation of the EU directive (EU 2013/35/EU) as an expert for the Finnish delegation.

He is a member of the ICNIRP Scientific Expert Group (SEG) in February 2017.

Position

Toivo was quoted in the book 'Behind the Screen: Nokia's success story in an industry of navel-gazing executives and crazy frogs': "It is fairly easy to prove that something is hazardous, but it is extremely difficult to prove that something is totally safe under all circumstances. It may take 20-30 years before any meaningful results are available from people who have been exposed to low power radiation."

In 2009 STUK published a position that 'children's mobile phone use should be limited.

A publication in 2006 – 'Epidemiological risk assessment of mobile phones and cancer: Where can we improve?' - together with Anssi Auvinen, concluded that "the major opportunity to improve the quality of evidence is, however, through prospective studies. The major limitation of epidemiological studies addressing the health effects of mobile phone use is related to exposure assessment. These limitations are inherent in case–control studies."

A 2008, in Vitro study of Pulsed 900MHz GSM Radiation on human Spermatozoa showed no effect.

In a 2009 publication – 'Specific absorption rate and electric field measurements In the near field of six mobile phone base station antennas' - Toivo and colleagues seem to suggest that the ICNIRP safety standards are very conservative: "It was also shown that the ICNIRP basic restriction for local exposure could be exceeded before the basic restriction for whole-body exposure if the distance to the antenna is less than 240mm."

With several ICNIRP colleagues he published the 'Progress report: ICNIRP Statement on non-ionizing radiation for cosmetic purposes' for the IEEE. They concluded that "'for cosmetic devices using radiofrequency EMF and optical radiation, there is the potential that occupational exposure limits can be exceeded if adequate protection measures are not applied."

Possible conflicts of interest

Hid DOI states that he gets funds from ministries which go directly to the Radiation and Nuclear Safety Authority STUK.

Andrew Wood

Biography

Wood is Professor in Bioelectromagnetic Research Group at Swinburne University of Technology in Melbourne. He also is a Chief Investigator with the new Australian Centre for Electromagnetic Bioeffects Research (a centre to which Rodney Croft and Sarah Loughran are also connected).

Wood used to work at Telstra Research Labs and is now a leading researcher at Swinburne Radiofrequency Dosimetry Laboratory, which is a part of the Bioelectomagnetic Research

Group. Telstra is Australia's largest telecommunications company. Swinburne university and in particular the Radiofrequency Dosimetry Laboratory has close relationship with and is co-funded by Telstra, the biggest Telecom company in Australia.

The close working relationship between the Swinburne University and Telstra is not new, as Don Maisch pointed out: "In fact the Chancellor of Swinburne University, Mr. Bill Scales (2005-2014) was previously Telstra's Group Managing Director, Regulatory, Corporate and Human Relations, and Chief of Staff at Telstra. He was also Telstra's Director of IBM Global Services Australia Ltd. and a Director of the Telstra Foundation."

Wood was a member of the Radiation Health Committee of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) for over ten years.

He is a member of the Scientific Expert Group since March 2013.

Position

Wood does not see dangers of 5G and warns for being too cautious: "Wireless technologies bring enormous benefits, and being over-cautious would potentially deny these benefits to needy communities."

In a recent article he stated that studies which show health effects have a poor quality: "There are some comprehensive reviews of these, demonstrating that the quality of the studies is very variable, and that, for example, results claiming to show increased genetic damage or other biological effects are much more common in studies of low quality, whereas higher-quality studies predominantly show no significant effects."

Possible conflicts of interest

In a 2016 publication that gave an overview of the work Wood's group performed he and his co-authors wrote: "Over its 25-year history the Bioelectromagnetics Group has received support from national competitive grants and from industry research support schemes. It has been a node for both the Australian Centre for Radiofrequency Bioeffects Research (ACRBR) and the Australian Centre for Electromagnetic Bioeffects Research (ACEBR—see article in this edition). It has benefitted from industry collaboration and with national regulatory authorities."

The close collaboration with industry we see time and again. Just like the actual chair of the ICNIRP-commission Croft, Wood had actively collaborated with McKenzie, who is a manager at the Mobile Carriers Forum (MCF). See for more information the portrait of Croft.

In 2016, he published an article together with an employee of telecommunications company Telstra.

He has done contract work on the issue of smart meters for the private company EMC Technologies Pty Ltd.

According to his Declaration of Personal Interest he receives research support "from two engineers employed by Telstra Corp and one by the Australian Mobile Telecommunications Association."

Tongning Wu

Biography

According to ICNIRP's website Tongning Wu is a senior engineer in the Chinese Academy of Information and Communications Technology. His research focusses on electromagnetic dosimetry, anatomical modelling and biomedical applications of electromagnetic fields.

He is the member of International Advisory Committee (IAC) on Electromagnetic Fields of WHO. He also participated in the IEC/IEEE workgroups on EMF safety. He is currently the co-rapporteur of ITU-D Q7/2 (Strategies and policies concerning human exposure to electromagnetic fields).

He became a member of the ICNIRP Scientific Expert Group (SEG) in 2019.

Position

Wu agrees with the general ICNIRP assessment that "to date, no adverse health effects of the EMF, linked to these applications, have been established." This was also one of the conclusions of a study 'Electromagnetic fields (EMF) exposure' published in 2019.

In 2012 WU published a study on 'A large-scale measurement of electromagnetic fields near GSM base stations in Guangxi, China for risk communication'. The results were that "in general, the measurement mission promotes the science on EMF exposure among the general public. Risk-related public behaviours have been positively influenced. The mission also facilitates the cooperative conflict resolution. It helps strengthen the effectiveness of risk communication."

Possible conflicts of interest

His DOI gives no information.

See Van Rongen and others on the role of IEEE/ICES.

Annex I

Questions put to ICNIRP's secretariat

1 - When will the ICNIRP Annual report 2019 be published?

2 - Are the 14 members of the Commission being paid for their work for ICNIRP (for "representing ICNIRP externally and mostly in its relations with the international and national partners and the press" as well as for their collaboration on specific Projects?)

3 - Same questions as n° 2 go for the Scientific Expert group and the Project Groups?

4 - If they are not paid, do you consider this as a normal practice that international renowned experts work for free, especially given the importance and influence of the work of ICNIRP?

5 - ICNIRP itself claims it is "free of vested interests". ICNIRP's budget relies on support granted by public bodies; Why is the income not specified in your annual reports? Is it possible to get specifications from which public bodies you get which amounts?

6 Who selects the 14 members of the Commission and how?

7 - ICNIRP's statutes state: 'No member of the Commission shall hold a position of employment that in the opinion of the Commission will compromise its scientific independence'

Do we understand it correctly that basically the Commission evaluates itself about possible conflicts of interest? What are the rules by which the Commission judges if interests of the members compromise the scientific independence?

8- In its statement on the declarations of interests ICNIRP states: "The evaluation of personal integrity is very complex and might never be achievable in a perfect way. It is the duty of the ICNIRP Commission to carefully consider and decide if the declared interests potentially constitute a conflict of interest."

By which criteria or protocol are these considerations and decisions being made?

9- Do you consider the membership of IEEE ICES by some ICNIRP-members as a possible conflict of interests?

10- How do you explain the fact that a private organisation like ICNIRP, which is not accountable in democratic terms to anyone, has the position to de facto "determine" via guidelines the EMF policies of most EU member states?

Several attempts to get a reaction to

these questions remained unanswered'

Annex II

Questions put to emfproject@who.int

On your website, you write: "Because disparities in EMF standards around the world has caused increasing public anxiety about EMF exposures from the introduction of new technologies, WHO commenced a process of harmonization of electromagnetic fields (EMF) standards worldwide. With 54 participating countries and 8 international organizations involved in the International EMF Project, it provides a unique opportunity to bring countries together to develop a framework for harmonization of EMF standards and to encourage the development of exposure limits and other control measures that provide the same level of health protection to all people. "

1 - Is there a time schedule for this process of harmonization of electromagnetic fields (EMF) standards worldwide?

2 - We see on your website that the last EMF -WHO meeting took place in 2018. Are there any new meeting planned and if yes when?

3 - Do you know what IARC is currently working on and if so when will IARC publish an update of the monograph?

https://publications.iarc.fr/Book-And-Report-Series/Iarc-Monographs-On-The-Identification-Of-Carcinogenic-Hazards-To-Humans/Non-ionizing-Radiation-Part-2-Radiofrequency-Electromagnetic-Fields-2013

4 - How do you consider the debate on "conflicts of interests" in this specific research area? Would you agree that there has been and still is a lot of attention for this debate? Has his debate been useful in narrowing the divide in the scientific community? What is in your view the role of the WHO on this?

(see for example this recent letter published in "Bioelectromagnetics": https://onlinelibrary.wiley.com/doi/full/10.1002/bem.22225)

These questions remained unanswered

The International Commission on Non-Ionizing Radiation Protection: Conflicts of interest, corporate capture and the push for 5G

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Review Article

Increased Generational Risk of Colon and Rectal Cancer in Recent Birth Cohorts under Age 40 - the Hypothetical Role of Radiofrequency Radiation from Cell Phones

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Abstract

To determine if there are shifts in patterns of cancer, rates of disease can be evaluated in terms of Generational Risk (GR), comparing those born recently with those born decades earlier. Using data from the U.S. Centers for Disease Control and Prevention (CDC), the U.S. Surveillance Epidemiology and End-Results (SEER) Program and Iranian cancer registries, increases in GR of colon and rectal cancer in those under age 50 are presented. For the U.S. those born in the 1990s have a doubled risk of colon cancer (GR=2) and a fourfold increase in rectal cancer (GR=4) by the time they reach age 24 compared to those born six decades ago. Experimental studies have determined that the colon and rectum of Sprague-Dawley rats are exquisitely sensitive to both ionizing and non-ionizing radiofrequency radiation (RFR), expressing significant differences in patterns of methylation of a number of well-identified proteins and other biomarkers predictive of cancer risk. Modeling of nonionizing exposures also indicates that absorption of RFR into the colon and rectum from cell phones stored in the pocket exceeds current test limits by up to 5-fold. French government tests of phones positioned next to the body report exposures to non-ionizing radiation that are up to 11 times more than current guidelines. Based on these findings, it is prudent to develop policies to reduce direct exposures to RFR from cell phones, as occurs when they are kept next to the body, and to promote advances in hardware and software that reduce direct exposures to RFR.

Keywords: Computerized tomography, Radiofrequency radiation, Colo-rectal cancer, Cell phones, Generational risk

Abbreviations: ALARA: as Low as Reasonably Achievable; CDC: Centers for Disease Control; CRC: Colo-rectal Cancer; CT: Computerized tomography; GR: Generational Risk; GSM900: Global System for Mobile Communication; RFR: Radiofrequency Radiation; RAR: Retinoic Acid Receptor; SEER: United States Surveillance Epidemiology and End-Results Program; US: United States

Colorectal cancer (CRC) is the third most common cancer in the world, and the fourth leading cause of cancer deaths, with about 700,000 estimated annually [1].While incidence is greater in developed nations, deaths from the disease are more common in rapidly developing nations that lack the infrastructure to fi d and treat the disease. As with most types of cancer, rates of CRC increase with age. The disease remains relatively rare in young persons. While there has been a major increase in incidence globally [2,3]. Overall rates are dropping in the U.S. and Europe [1], but not all age groups share in that decline. The proportion of persons under age 50 diagnosed with the disease has doubled since 1990, from 6% to 13% in 2017.

Epidemiological studies have identifi d a number of specific risk factors for CRC including obesity, inactivity, diets high in red and cured meat, alcohol, smoking, and other factors [4]. Tremendous changes of dietary habits have occurred in both the developed and the developing world during the last decades. Recorded overall declines in CRC in those over age 50 in the U.S. and elsewhere are generally attributed to improvements in screening with colonoscopy and other procedures and do not refl ct reductions in these known risk factors. Surgical removal of pre-cancerous polyps is believed to account for much of the decline in CRC in the elderly. While improvements in access to care and increases in diagnostic ascertainment may in part account for these continued declines in the elderly, they are unlikely to account in any signifi ant way for increases that occur in those under age 50 in whom screening is neither recommended nor conducted. Inherited germ-line mutations, such as Lynch syndrome, are responsible for about 5% of all disease [5].

Th s review fi st explores trends in Generational Risk (GR) of CRC in order to document patterns in younger and older persons [5]. Secondly, potential explanations for these patterns are investigated, concentrating on the increase in exposure to non-ionizing radiation that has occurred world-wide, including the young. Finally, prudent precautionary policies in the light of these fi dings are advised.

We examined colon and rectal cancer incidence data from the national cancer registry of the U.S., the U.S. Centers for Disease Control and from the Iranian national cancer registry. Patterns were evaluated for secular time trends and in terms of birth cohorts, using established methods for determining GR, contrasting incidence in those born after 1990 with those born before 1950. Novel toxicological investigations of CRC cells response to ionizing and non-ionizing radiation are also presented as they provide clues regarding possible etiologic factors that could underlie these patterns of disease and inform policies aimed at reducing risk factors.

Figure 1 reveals contrasting patterns of CRC cancer for older and younger Americans. There are major declines in incidence of CRC in those over age 54, in whom 90% of all CRC occurs. In contrast, a countervailing pattern is evident in those born after 1950, with a marked increase in the past two decades of CRC incidence in those born in 1970 or later compared with rates in those under age 40 in the past two decades. Employing the GR model we conclude that by the time they reach age 24 those born after 1970 are developing more than four times more rectal cancer (right side of figu e) and twice the rate of colorectal cancer (left side of fi -ure) compared to those born before 1940. Because the numbers of cases are quite small, the standard deviation in the rates will be considerable for those in their twenties. Nonetheless, the sharp increase in rates for younger birth cohorts in whom improved access to diagnostic technology is not a likely factor signals that there is a real underlying surge in CRC underway in the young. Siegel, et al. [6] recently evaluated patterns of colon and rectal cancer in the U.S. in the 4 decades up to 2013. They found that in contrast with the modest annual increases in colon cancer of less than 1% annually for all age groups under age 55, trends in incidence of rectal cancer are considerably greater with rates growing most rapidly and sharply in those ages 20-29 in the past decade. Specifically, rectal cancer incidence rates increased annually 3.2% from 1974 to 2013 in adults age 20 to 29 years, but more recently grew 4.0% annually. In contrast, for that age 55 and over rates generally declined throughout the entire 40-year study period. Similar fi dings have been reported from Europe and Iran [7,8].

Patterns of CRC in Iran (Figure 2) are illuminating as they indicate that for both men and women of all ages, incidence has recently risen sharply, from about 2 per 100,000 in 2000 to more than 8 and 10 per 100,000 respectively in females and males, an increase of 4 to 5-fold. Moreover, combined rates of colon and rectal cancer have risen from 5 per 100,000 in 2001 to more than 20 per 100,000 in males in 2011. In Iran, surgeons are reporting more cases of the disease in younger patients (Masood Sepephrimanesh, personal communication).

In an effort to determine whether radiofrequency radiation could be affecting rates of CRC, Iranian scientists from the Ionizing and Non-ionizing Radiation Protection Research Center of Shiraz University of Medical Sciences have reported on a series of basic research studies where they devised, validated and evaluated special chemical fi gerprints for relevant cellular patterns by staining genetic and epigenetic factors associated with CRC carcinogenesis. The biochemical elements they examined include the estrogen receptor, and genes believed to be critical to inflammatory processes, including COX2, APC, MINT, and MLH1 gene promoters that may represent early stages of colorectal carcinogenesis [9,10]. The grounds for incorporating and examining these biological indicators derive from several studies that have found that a number of these well-identifi d proteins are hypermethylated in CRC: ER alpha and MYOD, p53 the cell cycle regulatory gene, cyclin A1, UDP-glucoronosyl transferase and retinoic acid receptor. Thus, it is possible that alterations in patterns of methylation in these genes may well constitute an early biomarker of colon carcinogenesis [11] and are considered by several investigators to be prognostic for a high risk of CRC malignancy [12]. A number of additional studies have recently confi med that methylation of ERα, MYOD, MGMT, SFRP2, P16, APC, DCC, MINT, COX2, HLFT, SOCS1, and hMLH1 gene promoters appear to have critical functions for the onset of colorectal carcinogenesis [9,10].

Mokarram, et al. [13] compared epigenetic patterns of ERα after exposure to ionizing radiation, with those occurring after exposure to non-ionizing radiofrequency radiation. Their innovative study employed biomarkers that have previously been established to signal damaging exposures to ionizing radiation, especially γ-rays. All groups studied in this experiment had methylated ER allele, while the un-methylated band varied considerably. While all of the control group displayed un-methylated bands, not one of the rats exposed to either radiofrequency or gamma radiation had any such bands. Th s indicates that methylation patterns may constitute an important validated biomarker of exposure to radiofrequency radiation that has the potential to play a role in the expression and promotion of CRC.

Recently, DNA hyper-methylation has been identifi d as a vitally important potential biomarker of cancer risk that can be used to predict rates of recurrence and advance of the disease and can be a signal property of several forms of cancer [11]. Hypomethylation of DNA may also control gene expression and chromosomal stability. Thus, ER alpha and MYOD, p53 the cell cycle regulatory genes, cyclin A1, UDP-glucoronosyltransferase and retinoic acid receptor are hypermethylated in CRC and also can be found in early stages of the disease [11]. Several investigators now consider that the methylation status of the ER promoter in the lymph nodes constitutes a valid biomarker for the development of advanced malignancy in CRC patients with stage I and II colon cancer and can be used to indicate the likelihood of disease progression [12].

The Iranian experimental study is important because as they note: "For the fi st time, our data showed that the effect of exposure to mobile phone radiation and 3Gy gamma radiation are the same and both of them could decrease the U-allele in the treated colon tissues of rats compared to the controls (p=.000)."

Further support for altered DNA methylation patterns as predictors of CRC comes from Dong and Ren [14]. They note that CRC results from a multi-stage, multi-causal process, refl cting the combined impacts of a variety of genetic and epigenetic changes in CRC cells that can be signaled through epigenetic alterations in blood. Using the Food and Drug Administration approved Virtual Family 3-dimensional, anatomically-based modeling of exposures to non-ionizing radiofrequency radiation carried out by the National laboratories of the Federal University of Brazil in Porto Alegre also indicates signifi ant absorption of non-ionizing radiation takes place within the pelvic area from phones stored in the pants pocket of men, with male reproductive organs absorbing the highest levels. The pelvis has a high dielectric constant and permittivity, because it is mostly soft tissue and fat, lacking the dense bone of the skull. As a result, radiation can be more deeply

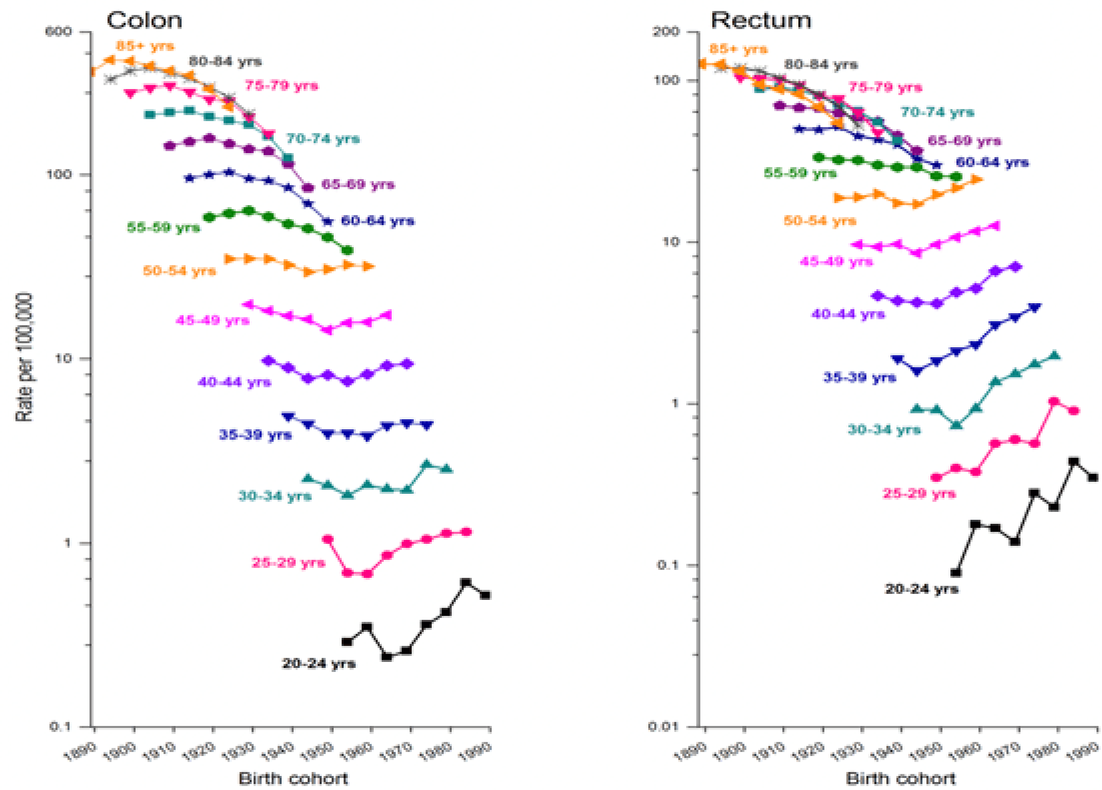

Figure 1: U.S. Trends in Age-Specific Colon and Rectal Cance Incidence Rates.
Source: R.L. Siegel, et al., JNCI, Vol 109, 2017 – Supplementary Figure 4

absorbed into the pelvis as compared with the brain.

Despite general declines of rates of CRC in developed nations, especially in those over age 54, puzzling and substantial increases have been reported in younger persons in the U.S. and Iran [6-8]. Similar increases have been noted in Canada [15]. Population-based screening in developing nations is not widely conducted, so this cannot account for much of the reported increase in the disease in younger persons in Iran. It is important to appreciate that the underlying and distinctly diverging secular trends in colon and rectal cancer reported by these authors began decades before cellphones were widely in use. Screening certainly has played a role in the continuing decline in CRC in the elderly. But as to the unexplained relatively recent increases in the young, it is important to consider a number of potentially relevant causal factors that have changed in the past two decades. These include obesity and physical inactivity, increased exposures to HPV, HIV, and other viral factors, diagnostic radiation from computerized tomography and non-ionizing radiofrequency radiation (RFR) from cellphones, laptops, and other devices.

Belyaev [16] has noted that ionizing and non-ionizing radiation have a number of distinct properties including, polarity, wave form, power density, and frequency and that their importance to biological systems can vary with temperature, host conditions and other factors that are not always well-controlled in various studies of non-ionizing radiation. The GSM900 (Global System for Mobile Communication) includes 124 different channels/frequencies. They differ by 0.2 MHz in the frequency range between 890 MHz and 915 MHz. Depending on the number of connected users op-

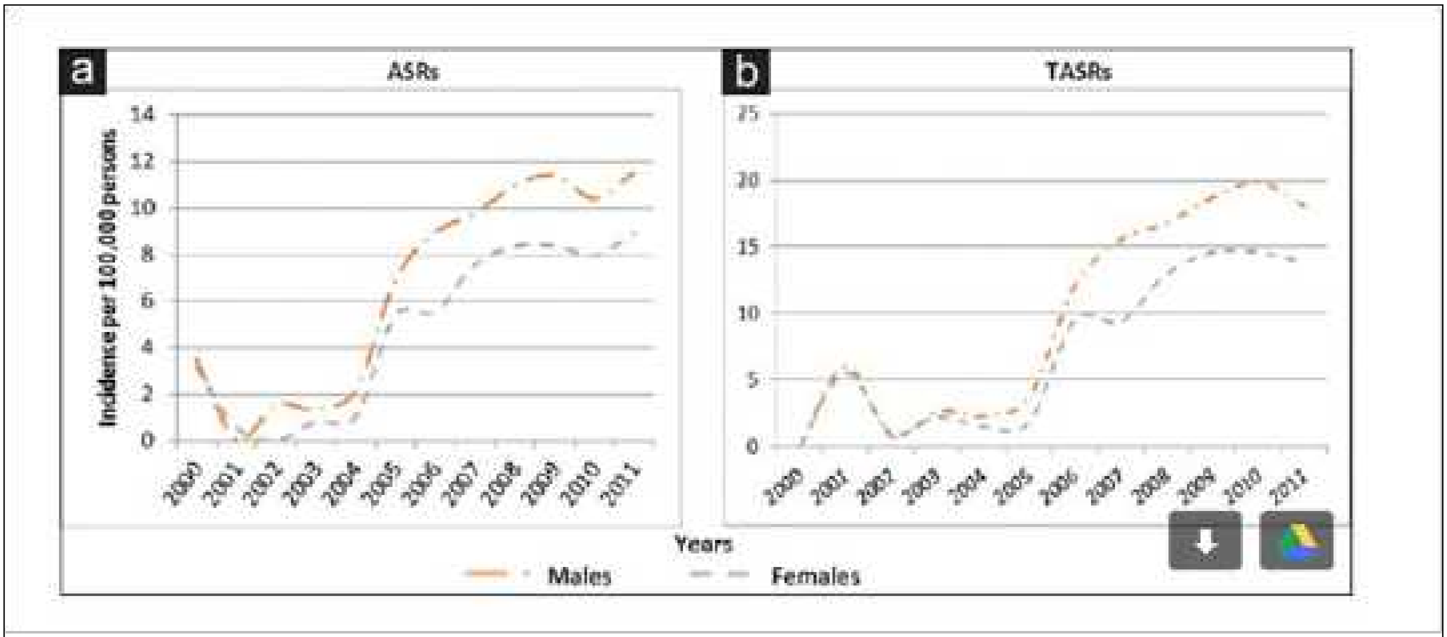

Figure 2: Trends in Age-Standardized Rates of Colorectal cancer in Iran 2000-2011. Source Dolatkhah, et al. [7]

erating at any one time, frequency is supplied by a base station to a mobile phone user and can be automatically changed to another frequency during the same call. Belyaev [16] also reports that contrary to differentiated cells, human mesenchymal stem cells do not adapt to effects of microwaves during chronic exposure. These results also suggest that less mature and differentiated cells, such as are more common in the young, may be more susceptible to proliferative responses.

When cell phones are stored next to the body, their four to six or more antennas continue to send signals to towers or hotspots up to 900 times a minute in search of an electronic handshake to maintain connectivity, especially when they are being employed when in motion. Because antennas are on the backs and sides of smartphones, keeping cell phones turned on in the pocket subjects users to frequent microwave radiation bursts. Putting cell phones on airplane mode eliminates exposures to radiofrequency radiation.

Both experimental and epidemiological evidence supports a role for RFR from cell phones in the pocket or laptop exposures. Avendaño, et al. [17] found that human sperm samples exposed ex vivo to levels of RFR from conventional laptops at a distance of 3 cm that were specially shielded not to produce battery heat developed signifi antly more genetic and epigenetic damage after 4 hours of continual downloading and uploading to simulate intense game-playing, video watching or other activities. Damage to human spermatozoa for 4 hours affected quality and quantity signifi antly--3-fold greater damage in exposed sperm in contrast to unexposed controls. These results are similar to those Houston, et al. [18] reported with in vitro studies of human sperm that found signifi ant evidence of such damage as oxidative stress, including the DNA damage marker, 8-hydroxy-2'-deoxyguanine as well as sperm fragmentation.

For the next decade it is expected that cell phones will need to rely on 3G and 4G for voice communications, even if 5G becomes available for speedier downloading movies, games, virtual reality and videos. It is important to point out that although absorption of faster, shorter millimeter waves of 5G alone will be superficial compared to earlier generations of 2G and 3G that reached 2 inches into the brain and much more deeply into the pelvis, there are growing concerns that these higher frequencies can produce unique biochemical reactions just below the surface of the skin that effectively transform them into more powerful systemic impacts on the immune system. Although millimeter wave exposures are absorbed into 1/64 inch of human skin, the beam-forming erratic properties of 5G signals may prove highly biologically reactive. It is possible that the sweat ducts in the human body will act as helical antennas, directing the millimeter waves deeper into the body, serving effectively as wave guides [19]. Moreover, some technologists have reported that, contrary to marketing claims that 5G is essential for autonomous vehicles, beam-forming properties are neither reliable nor easily controllable, and 4G systems are quite adequate to that task. Writing in a trade publication, technology writer and former industry executive, Desjardin [20], acknowledges that with respect to 5G no one has addressed questions of potential biological impact of complex modulation of 5G at 28.375 GHz, combined with 77 GHz from automotive radar, and 5.9 GHz from automotive infrastructure.

In addition, in considering the possible role of contemporary exposures to cellphone radiation for these unexplained patterns of CRC, it is important to consider recent reports from the French government frequency testing agency (ANFR) that most cell phones emit substantially more radiation than current test limits advise. Using FCC approved methods to conduct the testing, the agency found that 9 out of 10 phones exceeded the safety guidelines when held against the body by factors of 1.6-3.7 times for the European standard or by factors as high as 11 if 1-g SAR values were to be measured as required by the U.S. FCC [21].

Other exposures that appear relevant to these puzzling patterns of CRC include the greatly expanded use of pediatric diagnostic computerized tomographic (CT) scans. Brenner and Hall [22] estimated that a signifi ant proportion of young adult cancer in the future would refl ct CT practices that began in the 1980s, when the younger birth cohort was born. At that time, Brenner and Hall [22] reported that approximately 600,000 abdominal and head CT examinations were conducted annually in the United States on pediatric patients under the age of 15 years. Brenner and Hall [22] estimated that approximately 500 children might ultimately die of cancer attributed to CT radiation. By 2016, the number of CT scans conducted on both children and adults increased signifi antly to about 82 million. Although the average dose per procedure had declined, the average diagnostic radiation dose per individual has more than doubled since 1980. Currently, Americans, especially children, receive more ionizing radiation exposures from diagnostic radiation than from natural sources. The excessive use of this technology especially with infants and children led the American College of Pediatric Radiology to issue a white paper in 2007, urging that technologists be mindful of the need to keep pediatric exposures, As Low As Reasonably Achievable (ALARA). While current practices may reduce ionizing radiation overall, past scenarios involved emergency room physicians ordering repeat CT, even whole-body CT, where abuse was suspected.

Some recent evidence corroborating concerns about the long-term impacts of CT scans was provided by a retrospective study of 168,394 Dutch children that had undergone one or more CT scans, with those receiving the highest radiation having the greatest risk of brain tumors [23]. Another investigation in the UK, found that those under age 22 that underwent CT scans between 1985 and 2002 had greater risks of developing both brain cancer and leukemia [24].

In considering other known risk factors for CRC, such as obesity and inactivity, it is instructive to note that changes in these propensities have not changed as much as the rates we report here. Thus, obesity in adults 20-74 has more than doubled since 1979 and was 35% greater in 2014 [25]. However, because the latency for colorectal cancer is thought to be a decade or longer, changes in obesity are unlikely to explain much of the recent surge.

The studies reviewed here confi m statistically signifi ant and unexplained patterns of increase in CRC in younger persons. As a multi-factoral, multi-causal disease, cancer has numerous causes. While germ line mutations are relevant in about 5% of all cancer cases [26], the bulk of CRCs stem from acquired mutations that arise as a consequence of interactions with xenobiotic agents. The appearance of increased rates of this disease in younger persons is a matter that merits the most serious concern. Improved screening or use of technologies to increase diagnostic ascertainment such as improved imaging and greater access to endoscopy as well as general improvements in health care in this younger age group seem unlikely to account for these patterns.

We suggest two plausible contributing factors underlying these unexplained increases in CRC in the young—increased exposures to RFR from cell phones and laptops and/or increased exposures to ionizing radiation through CT scans. While obesity and inactivity are also important considerations, changes in these factors cannot in and of themselves account for the changes reported here. One of the attractive aspects of these proposed risk factors is that they can be easily addressed through education of health professionals and the general public, unlike lifestyle determinants such as diet and exercise.

The possibility that RFR and/or CT exposures in childhood could contribute to CRC in young adults should be accorded prompt attention. Methylation patterns in CRC are similar for both ionizing and non-ionizing radiation. Anatomically-based modeling investigations confi m that exposures to the colon and rectum appear to be quite substantial from cell phones held next to the body (in the pocket) and French test data show that typically cell phones emit many-fold more RFR than current test guidelines allow. Thus, it appears prudent to promote policies to reduce exposures to radiofrequency radiation and encourage ALARA during pediatric CT procedures, while continuing to promote advances in software and hardware of phones and scanners that can lower exposures to non-ionizing radiation during normal operations. In addition, major public educational programs should be developed to promote awareness of the need to practice safer technology, especially for the young, who may well be at greater risk of developing cancer due to their immunological immaturity.

The authors declare that they have no confli ts of interest in relation to this review.

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Health Matters

Science, Politics, and Groupthink

■ James C. Lin

The onset of the COVID-19 coronavirus in early 2020, lasting through the end of the year and beyond, has undoubtedly rendered 2020 incredible in many ways. COVID-19 has caused a devastating global pandemic with rapidly increasing case counts and deaths. Globally, the numbers of confirmed cases and fatalities exceed 83,113,878 and 1,812,218, respectively. In the United States, there were 19,821,487 confirmed cases and 343,818 deaths as of the end of 2020 [1]. It boggles the mind how COVID-19 descended into a conspiracy theory, pitting politics against science while millions of lives have been lost and so many more have pointlessly suffered from grief and pain. It does not seem to make sense.

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Why? Is it because science got wrapped up in politics, or is it politics interfering with science? Perhaps, the better or more practical questions are how much politics should be influenced by scientific findings and whether politics should intervene when science upsets the established political order enough to justify governmental action. These questions are not new or groundbreaking.

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Nicolaus Copernicus, a 16th century Polish astronomer, set forth the revolutionary view that Earth revolved around the sun and proposed a model of the universe that places the Sun rather than Earth at the center of the universe. Approximately a half-century later, Galileo turned his telescope to the heavens and saw the Milky Way with its numerous stars and the pockmarked surface of the moon and recognized that Jupiter has four moons of its own. Galileo traveled to Rome to meet with church leaders to present his discoveries supporting Copernicus' revolutionary view and to make the case for heliocentrism—that Earth moved around the Sun.

Instead, Galileo was condemned by the Holy Office of the Inquisition as heretical for holding the belief that the sun is the center of the universe, which was considered false and contrary to the Sacred and Divine Scripture. It was a dangerous idea, and one that cost Galileo his freedom. He was sentenced to imprisonment, followed by confinement for the rest of his life.

One may shrug off these ancient and modern incidents as episodic and proclaim them as absurd: to paraphrase *Ecclesiastes* 1, "Nothing is new under the Sun. Make no mistake, if it has not been found, it is there to be discovered; if it has not happened, it will only be a matter of time."

Fast forward to the 21st century, when, in 2011, the World Health Organization's International Agency for Research on Cancer (IARC) classified exposure to RF radiation as 2B—a possible cancer-causing agent to humans. The IARC had evaluated the then-available scientific studies and, although evidence was incomplete and limited (especially regarding results from animal experiments), concluded that the epidemiological studies of humans reported increased health risks for long-term users of cellular mobile telephones. These risks included gliomas (a type of malignant brain cancer) and acoustic neuromas (or acoustic schwannomas—a nonmalignant tumor of the auditory nerves on the side of the brain). This evidence was sufficiently strong to support a classification of exposure to RF radiation possibly being carcinogenic for humans [2], [3].

In 2018, the National Toxicology Program (NTP) of the U.S. National Institute of Environmental Health Science (NIEHS) reported observations of two types of cancers in laboratory rats that were exposed, for their entire lives, to RF radiation used for 2G and 3G wireless cellular mobile telephone operations [4], [5]. This is the largest health-effect study ever undertaken by the NIEHS/NTP for any agent. A 12-member peer review panel of independent scientists convened by NIEHS/NTP evaluated the toxicology and carcinogenesis studies and concluded, among other observations, that there was statistically significant and "clear evidence" that the RF radiation had led to the development of malignant schwannoma in the heart of male rats.

Shortly after the NTP report, the Cesare Maltoni Cancer Research Center at the Ramazzini Institute in Bologna, Italy, published the results from its comprehensive study on carcinogenicity in rats with lifelong exposure to 2G/3G 1,800-MHz RF radiation [6]. The study involved whole-body exposure of male and female rats under plane-wave equivalent or far-zone exposure conditions. A statistically significant increase in the rate of schwannomas in the hearts of male rats was detected for 0.1-W/kg RF exposure. It is critical to note that the recent NTP and Ramazzini RF exposure studies presented similar findings about heart schwannomas and brain gliomas. Thus, two relatively well-conducted RF exposure studies, employing the same strain of rats, showed consistent results of significantly increased cancer risks from mobile phone exposures.

Recently, a privately constituted group, with self-appointed membership, published a set of guidelines for limiting exposure to RF electromagnetic fields in the 100-kHz and 300-GHz frequency range [7]. The proposed guidelines were primarily based on the tissue-heating potentials of RF radiation to elevate animal body temperatures to greater than 1° C. While recognizing that the two aforementioned studies used large numbers of animals, best laboratory practice, and animals exposed for the entirety of their lives, the private group preferred to quibble with alleged "chance differences" between treatment conditions and the fact that the measured animal body core temperature changes reached 1° C, implying that a 1° C body core temperature rise is carcinogenic, ignoring the RF exposure. The group then pronounced that, when considered either in isolation or within the context of other animal carcinogenicity research, these findings do not provide evidence that RF radiation is carcinogenic.

Furthermore, the group noted that, even though many epidemiological studies of RF radiation associated with mobile phone use and cancer risk had been performed, studies on brain tumors, acoustic neuroma, meningioma, and parotid gland tumors had not provided evidence of an increased cancer risk. It suggested that, although somewhat elevated odds ratios were observed, inconsistencies and limitations, including recall or selection bias, precluded these results from being considered for setting exposure guidelines. The simultaneous penchant to dismiss and criticize positive results and the fondness for and eager acceptance of negative findings are palpable and concerning.

In contrast, the IARC's evaluation of the same epidemiological studies ended up officially classifying RF radiation as possibly carcinogenic to humans [2], [3].

An understandable question that comes to mind is this: How can there be such divergent evaluations and conclusions of the same scientific studies? Humans are not always rational or as transparent as advertised, and scientists are not impervious to conflicts of interest and can be driven by egocentric motivations. Humans frequently make choices and decisions that defy clear logic.

Science has never been devoid of politics, believe it or not. Here are a couple of cases in point.

Most people would readily say that the brilliant, celebrated Albert Einstein was a Nobel Laureate, having received the prize in physics. When asked about the subject of his research or scholarship, the default answer is "the theory of relativity" or "his observation of energy and mass being interchangeable (i.e., $E = mc^2$)." The response would rarely be otherwise. In fact, Einstein received his Nobel Prize in 1922 "for his services to theoretical physics, and especially for his discovery of the law of the photoelectric effect." Today, no knowledgeable physicist would dispute that Einstein deserved the Nobel Prize for his discovery of the photoelectric effect [9]. There lies the rub or paradox.

Among the many theories that Einstein had reported in the previous

17 years, his 1905 paper on photoelectric effect was a relatively minor contribution at the time, and it was the theory least accepted by contemporary theoretical physicists.

Cellular mobile communication and associated wireless technologies have proven, beyond any debate, their direct benefit to humans.

During the selection process in 1921, the Nobel Committee for Physics decided that none of that year's nominations met the criteria as outlined in the will of Alfred Nobel. However, Einstein was so renowned by that time that their failure to award him the prize had become an embarrassment. So the selection was a political decision by the Nobel Committee, most notably revealed by the insertion of "for his services to theoretical physics" as a telltale in the award citation. Regardless, the Nobel Committee exhibited courage and made amends for a major error.

The Nobel Prize in Physiology or Medicine for 2003 was awarded jointly to Paul Lauterbur and Peter Mansfield [10] "for their discoveries concerning magnetic resonance imaging." The award recognized the two Laureates' pioneering contributions, which led to the application of magnetic resonance imaging (MRI) in medical diagnostics and research. The discovery was a breakthrough in radiology, based on noninvasive and nonionizing radiation. MRI has significantly improved the diagnosis of numerous diseases and reduced risk and discomfort for patients. The announcement also led many to notice the absence of Raymond Damadian for his share of the Nobel Prize [11], [12].

Published records show that Damadian conceived of noninvasive magnetic resonance scanning, discovered tissue proton relaxation and density differences that are crucial to MRI, and achieved the first human whole-body images. Lauterbur devised methods to reconstruct 2D images a year later. Mansfield developed a faster pulse-sequence technique that differed from Lauterbur's reconstruction method a couple of years later. It appears unequivocal that all three scientists made important contributions in launching medical MRI. Why, then, was the Nobel Prize awarded to two of them?

There was apparent disciplinary allegiance, or groupthink, within the magnetic resonance research community. Science got wrapped up in politics and interfered to label the earlier contributions as insignificant or less consequential. Unfortunately, this time, the Nobel Committee managed neither to either confront nor mitigate a needless dispute.

Biases can impair rational judgment and lead to poor decisions. Emotions can keep humans from being rational and prevent us from arriving at obvious conclusions. At times, humans systematically make choices and decisions that defy clear logic. Regrettably, the herd mentality or groupthink is as rampant today as ever.

Some years ago, I commented, "Science has become partisan. And the corollary, if science becomes partisan, is it science or politics, or would it be political science?" [8]. Perhaps, it is simply a matter of the willing being politically correct.

When decisions are not arrived at by prudently balancing the facts or are made via impaired rational judgment, it could lead to poor decisions through biases. Sometimes, such poor decisions may impact only a small number of individuals. However, in cases like COVID-19, millions of people may suffer the unjust and needless consequences.

Cellular mobile communication and associated wireless technologies have proven, beyond any debate, their direct benefit to humans. However, as for the verdict on the health and safety of billions of people who are exposed to unnecessary levels of RF radiation over extended lengths of time or even over their lifetimes, the jury is still out. When confronted with such divergent assessments of science, the ALARA—as low as reasonably achievable—practice and principle should be followed for RF health and safety.

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Regarding ICNIRP'S Evaluation of the National Toxicology Program's Carcinogenicity Studies on Radiofrequency Electromagnetic Fields

Dear Editor:

IN THE International Commission on Non-Ionizing Radiation Protection (ICNIRP) note (ICNIRP 2019) on the evaluation of the recent carcinogenicity studies of radiofrequency electromagnetic fields (RF-EMF) in experimental animals, the authors made several incorrect statements that appear to be written to justify retaining exposure standards that were established more than 20 y ago. In fact, the ICNIRP note concludes, "…if the research was shown to have relevance to humans, this would represent a crucial issue for ICNIRP to incorporate into the advice and guidance that it provides to the community through a range of formats, such as its RF EMF exposure guidelines." This correspondence focuses on correcting ICNIRP's false claims about the methodology, interpretation, and relevance of the National Toxicology Program studies on cell phone RF radiation (NTP 2018a and b). Several issues raised in the ICNIRP note were addressed by Melnick (2019) and in the NTP response to the initial reviews of the cancer findings in rats that are included in the NTP report of partial findings of the carcinogenesis studies of cell phone radiofrequency radiation (Wyde et al. 2016) but were ignored in the ICNIRP note.

ICNIRP wrongly claims that methodological issues "preclude drawing conclusions about carcinogenicity" from the NTP studies on RF radiation

Pathology review procedures

The NTP has provided results on the carcinogenicity of approximately 600 environmental and occupational agents. These results have been used by IARC (International Agency for Research on Cancer) and other public health agencies throughout the world to assess human risk and set health-protective exposure standards. The three-tier pathology review process is the most rigorous approach used by any research organization to identify neoplastic and non-neoplastic lesions associated with exposure to a test agent. The ICNIRP note claims that because the initial pathology examination was not blinded as to the dose group in which slides were read, there were biases in these histopathological evaluations. However, the NTP's pathology review process involves much more than "samples where pathology was found (i.e., only a few percent of the total number) were then analyzed by another pathologist who was partially blind to the exposure status." For all NTP studies, an independent quality assessment pathologist (second tier) reviews all lesions identified by the laboratory pathologist plus 10% of all remaining tissues. The reviews of the histopathology slides and final diagnoses of lesions in the RF radiation studies were made by pathology working groups (third tier involving over 30 pathologists). The latter reviews were conducted similarly to all other NTP studies in that the pathologists did not know whether the slides they were examining came from an exposed or an unexposed animal (Maronpot and Boorman 1982). In fact, the reviewing pathologists didn't even know that the test agent was RF radiation. The assertion by ICNIRP, which has never been made in the 40-y existence of the NTP, impugns the validity of all 600 bioassays performed by this program. However, for anyone questioning the diagnosis of any tissue in this study, unlike most other institutional studies, all of the slides from the NTP studies are available for examination at the NTP archives.

Rat survival rates

The ICNIRP note states "…that survival was lower and mortality faster in the male rat controls than in the exposed groups" and, therefore, "There remains a strong possibility that the decrease in survival resulted in underrepresentation of late-developing tumors in the controls that importantly affected the statistical results." However, as explained by Melnick (2019), this comment is an inaccurate portrayal and interpretation of the data for at least two reasons: (1) there was no statistical difference in survival between control male rats and the exposure group with the highest rate of gliomas and heart schwannomas (CDMA-exposed male rats, SAR = 6.0 W kg^{-1}), and until week 93 of the 2-y study, survival was greater in control male rats than in the 6 W kg^{-1} CDMA-exposed male rats [the mean survival for male rats in the 6 W kg^{-1} CDMA exposure group (637 d) was actually 5 d less than that for control male rats (642 d) (NTP 2018a)]; and (2) no glial cell hyperplasias (potential precancerous lesions that can progress to a malignant glioma) or heart schwannomas were observed in any control rat, even though glial cell hyperplasia was detected in exposed rats as early as week 58 of the 2-y study, and heart schwannoma

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was detected as early as week 70 in exposed rats. Thus, survival was sufficient to detect tumors or pre-cancerous lesions in the brain and heart of control rats.

In their draft of this note that was posted last year (https://www.icnirp.org/cms/upload/publications/ICNIRPnote2018.pdf), ICNIRP cited a paper by Novilla et al. (1991) on the prevalence of spontaneous endocardial proliferative lesions in rats. The fact that Novilla et al. did not see either hyperplasias or schwannomas in 100 control male Sprague-Dawley rats lends further credibility to the absence of these lesions in the NTP study in Sprague-Dawley rats and supports the increased incidences of cardiac schwannomas being due to exposures to cell phone RF radiation. In addition, survival-adjusted overall primary tumor rates were greater in male rats exposed to GSM or CDMA RFR compared to concurrent control rats, with statistical significance observed in the 1.5 W kg^{-1} (CDMA) and in the 3.0 W kg^{-1} (GSM and CDMA) exposure groups (NTP 2018a; Lin 2019).

Multiple comparisons

Because of the large number of statistical comparisons, the ICNIRP note claims that by "…using a significance level of $p < 0.05$, many hundreds are expected to be significant by chance alone," and "It is therefore not possible to determine whether any of the results are due to RF-EMF exposure, as opposed to chance." This issue came up in the peer review of the NTP report of partial findings from the carcinogenesis studies of cell phone RF radiation (Wyde et al. 2016) and was addressed in the NTP's response to the reviewer's comments: "Although the NTP conducts statistical tests on multiple cancer endpoints in any given study, numerous authors have shown that the study-wide false positive rate does not greatly exceed 0.05 (Fears et al. 1977; Haseman 1983; Office of Science and Technology Policy 1985; Haseman 1990; Haseman and Elwell 1996; Lin and Rahman 1998; Rahman and Lin 2008; Kissling et al. 2014). One reason for this is that NTP's carcinogenicity decisions are not based solely on statistics. Many factors go into this determination, including whether there were pre-neoplastic lesions, whether there was a dose-response relationship, biological plausibility, background rates and variability of the tumor, etc. Additionally, with rare tumors especially, the actual false positive rate of each individual test is well below 0.05 due to the discrete nature of the data, so the cumulative false positive rate from many such tests is less than a person would expect by multiplying 0.05 by the number of tests conducted (Fears et al. 1977; Haseman 1983; Kissling et al. 2015)" (Wyde et al. 2016). Gliomas and heart schwannomas, which were found in the NTP studies on RF radiation, are uncommon tumors that occur rarely in control Sprague-Dawley rats.

Additional incorrect statements and misinformation in the ICNIRP critique that aim to undermine the utility of the NTP studies for assessing human health risks

1. One reason given by the ICNIRP Commission for dismissing the carcinogenic effects of RF-EMF in experimental animals is "...because there is currently no verified mechanism that would predict that RF EMFs would be carcinogenic." However, there is no requirement to establish a verified mechanism before accepting the carcinogenicity results of an agent in experimental studies. For most or perhaps all of the NTP studies that demonstrated carcinogenic activity, no verified mechanism had been identified when the studies had been completed. With respect to RF-EMF, Yakymenko et al. (2016) reported that evidence of oxidative stress was observed in 93 of 100 studies dealing with oxidative effects of low intensity RF radiation. Furthermore, oxidative stress can lead to mutations, chromosomal translocations, and genetic instability (Smith et al. 2016), and DNA damage was observed in brains of rats and mice exposed to RF radiation in the NTP studies (NTP 2018a and b; Smith-Roe et al. 2019). Oxidative stress caused by EMFs is thought to be due to the altering of recombination rates of short-lived radical pairs leading to increases in free radical concentrations (Barnes and Greenebaum 2015). Thus, oxidative stress leading to DNA damage may be involved in the induction of tumors from exposure to RF radiation (Lai and Singh 1997).
2. The ICNIRP Commission claims that "none of the compared pathologies were specified a priori as primary end points." This is wrong; all of the endpoints in the NTP study were specified in the NTP Specifications for the Conduct of Studies to Evaluate the Toxic and Carcinogenic Potential of Chemical, Biological and Physical Agents in Laboratory Animals, and in the Statement of Work for the conduct of the studies on RF radiation prior to the start of these studies.
3. In their evaluation of the carcinogenic potential of RF-EMF, the ICNIRP note failed to recognize that focal hyperplasias (proliferative lesions) of glial cells in the brain and of Schwann cells in the heart are putative preneoplastic lesions that may progress to malignant glioma or to cardiac schwannoma, respectively. In fact, the term hyperplasia is not present in the ICNIRP note.
4. While the ICNIRP note focused on the carcinogenicity of RF-EMF from animal studies, it neglected to point out that other adverse effects were observed in the NTP studies, including reduced birth weights, DNA strand breaks in brain cells (which is supportive of the cancer findings), increased incidences of

proliferative lesions (tumors and hyperplasia) in the prostate gland, and exposure-related increases in the incidence of cardiomyopathy of the right ventricle in male and female rats. In addition, other studies have reported adverse effects on male and female reproduction and neurobehavioral effects resulting from exposure to low intensity non-ionizing radiation (Belpomme et al. 2018).

5. In their attempt to downplay the concordance between schwannomas observed in animal studies and in human studies on cell phone radiation, the ICNIRP Commission claimed that an increased incidence of vestibular schwannoma (also called acoustic neuroma) from mobile phone use was reported "mainly by one research group" (Hardell et al. 2005, 2013). This statement is wrong since the INTEPHONE Study group (2011) reported that the odds ratio (OR) for acoustic neuroma after ≥10 y of mobile phone use was 2.79 (95% confidence interval: 1.51-5.16) for ≥1,640 h of cumulative call time. In addition, there were significant increases in the incidence of acoustic neuroma for ≥10 y use and on the same side of the head as reported phone use among the North European countries that participated in the Interphone study (Lönn et al. 2005; Shoemaker et al. 2005). The fact that "malignant cardiac schwannomas are extremely rare tumors in humans" and have not been investigated in epidemiological studies of RF-EMF does not detract from the concordance in cell type affected in animals and humans. The NTP findings of significantly increased incidences and/or trends for gliomas and glial cell hyperplasias in the brain and schwannomas and Schwann cell hyperplasias in the heart of exposed male rats are most important because the IARC classified RFR as a "possible human carcinogen" based largely on increased risks of gliomas and acoustic neuromas (which are Schwann cell tumors on the acoustic nerve) among long-term users of cell phones.

The hypothetical argument raised by ICNIRP about the effect of one additional cardiac schwannoma in the control group on *p* values lacks scientific credibility; one must analyze the available data rather than insert arbitrary values to downplay the significance of a true response. As noted above, carcinogenicity evaluations by the NTP are not based solely on statistics; other factors such as the presence of preneoplastic lesions and the rarity of the tumor also impact the evaluation of carcinogenic activity.

6. The ICNIRP note claims that, "The exposure levels used in NTP would indeed have raised body core temperature substantially," which "would have put them [male rats] under greater metabolic stress due to their greater thermoregulatory requirements." The main reason for this claim is that the "NTP measured superficial temperature rather than the body core temperature." However, there is no evidence to support the claim of substantial elevation of core temperature or that the rats were under metabolic stress. The NTP study used subcutaneously implanted transponders to monitor the effects of RF exposure on core body temperature; this approach was chosen because Kort et al. (1998) had shown that temperature changes recorded by the subcutaneous transponders did not differ significantly from rectal temperature measurements in rats or mice. In addition, it is clear that animals tolerated the exposure levels used in the NTP study, as there were no significant effects on body temperature, body weights in the 2-y study, induction of tissue damage in the 28-d study, nor exposure-related clinical observations.

7. The ICNIRP note claims that the "NTP exposures are not directly relevant to those encountered in the community" because "the NTP exposure of 6 W kg^{-1} is therefore 3 times higher than the local exposure restriction and 75 times higher than the whole-body exposure restriction for the general public." While the exposure limit to RF radiation for the general population in the US and Europe is 0.08 W kg^{-1} averaged over the whole body, the localized exposure limit is 1.6 W kg^{-1} averaged over any 1 g of tissue in the US (FCC 1997) and 2 W kg^{-1} averaged over any 10 g of tissue in Europe; for occupational exposures, the limit is five times higher (0.4 W kg^{-1} for whole-body exposures in the US and Europe, and 8 W kg^{-1} and 10 W kg^{-1} for localized exposures in the US and in Europe, respectively) (FCC 1997; ICNIRP 1998). Thus, the whole-body exposure levels in the NTP study were 19 to 75 times higher than the FCC's and ICNIRP's whole-body exposure limit for the general population and only 3.8 to 15 times higher than the occupational whole-body exposure limit. Whole-body SAR, however, provides little information about organ-specific exposure levels (IARC 2013). When an individual uses a cell phone and holds it next to his or her head, body tissues located nearest to the cell phone antenna receive much higher exposures than parts of the body that are located distant from the antenna. Consequently, the localized exposure level is more important for understanding and assessing human health risks from cell phone RF radiation. When considering organ-specific risk (e.g., risk to the brain) from cell phone RF radiation, the important measure of potential human exposure is the local SAR value of 1.6 W kg^{-1} (US) or 2 W kg^{-1} (Europe). In the NTP study in which animals were exposed in

reverberation chambers to whole-body RF radiation at SARs of 1.5, 3, and 6.0 W kg^{-1}, exposures in the brain were within 10% of the whole-body exposure levels. Thus, with respect to dosimetry in the brain, the exposures in the brain were similar to or only slightly higher than the localized exposure limits set by the FCC and ICNIRP for the general population (1.6 and 2 W kg^{-1}, respectively), and lower than the localized limits for occupational exposures of 8 and 10 W kg^{-1} (FCC 1997; ICNIRP 1998). Consider the converse scenario. If the brain and whole-body exposures were limited to 0.08 W kg^{-1}, then localized exposures in humans from use of cell phones held next to the ear could be 20 to 25 times greater than exposures to the brain of rats in the NTP study. Under this condition, a negative study would not be informative for evaluating organ-specific human health risks associated with exposure to RF radiation. The ICNIRP statement, "Research using substantially lower exposure levels would be required in order to determine whether there was a risk to the public," is contradictory with methodologies used to assess population-based human cancer risk (US EPA 2005).

8. The NTP cancer study was 2 y in duration; animals were not exposed "over the whole of their lives." Surviving animals were killed at about 110 wk of age; e.g., more than 70% of mice were still alive at the end of the study (NTP 2018a and b).

CONCLUSION

ICNIRP's misrepresentation of the methodology and interpretation of the NTP studies on cell phone RF radiation does not support their conclusion that "limitations preclude drawing conclusions about carcinogenicity in relation to RF EMFs." In contrast to the ICNIRP evaluation, a 3-d independent peer-review of the NTP studies concluded that there was *clear evidence of carcinogenic activity* in male rats exposed to RF radiation (NTP 2018c). In addition, the dosimetry issue raised in the ICNIRP note falsely portrays the relevance and utility of the NTP cancer data for assessing human cancer risks. After all, it was the US Food and Drug Administration that requested the NTP studies of cell phone radiation in experimental animals to provide the basis to assess the risk to human health. The NTP studies show that the assumption that RF radiation is incapable of causing cancer or other adverse health effects other than by tissue heating is wrong. If ICNIRP's goal is truly aimed at protecting the public from potential harm, then it would be appropriate for this group to quantify the health risks associated with exposure to RF-EMFs and then develop health-protective guidelines for chronic exposures, especially for children, who are likely to be more susceptible than adults to adverse effects of RF radiation. At the very least, ICNIRP should promote precautionary advice for the general public rather than trying to justify their decision to dismiss findings of adverse health effects caused by RF-EMFs and thereby retain their 20+ y-old exposure guidelines that are based on protection against thermal effects from acute exposures.

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Review Article

Occupational exposure to radiofrequency electromagnetic fields

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OCCUPATIONAL EXPOSURE TO RF EMF

Abstract: High exposures to radiofrequency electromagnetic fields (RF EMF) are possible in workplaces involving sources used for broadcasting, telecommunication, security and identification, remote sensing and the heating and drying of goods. A systematic literature review of occupational RF EMF exposure measurements could help to clarify where more attention to occupational safety may be needed. This review identifies specific sources of occupational RF EMF exposure and compares the published maximum exposures to occupational exposure limits. A systematic search for peer-reviewed publications was conducted via PubMed and Scopus. Relevant grey literature was collected via web searches. For each publication, the highest measured electric field strength, magnetic flux density or power density was extracted. Maximum exposures exceeding the limits were reported for dielectric heating, scanners for security and radiofrequency identification, plasma devices and broadcasting and telecommunication transmitters. Occupational exposure exceeding the limits was rare for microwave heating and radar applications. Some publications concerned cases studies of occupational accidents followed by a medical investigation of thermal health effects. These were found for broadcasting antennas, radar installations and a microwave oven and often involved maintenance personnel. New sources of occupational exposure such as those in fifth generation telecommunication systems or energy transition will require further assessment.

Key words: Electromagnetic fields, Radiofrequency, Exposure, Occupational, Regulation

Introduction

Radiofrequency electric, magnetic and electromagnetic fields (RF EMF) with frequencies from 100 kHz to 300 GHz can be used to convey information (broadcasting, telecommunication, radiofrequency identification), for remote sensing (radar, security scans) for heating and drying of goods and for medical diagnostic or therapeutic purposes. If they are sufficiently strong, RF EMF can lead to excessive heating and tissue damage. Some of the strongest human-made sources of EMF can be found in the workplace. The International Commission for Non-Ionizing Radiation Protection (ICNIRP) has defined basic restrictions in terms of the specific absorption rate (SAR) and power density in the body, below which these health effects will not occur[1, 2)]. Reference levels in terms of the electric field strength, magnetic field strength or flux density and power density of the external fields outside the body have been derived from these basic restrictions. When workers are exposed to RF EMF weaker than the reference levels, the basic restrictions will not be exceeded under most circumstances, except for exposure of the limbs at frequencies between 100 kHz and 110 MHz. For this frequency range, separate reference levels were set for limb current, since exposure below the action levels for electric field strength does not guarantee that the SAR in the limbs, with their relatively small diameter, is not exceeded. The European Union (EU) has used the 1998 ICNIRP basic restrictions and reference levels to set legal limits for worker exposure to RF EMF in its occupational health and safety legislation by way of Directive 2013/35/EU (further called 'EU Directive'). In the EU Directive, the reference levels are called 'action levels' and the basic restrictions 'exposure limit values' (Table 1 and Table 2)[3)]. Although the original transposition deadline was 1 July 2016, due to delays in the legal process in some member states the EU directive had been implemented in all EU member states by August 2017[4)].

A systematic assessment of published studies on occupational RF EMF exposure could help to clarify where more attention to occupational safety may be needed. The European Commission has published a guide of good practice for the EU Directive, which tabulates working environments in which the action levels may be exceeded and further risk assessment is required[5)]. On the basis of the good practice guide and the results of a search with general RF EMF search terms (see 'methods' section), six categories of working environments were selected for review of occupational RF EMF exposure.

In the category of dielectric heating, a dielectric material (polarisable insulator) is placed in an alternating RF EMF between two electrodes, resulting in energy absorption without conduction and consequently heating. It is mainly used to deform, melt, weld or seal plastic materials[6)]. Frequencies for this application lie between 4 and 70 MHz, with a strong concentration in the 27 MHz band. The same physical principle is employed at higher frequencies (mainly at 915 MHz and 2.45 GHz) for microwave heating of food, wood and ceramics for purposes of drying, curing, shaping, sterilisation or pest control[7)]. In the category security and radiofrequency identification (RFID), RF EMF in the frequency bands around 100 kHz, 10 MHz, 1 GHz and 24 GHz are used for article detection and identification and for security scans of persons and objects[8)]. In industrial processes involving plasma etching, plasma sputtering and vapour deposition, RF EMF are used to apply thin layers of material to components in the electronics industry[9)]. In the category broadcasting and telecommunication, RF EMF are employed to convey radio and television signals and information for mobile communication and wireless data transfer by the general public and by industry, air and marine traffic control, the emergency services and the military. Frequency use ranges widely between 100 kHz and 300 GHz[10)]. Radar uses the reflection of RF EMF to determine the range, angle, velocity or composition of objects. It can be applied to detect and analyse the motion or composition of aircraft, missiles, ships, vehicles, weather formations, terrain and soil layers. Frequency bands vary according to application from 3 MHz to 110 GHz[11)].

The present review complements two earlier reviews using the same methodology. The most recent of these (2018) focused on low frequency and RF EMF sources that are exclusively used in medical, physiotherapy or dental practice[12)]. These sources of occupational exposure have therefore been excluded from the present review. Occupational exposure to low frequency magnetic fields was reviewed in 2014[13)], which included induction heaters with frequencies up to 1 MHz. Sources that are also used by the general population outside the workplace, such as mobile phones and other wireless consumer products, also fall outside the scope of the present review.

Methods

Data collection

A systematic literature search for peer-reviewed articles on occupational exposure to RF EMF published up to December 2020 was conducted in PubMed (http://www.ncbi.nlm.nih.gov/pubmed/) and Scopus (http://www.scopus.com/). Pagination of advance publications was added if available before submission of the manuscript. For a first general search, a combination of blocks of search terms were used, relating to RF EMF [((“radio frequ*” OR radiofrequ* OR rf OR microwave* OR “millimeter wave*” OR “millimetre wave*” OR “mm wave*” OR radar*) AND (field* OR radiat* OR wave*))], occupational setting [(worker* OR occupation* OR workplace OR employ* OR working OR “work floor”)] and exposure [(exposure OR dosimetry OR intensity OR “power densit*” OR “field strength*” OR “flux densit*” OR “specific absorption” OR sar)] but excluding frequencies in the range of optical radiation [(NOT (“optical radiation” OR ultraviolet OR uv OR infrared OR “visible light”)]. Secondly, searches for specific sources of occupational exposure to RF EMF were conducted in Pubmed and Scopus, using a combination of the search terms related to RF EMF and occupational setting (see above) with each of the following sets of source-specific search terms: [((dielectric* OR plastic) AND (heating OR heater* OR welding OR welder* OR sealing OR sealer* OR curing OR curer*))]; [(oven* OR drying OR dryer*)]; [(“article surveill*” OR antitheft* OR “anti theft*” OR security* OR rfid* OR “radiofrequency identification*”)]; [(telecom* OR radio OR television OR broadcast* OR tetra OR c2000) AND (mast* OR antenna* OR transmitter* OR station* OR beacon* OR tower*)]; [(radar*)]; [(military OR “armed forces” OR aircrew* OR soldier* OR sailor* OR army OR airforce* OR “air force*” OR navy)]; [(wireless AND “power transfer*”)]; [(plasma AND (etching OR sputtering OR stripping OR “vacuum deposition*” OR “surface treatment*”)]. In Scopus, document types such as conference abstracts that were not full journal articles were excluded, as well as subject categories not relevant for RF EMF exposure (SUBJAREA,

“MATE”; SUBBJAREA, “CHEM”; SUBJAREA, “CENG”; SUBJAREA, “EART”; SUBJAREA, “BUSI”; SUBJAREA, “ARTS”; SUBJAREA, “ECON”). For Pubmed, 1,879 results were found with the general search terms and 2,397 with the source-specific search terms (with an unknown overlap between the two). After screening of titles and, if necessary for clarification, abstracts, 89 articles were selected as potentially relevant, 31 of which were discarded after full-text screening for lack of suitable individual exposure values. For Scopus, 1,771 results were found with the general search terms and 3,662 with the source-specific search terms (with an unknown overlap between the two). After screening of titles and, if necessary for clarification, abstracts, 42 articles were selected as potentially relevant and were not also found with the Pubmed search, 27 of which were discarded after full-text screening for lack of suitable individual exposure values.

Relevant grey literature (measurement reports) in English, German, French or Dutch was identified on the websites of the following organisations: Agence nationale de securité sanitaire, alimentation, environnement, travail (ANSES) (France), Bundesamt für Strahlenschutz (Germany), Deutsche Gesetzliche Unfallversicherung (Germany), European Commission (Brussels), Health and Safety Executive (UK), Institut national de recherche et de sécurité (INRS) (France), Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro (INAIL) (Italy), National Institute for Occupational Safety and Health (NIOSH) (USA), National Technical Reports Library (USA), Public Health England (UK), TNO (Netherlands), Vito (Belgium).

Data extraction

Only those publications listing individual maximum exposure values at specific frequencies were used, because frequency-averaged or group-averaged data make it impossible to compare maximum individual exposures to the action levels (reference levels) or exposure limit values (basic restrictions). Where the exposure was listed as a proportion of the action levels, the actual exposure was calculated by multiplying with the action level at the relevant frequency. Wherever possible, for frequencies below 10 GHz the 6-minute averaged values were used in accordance with the EU Directive and the underlying 1998 ICNIRP guidelines. Where only measurements in shorter time intervals were available, this is clearly mentioned as a caveat when comparing with the exposure limits. Where exposure was intermittent and the duty cycle was given, exposure values corrected for duty cycle were used. Where multiple publications were produced by the same authors, based on same subjects and study protocol, the maximum exposure values were extracted from only one of these publications. Apart from the distance to the source, worker exposure from radiofrequency devices also depends on the output power of the device in question (for example for dielectric heating equipment). It was assumed that the maximum exposures extracted are associated with the highest output power under normal working conditions. Where available, both maximum electric field and magnetic field measurement values were extracted for the same exposure since these may not always be coupled at the place of exposure. In accordance with the EU Directive, all magnetic field measurements are presented as magnetic flux density. Where only the magnetic field strength was available, the magnetic flux density was calculated by multiplying with the magnetic permeability ($4\pi \times 10^{-7}$ H/m). For radar exposure, where the (equivalent) frequency exceeded 6 GHz for a substantial proportion of measurements and energy deposition is limited to the outer layer of the body, the maximum equivalent plain wave power density was extracted for comparison with the exposure limits. In the minority of radar publications where only electric field strength was given at such frequencies, the power density was calculated using the formula: $S = E^2/Z$ with $Z = 377\ \Omega$. For lower frequencies and the minority of publications where only the maximum power density was given, this was converted to electric field strength for easier comparison, using the formula: $E = \sqrt{(S \times Z)}$ with $Z = 377\ \Omega$. For pulsed fields, such as those of some radar devices, the peak power density in the pulse was extracted where available and compared with the relevant action level (reference level) times 1,000 (for power density), as instructed in the EU Directive and underlying ICNIRP guidelines. Where peak values were measured or calculated, they have been converted to root-mean-square (rms) values by dividing by $\sqrt{2}$, for comparison with the action levels. Where no mention of peak or rms values was made in the publication, rms values were assumed. Exposure measurements were directly compared to action levels, without taking measurement uncertainty into account, since the source publication did not generally provide sufficient information on measurement uncertainty.

Exposure at the main frequency component with highest exposure was used, even though higher harmonics may also contribute to exposure. Where action levels are exceeded, this should be seen as an indication that there are potential issues with exposure levels for higher harmonics and that the frequency-summated exposure may be higher. The highest value of electric field strength, magnetic flux density or power density measured at the actual workplace was used as an indicator of maximum exposure to the source. When this was not available (usually when fields were measured at a standardised distances to the source), the highest value measured at distance that was possible with intended or foreseeable use was taken. When measurements were made at multiple heights from the floor, the height with the highest exposure was chosen. Not all publications contained sufficient information to determine whether the maximum measured values listed were restricted to the limbs. Where insufficient information was available it was presumed that all measured values may have involved head or trunk exposure. In the figures, a distinction is made between data points from publications before 2012 and data published from 2012 onwards, since it had become clear by then that the 2013 EU Directive would be applying legally binding exposure limits based on the 1998 ICNIRP guidelines.

For those publications in which the SAR or absorbed power density were calculated, these data are discussed in the text and related to the relevant exposure limit value (basic restriction). In some publications exposure was clearly due to an accident, where possible exposure above the limit values was suspected and an occupational medical investigation was conducted. Data from these publications are not included in the figures, but discussed separately in the text for each category of working environment.

Results

Dielectric heating (plastic welding)

A total of 25 publications had data on worker exposure near devices for dielectric heating to deform, melt, weld or seal plastic materials (3 of which published after 2011). Most of these investigations corrected for the fact that the apparatus was only active for part of the 6-minute averaging period ('duty cycle' smaller than 1), making the time-averaged exposure lower than that in the active period. The highest measured electric field strengths and magnetic flux densities to which workers could be exposed are shown in Fig. 1. The majority of these highest exposure values were above the action levels in the EU Directive for the electric as well as the magnetic field. In 2 publications with transgression of action levels the local and whole body averaged SAR was calculated[26, 31)]. In one of these, the situation with transgression of the action levels also resulted in a local SAR in the legs that exceeded the exposure limit value[26)]. In 3 out of the 7 publications where the limb current was measured, this could exceed the action level[27, 29, 35)]. In working environments where action levels are exceeded, EU Directive requires that the employer takes measures to reduce exposure, or demonstrates that the exposure limit values are not exceeded. Some publications investigated the effect of exposure reduction measures and showed that the field strength remained below the action levels after applying appropriate shielding to the device[16, 25, 36)].

Security and RFID

A total of 17 publications had data on worker exposure near devices for security scans or RFID (6 of which published after 2011). These concerned measurements of (potential) workplaces near gates or hand-held scanners for the detection or deactivation of anti-theft labels in shops, security scanners in public buildings including airports and scanners for the identification of objects via RFID (e.g., access passes, goods). The highest measured field strengths and magnetic flux densities to which workers could be exposed are shown in Fig. 2. For body scanners using millimetre waves (frequencies around 2.4 GHz) the field strength was always lower than the action levels and the calculated SAR was below the exposure limit values[45, 46)]. For anti-theft gates and RFID-scanners, which use RF EMF with frequencies around 100 kHz and 10 MHz, the majority of maximum exposure values was higher than the action levels, both for publications before and after 2012. However, an important caveat is that the exposure was not averaged over 6 minutes in these publications and the realistic exposure duration was not investigated. In 6 publications the local and whole body averaged SAR were calulated[40, 45–48, 51)]. One of these showed a whole body averaged SAR higher than the exposure limit value, if exposure lasted longer than 6 minutes[48)]. Contact currents were reported in 1 publication, but these did not exceed the action level[40)].

Plasma devices

A total of 3 publications had data on worker exposure near equipment for radiofrequency industrial surface treatments, including plasma etching, plasma sputtering and vacuum deposition (2 of which published after 2011) (Fig. 3). Action levels were exceeded near (closer than 10 cm to) a device for plasma sputtering operating at 13.6 MHz[40] and near a microwave generator used for plasma excitation operating at 2.3 GHz[54]. If exposure would last sufficiently shorter than 6 minutes or if a greater distance could be observed, exposure would be expected to remain under the action levels. In 1 publication contact currents were measured, which exceeded the action level with a device for plasma sputtering (both touch and grasp contact), but not with a device for plasma-etching[40].

Broadcasting and telecommunication

A total of 31 publications had data on worker exposure in working environments near broadcasting antennas (radio and television) or antennas or professional user devices for mobile telecommunication (telecom operators, company mobile radio, emergency services, armed forces), 14 of which were published after 2011. Maximum occupational exposure exceeding the action levels occurred more frequently for broadcasting antennas than for telecommunication antennas and in most cases was found in publications before 2012 (Fig. 4). The majority of publications assumed that exposure could last at least 6 minutes, but it was not usually reported how likely that was to happen in normal work activities. In 2 publications concerning workers near an FM antenna the SAR was calculated where the action levels were exceeded and was found to exceed the exposure limit value for the whole body[73, 81]. In 5 publications concerning networks for the emergency services, the local SAR exposure limit value for handsets or vehicle antennas was not exceeded[66, 67, 82–84]. The local head SAR was exceeded during maintenance work on an unscreened portaphone transmitter[58]. Limb current was measured and exceeded the action level in 1 publication for medium frequency (1.3 MHz) and high frequency (6 MHz) transmitters, but in both cases the action levels for electric field strength were also exceeded[63]. Contact currents were reported in 1 publication (military high frequency antenna), but these did not exceed the action level[64]. Three publications (not shown in graph) concerned an accident (incident where overexposure was suspected), followed by a medical examination. In the first of these, the exposure of maintenance personnel near a broadcasting antenna proved to be lower than the action levels[85)]. In a second case study, a maintenance lift got stuck in front of a broadcasting antenna, where the exposure was 4 times the action level for 2.5 minutes. Registered symptoms were an acute feeling of warmth and skin redness, headache, diarrhoea, malaise and paresthesia which lasted several days after the incident[86)]. A second publication by the same author reported similar symptoms in case studies of antenna engineers working near broadcasting antennas for extended periods, where action levels could have been exceeded[87)].

Microwave drying and heating

A total of 5 publications had data on worker exposure near devices for drying, curing or heat sterilisation of goods (1 published after 2011). Four of these used microwave frequencies (2.5 GHz) and showed that the maximum power density at the workplace was lower than the action level (Fig. 5). One publication showed exposure higher than the action level for one of the two devices investigated, but this concerned an oven where the shielding door had a defect[88)]. One publication concerned radiofrequency textile driers operating at 27 MHz, where electric field strength and magnetic flux density immediately next to the opening could exceed the action levels five-fold, presuming an exposure of at least 6 minutes[91)]. One publication concerned an accident (incident where overexposure was suspected), followed by a medical examination. A maintenance worker repairing microwave ovens (2.5 GHz) with interrupted interlock protection was exposed to a power density of four times the action level, on repeated occasions with a duration of at least 4 minutes. Symptoms were a feeling of warmth, skin redness and a burning sensation in the eyes[92)].

Radar

A total of 20 publications had data on worker exposure in working environments involving radar installations for identification and analysis of aircraft, missiles, shipping, cloud formations or for road speed detection. Five of these were published after 2011 and 6 publications concerned military installations. When determining exposure, the fact was taken into account that for certain radar applications the bundle moves or rotates and exposure only occurs part of the time (‘duty cycle’). In the majority of publications, exposure was lower than the power density action levels (Fig. 6). Exposure exceeding the action levels was reported in 2 publications. The first of these concerned a police officer located in the bundle of a speed detector, which may be considered as unintended use[100)]. The second concerned the operator of a military target radar[101)]. For pulsed radar, apart from the time-averaged exposure, the peak exposure in the pulses is important. The reference level for power density for peak exposure in the pulse is 1,000 times the reference level for time-averaged exposure[1, 3)]. For the 3 publications in which the peak exposure in the pulse was given (air traffic and shipping radar), this was lower than 1,000 times the action level[53, 103, 104)]. Five publications (not shown in graph) concerned an accident (incident where overexposure was suspected), followed by a medical examination. All of these involved military radar applications: 3 publications with exposure of maintenance personnel (1.5 to 3 times the action level)[106–108)] and 2 publications with onboard exposure of navy personnel to RF EMF from a target location radar (4 times the action level)[109)] or the area radar of a closely passing ship (10 times the action level)[110)]. In the latter case, the action levels for peak exposure in the pulse and the exposure limit value for whole body SAR were also exceeded. Recorded symptoms varied from psychological stress to a feeling of warmth, malaise, pain, dizziness, nausea or irritated eyes.

Other sources

One publication was found which assessed occupational RF EMF in a scientific laboratory (nuclear facility). Electric field strength near a pump source for laser radiation (5 MHz) and near an RF quadrupole accelerator (55 MHz) were in the order of 1% of the action levels[111)]. The publications that were found on the strength of RF EMF associated with wireless power transfer did not specifically concern occupational exposure.

Discussion

The results of this systematic literature review show that the action levels and exposure limit values for RF EMF in the EU Directive (derived from the 1998 ICNIRP guidelines) can be exceeded, in varying proportions, for maximum exposures in working environments involving dielectric heating of plastic materials, security or RFID scanners, plasma devices, broadcasting and telecommunication, but only rarely for microwave drying or heating and radar.

For plastic welding using RF EMF-induced dielectric heating, the majority of highest exposure values registered exceeded the action levels. Since these publications usually took account of time-averaging and duty cycle, the possibility of overexposure is realistic in these cases and exposure reduction measures would be in order. The alternative is to calculate whether the SAR basic restrictions are not exceeded, but this is normally unrealistic for employers since the necessary calculations and computer simulations can be generally only be performed by experts in numerical dosimetry[112)]. A similar potential for maximal exposures exceeding the action levels occurs with textile or glue dryers which operate in the same ('diathermy') frequency band of 27 MHz[91)]. The available literature seems to indicate that there is less potential for overexposure for microwave drying, curing or sterilisation, provided that shielding doors are in good working order. Exposure reduction for plastic welding or other industrial applications of diathermy can involve the application of shielding or replacement with new equipment with more effective shielding, the removal of reflecting objects near the workplace, effective grounding and proper maintenance[16, 25, 36)].

For security and RFID-scanners, the majority of publications reported instantaneous maximum exposure levels higher than the action levels. However, the 6-minute averaged exposure can still remain under the action levels if the exposure duration is short enough. One would expect that this would usually be the case, unless the worker lingers next to a security gate for longer periods of time. The simplest control measures here would be increasing the distance to the scanner and limiting the time near the scanner when close approach is deemed necessary. For full body scanners using millimetre waves, overexposure is not an issue, even if workers are scanned themselves for security reasons.

For radiofrequency plasma devices, it is possible that action levels are exceeded close to the source, but again this presupposes that the worker’s exposure lasts 6 minutes or longer. Ineffective shielding (panelling or casing) may be a source of avoidable high exposure for plasma devices. In an extreme case, when maintenance is performed on an active device by a worker inside the protective panelling, the exposure close to the device can be 10 times the action level[53)]. This underlines the need to pay special attention to maintenance workers in risk assessments for occupational RF EMF exposure.

For broadcasting and telecommunication antennas, there was evidence that the maximum exposures could exceed the action levels and exposure limit values near the antenna installation, again assuming that they would last at least 6 minutes. Unlike publications before 2012, the majority of publications after 2011 gave maximum occupational exposures lower than the action levels, although higher exposures could still occur for both broadcasting and telecommunication antennas. This may indicate increasing awareness of the legal exposure limits, coupled to the technical know-how on monitoring worker exposure in the broadcasting and telecommunication sector. Local SAR from handsets specific for the working environment under normal use (company networks, emergency services, armed forces) did not exceed the exposure limit values. The only exposure exceeding the local SAR was found for maintenance work on an unscreened portaphone older than 1991, again underlining the potential for higher exposure of maintenance personnel[58)]. The three case studies on overexposure accidents at antenna sites associated with a medical examination also concerned personnel performing maintenance work[85–87)].

For radar, the vast majority of published maximum workplace exposures under normal working conditions was lower than the action levels. Of the three publications which found an exposure higher than the action levels, one concerned a mechanic at an aircraft manufacturer (‘maintenance’)[103)], one a military radar operator[101)] and one a policeman in the beam of a traffic scanner[100)], which could be considered unintended use. In the latter publication, only 0.4% of all workplace measurements performed exceeded the action levels. The five accidental overexposure incidents with medical examinations all concerned military radar systems. Three of them involved maintenance personnel[106–108)] and the two remaining case studies concerned navy personnel accidentally exposed to radar beams from target locators[109)] or from a closely passing ship[110)]. Only one publication was found on the varied RF EMF exposures that can occur in the setting of research laboratories. More attention to these potentially diverse working environments may be warranted.

As discussed in the preceding reviews[12, 13], the approach to reviewing maximum exposures with regard to exposure limits has several limitations. Only the maximum exposures at the workplace per frequency per publication are listed as an indication of worst-case conditions. They were usually performed at a fixed height and did not take account of spatial averaging, giving a conservative estimate of exposure[5]. These maximum exposures are not necessarily representative of the majority of exposures and may not always represent good working practice. For dielectric heating (e.g., plastic welding) in particular, most of the literature database is older than 2012, and it may be that more recent devices in combination with mitigation measures have reduced the potential for worker overexposure. On the other hand, it cannot be excluded that even higher exposures are possible in working environments or scenarios that are not covered by the publications reviewed here. A comparison with the limits in the EU Directive was only made for the main frequency of the source in question. Other frequency components may add to the total exposure and multiple RF EMF sources in the same workplace also need to be added to total exposure. When comparing exposure measurements to legal limits, measurement uncertainty needs to be taken into account[5], but source publications in the present review did not generally provide sufficient information to assess the impact of measurement uncertainty.

The technology of sources of occupational RF EMF exposure continues to evolve. Exposure guidelines and regulation likewise need to evolve to incorporate these developments, as do the techniques used to assess occupational exposure. One example of such developments are the new applications that are becoming available in the fifth generation of mobile telecommunication systems (5G). The higher frequencies and more superficial energy deposition, the use of beam forming, the more widespread use of small cells and local networks for machine-to-machine communication and the use of ultra-wideband pulsed fields do not necessarily create higher exposures, but do make exposure assessments more complicated[113, 114]. Apart from some limited adjustment of reference levels and averaging times, the most recent ICNIRP guidelines for RF EMF introduce new limits for brief, localised exposure at frequencies from 400 MHz to 300 GHz, which are relevant in this context[2]. It should be investigated whether these limits for brief, localised exposures raise new compliance issues for the types of working environments discussed in this review. Another example of novel types of exposure is the increased use of wireless power transfer, for example in charging electric vehicles such as busses and trucks, which generally uses RF EMF in the frequency range from 100 kHz to 50 MHz[115]. Publications in recent years indicate that nearby exposure is lower than the action levels, but these assessments were not specific for occupational exposure[116, 117]. Further investigation of occupational exposure scenarios would be useful.

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Table 1. Exposure limit values for thermal effects in Directive 2013/35/EU

Frequency	Health effects ELV SAR (W/kg)	Health effects ELV power density (W/m^2)
100 kHz ≤ f < 6 GHz		
whole body average	0.4	–
localised 10 g, head and trunk	10	–
localised 10 g, limbs	20	–
6 GHz ≤ f < 300 GHz	–	50

Abbreviations: ELV, exposure limit value; SAR, specific absorption rate.

Note 1: Averaging mass for maximum localised SAR is any 10 g of contiguous tissue with roughly homogeneous electrical properties. Note 2: Power density shall be averaged over any 20 cm^2 of exposed area. Spatial maximum power densities averaged over 1 cm^2 should not exceed 20 times the value of 50 W/m^2. Power densities from 6 to 10 GHz are to be averaged over any six-minute period. Above 10 GHz, the power density shall be averaged over any $68/f^{1,05}$ -minute period (where f is the frequency in GHz).

Table 2. Action levels for thermal effects in Directive 2013/35/EU

Frequency	AL electric field strength (V/m)	AL magnetic flux density (μT)	AL power density (W/m^2)
100 kHz $\leq f <$ 1 MHz	6.1×10^2	$2.0\times10^6/f$	–
$1 \leq f <$ 10 MHz	$6.1\times10^2/f$	$2.0\times10^6/f$	–
$10 \leq f <$ 400 MHz	61	0.2	–
400 MHz $\leq f <$ 2 GHz	$3\times10^{-3}\sqrt{f}$	$1.0\times10^{-5}\sqrt{f}$	–
$2 \leq f <$ 6 GHz	1.4×10^2	4.5×10^{-1}	–
$6 \leq f <$ 300 GHz	1.4×10^2	4.5×10^{-1}	50

Abbreviations: AL, action level.

Note 1: f is the frequency in hertz (Hz). Note 2: Squared AL for electric field strength or magnetic flux density are to be averaged over a six-minute period. For RF pulses, the peak power density averaged over the pulse width shall not exceed 1,000 times the respective AL value. For multi-frequency fields, the analysis shall be based on summation, as explained in the practical guides referred to in Article 14 of the EU Directive. Note 3: AL for electric field strength or magnetic flux density represent maximum calculated or measured values at the workers' body position. In specific non-uniform conditions, criteria for the spatial averaging of measured fields based on established dosimetry will be laid down in the practical guides referred to in Article 14 of the EU Directive. In the case of a very localised source within a distance of a few centimetres from the body, compliance with ELVs shall be determined dosimetrically, case by case. Note 4: Power density shall be averaged over any 20 cm^2 of exposed area. Spatial maximum power densities averaged over 1 cm^2 should not exceed 20 times the value of 50 W/m^2. Power densities from 6 to 10 GHz are to be averaged over any six-minute period. Above 10 GHz, the power density shall be averaged over any $68/f^{1,05}$ -minute period (where f is the frequency in GHz).

Fig. 1. Maximum electric field strength (left y-axis) and magnetic flux density (right y-axis) at the worker's position per publication, per main frequency component for dielectric heating of plastic.

Legend: — = electric field action levels; --- = magnetic field action levels; ● = electric field strength; ○ = magnetic flux density. Symbols in grey represent data published before 2012 and symbols in black data published in or after 2012. Literature references used: [14–36].

Fig. 2. Maximum electric field strength (left y-axis) and magnetic flux density (right y-axis) at the worker's position per publication, per main frequency component for security gates and scanners and RFID scanners or active transponders.

Legend: — = electric field action levels; --- = magnetic field action levels; ● = electric field strength; ○ = magnetic flux density. Symbols in grey represent data published before 2012 and symbols in black data published in or after 2012. Literature references used: [33, 37–52]

Fig. 3. Maximum electric field strength (left y-axis) and magnetic flux density (right y-axis) at the worker's position per publication, per main frequency component for plasma devices (plasma etching, plasma sputtering and vapour deposition).

Legend: — = electric field action levels; --- = magnetic field action levels; ● = electric field strength; ○ = magnetic flux density. Symbols in grey represent data published before 2012 and symbols in black data published in or after 2012. Literature references used: [40, 53, 54]

Fig. 4. Maximum electric field strength (left y-axis) and magnetic flux density (right y-axis) at the worker's position per publication, per main frequency component for broadcasting and telecommunication antennas.

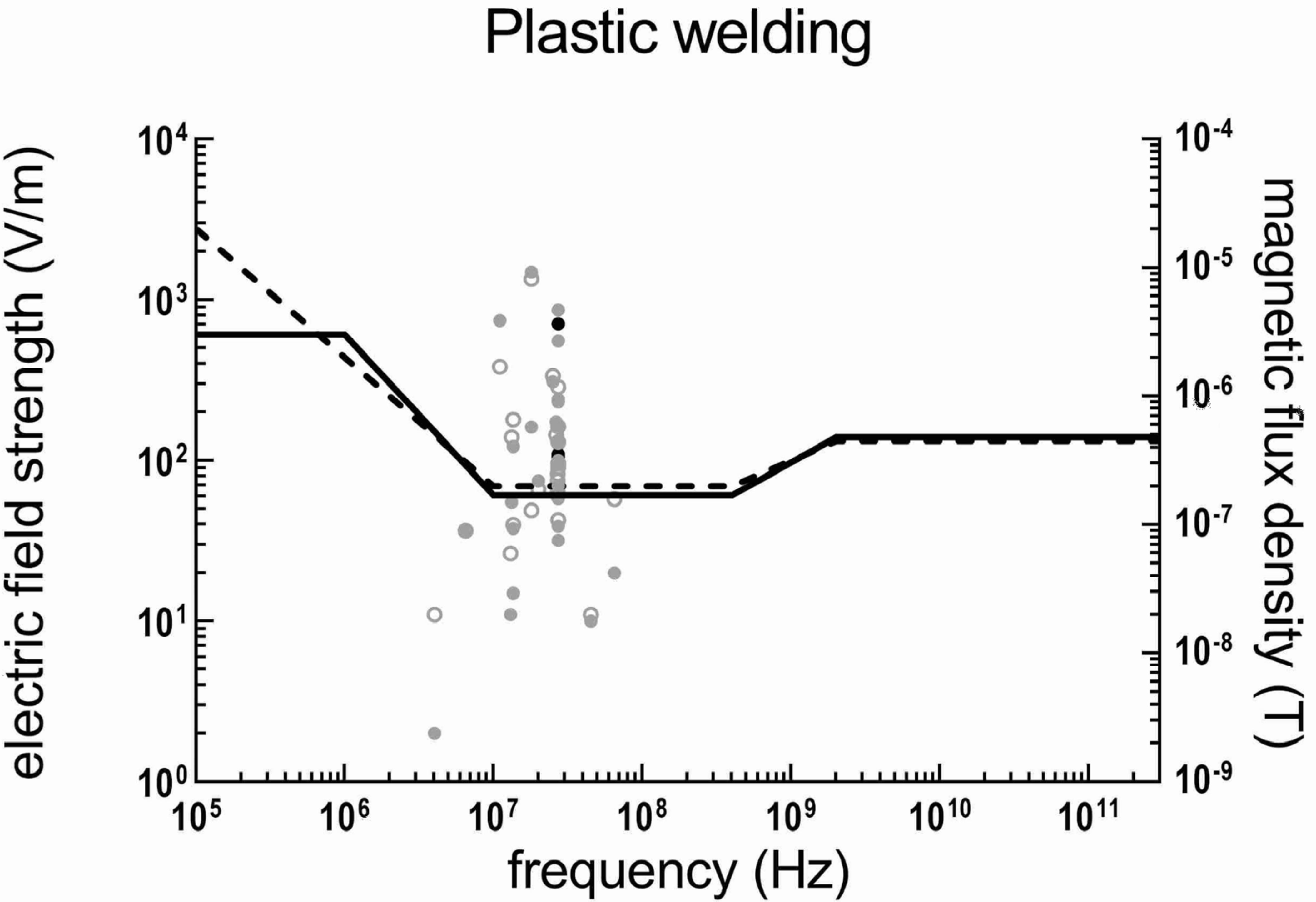
Legend: — = electric field action levels; --- = magnetic field action levels; ● = electric field strength, broadcasting; ○ = magnetic flux density, broadcasting; ■ = electric field strength, telecommunication; □ = magnetic flux density, telecommunication. Symbols in grey represent data published before 2012 and symbols in black data published in or after 2012. Literature references used: [27, 53, 55–81]

Fig. 5. Maximum electric field strength at the worker's position per publication, per main frequency component for industrial drying or heating processes.

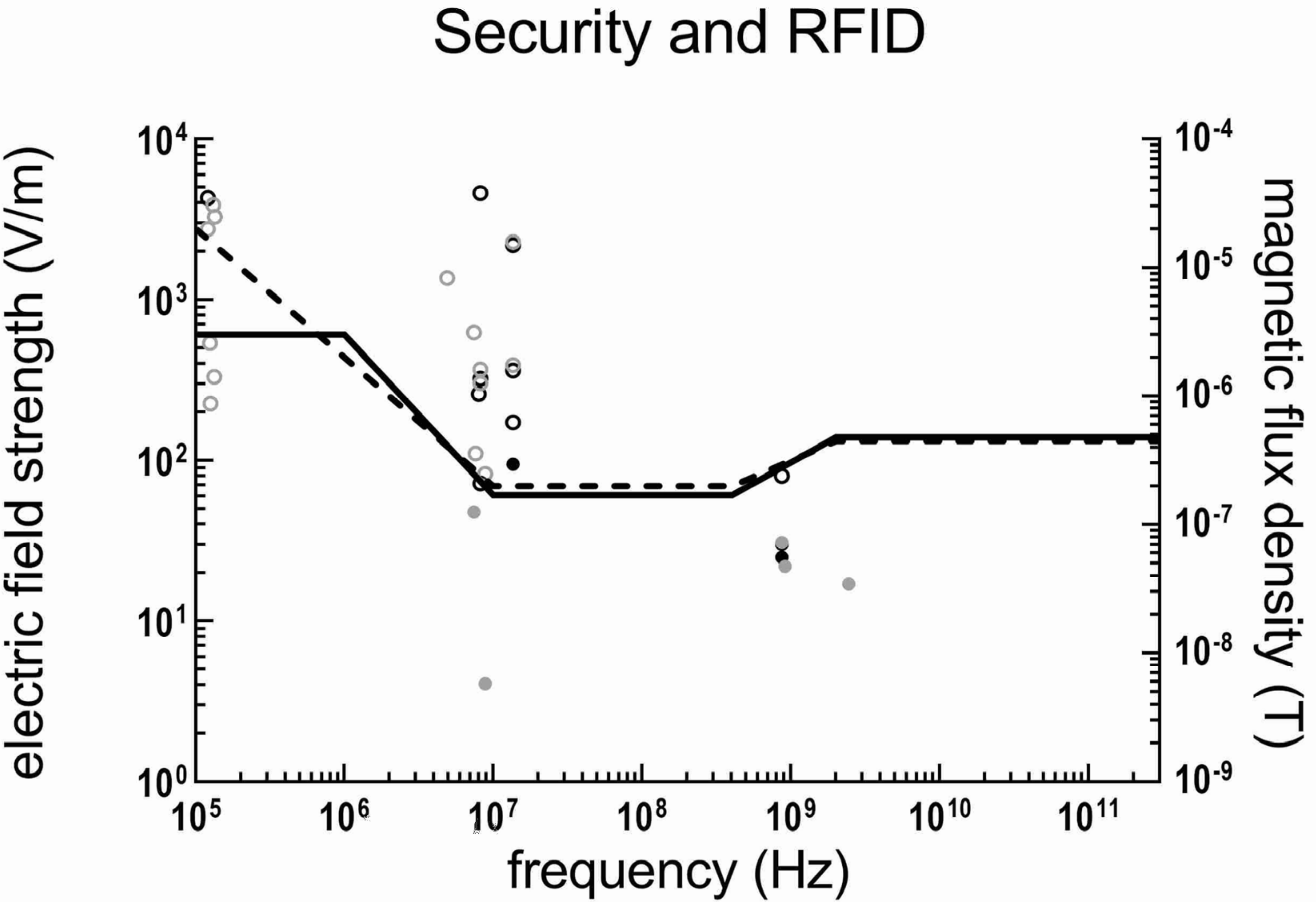
Legend: — = electric field strength action levels; ● = electric field strength. Symbols in grey represent data published before 2012 and symbols in black data published in or after 2012. Literature references used: [40, 88–91)]

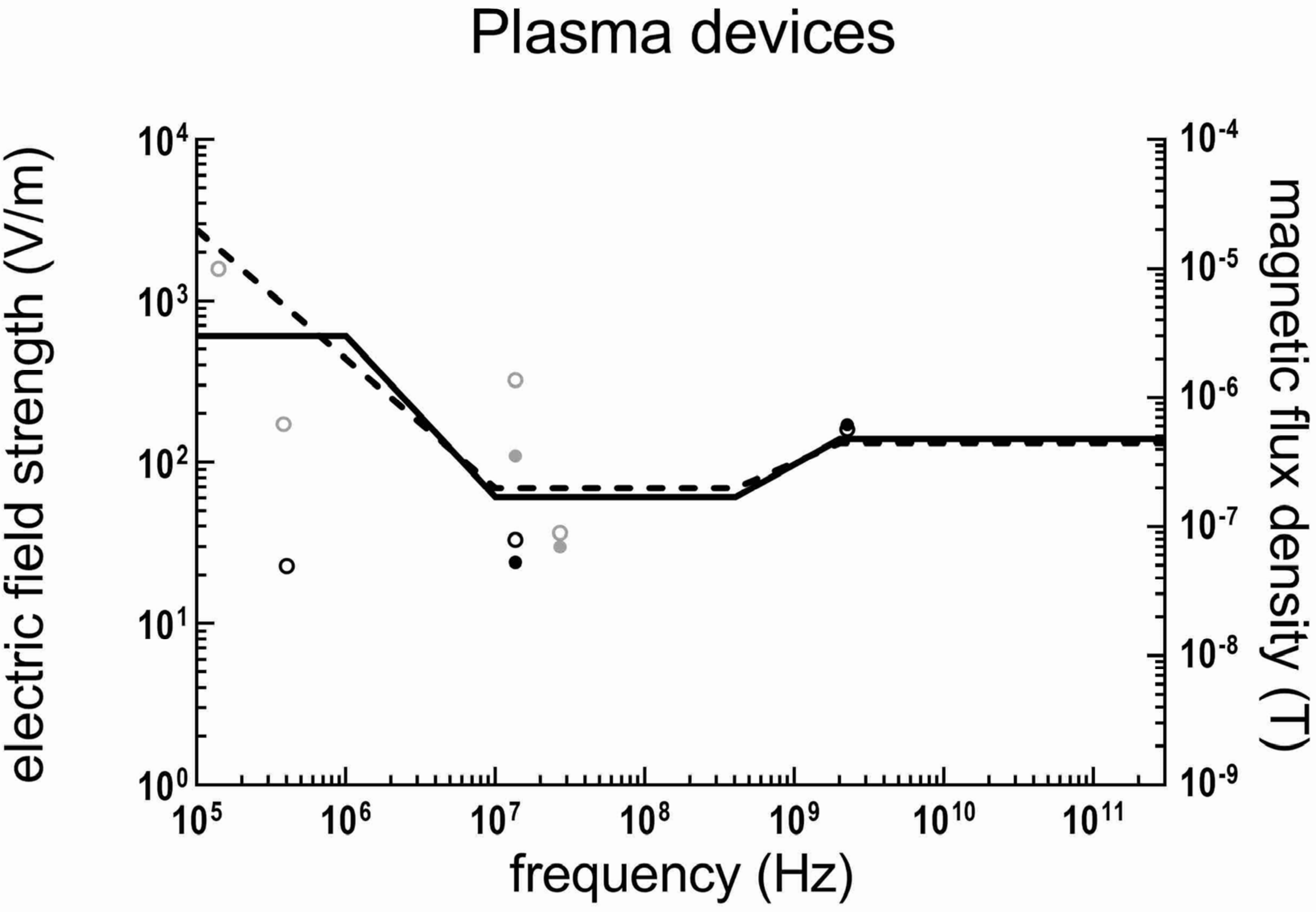
Fig. 6. Maximum equivalent plain wave power density at the worker's position per publication, per main frequency component for radar devices.

Legend: — = power density action levels; --- = ICNIRP 1998 power density reference levels; ● = power density. Symbols in grey represent data published before 2012 and symbols in black data published in or after 2012. Literature references used: [27, 53, 57, 69, 71, 76, 80, 93–105)]

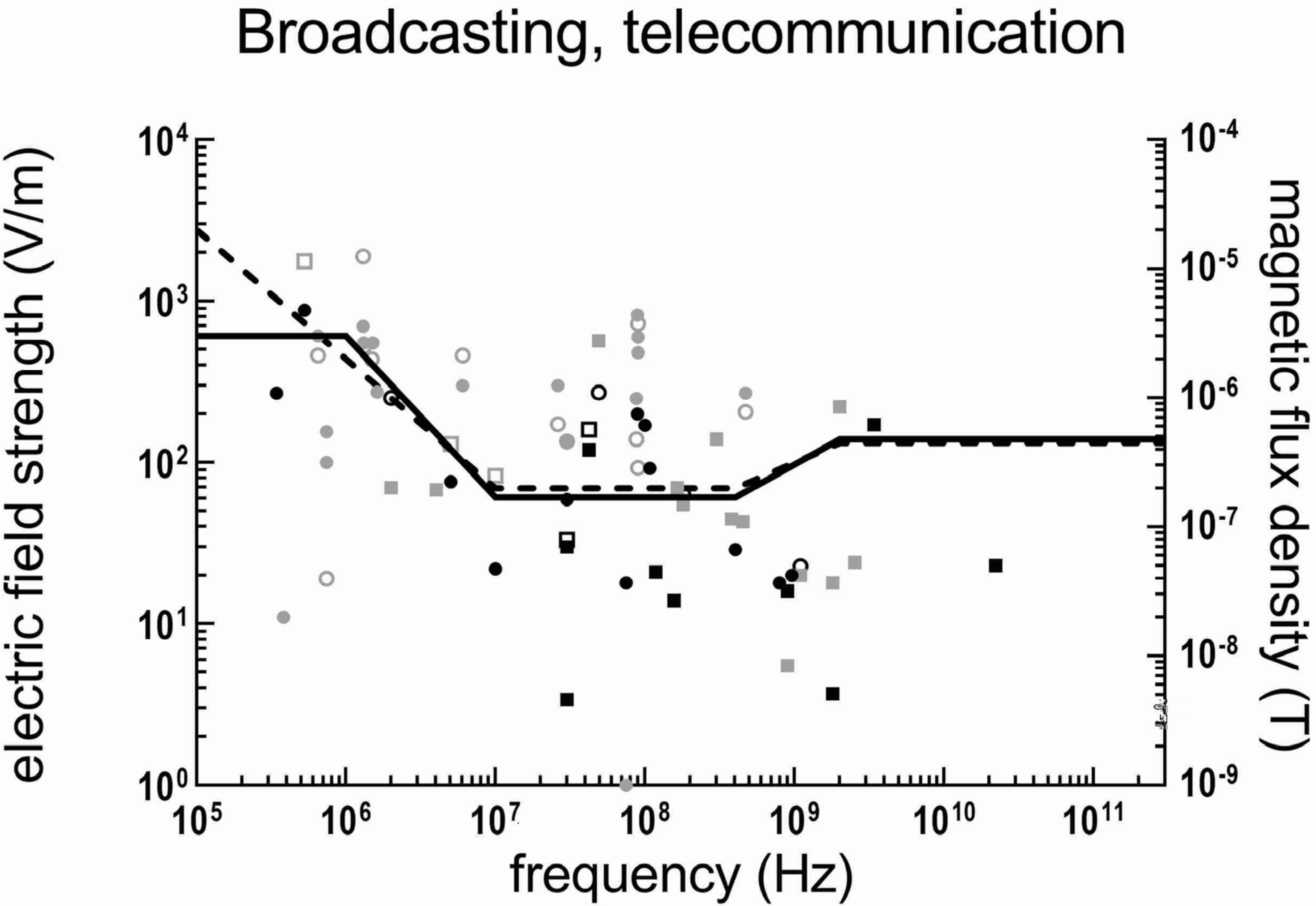


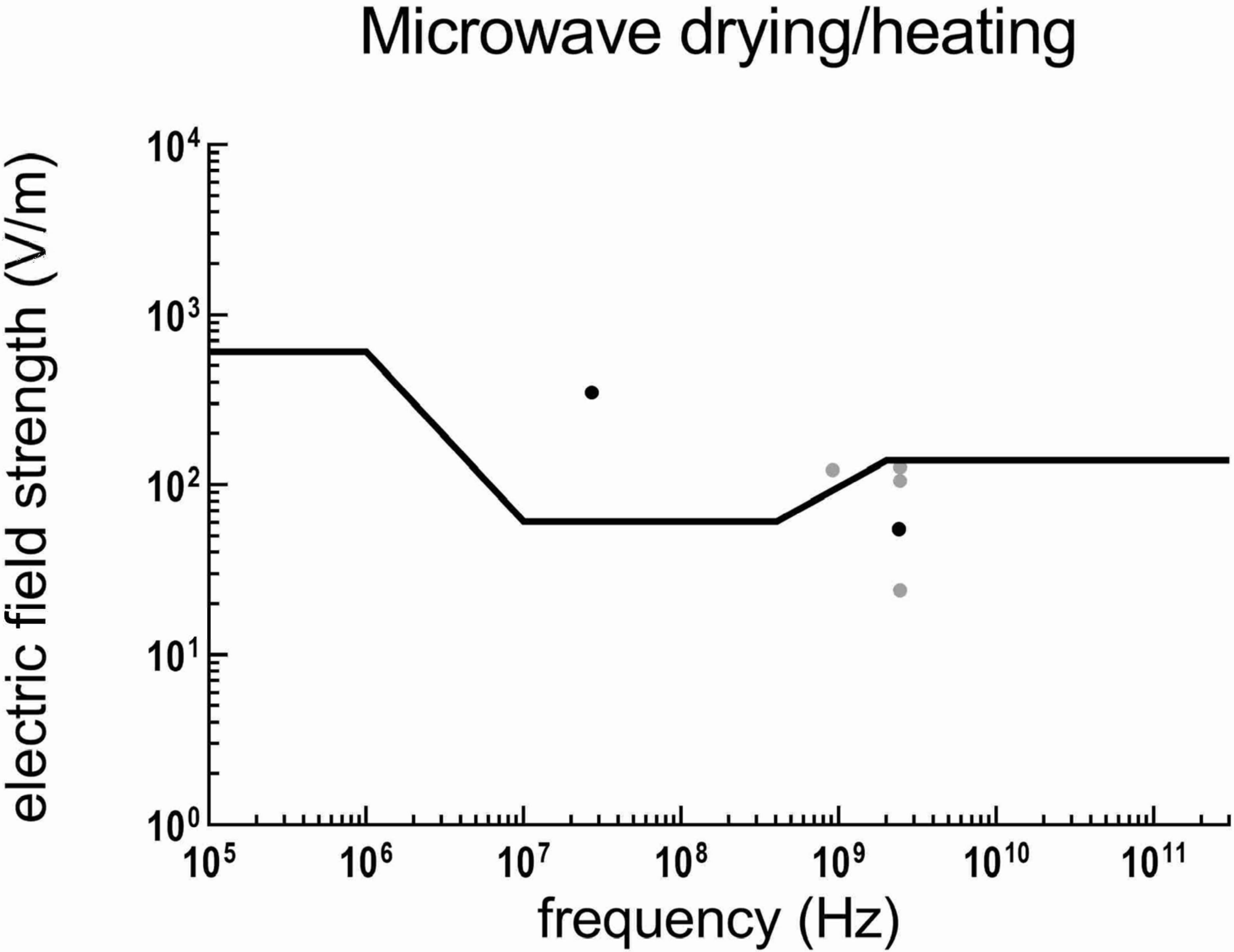
Plastic welding
electric field strength (V/m)
magnetic flux density (T)
frequency (Hz)
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}

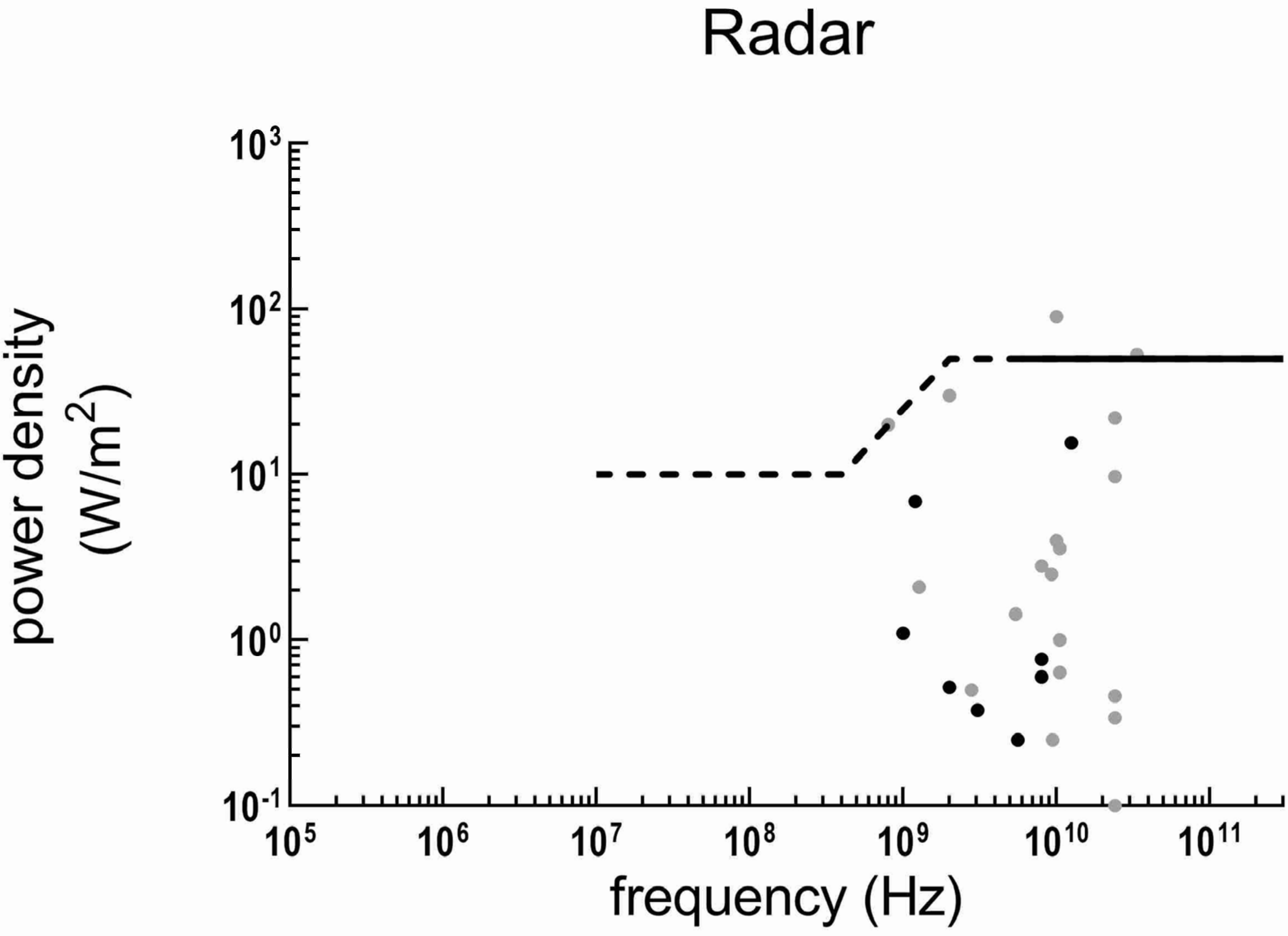

Security and RFID
electric field strength (V/m)
magnetic flux density (T)
frequency (Hz)
10^4
10^3
10^2
10^1
10^0
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^5
10^6
10^7
10^8
10^9
10^10
10^11



Plasma devices
electric field strength (V/m)
magnetic flux density (T)
frequency (Hz)
10^0
10^1
10^2
10^3
10^4
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}


Broadcasting, telecommunication
electric field strength (V/m)
magnetic flux density (T)
frequency (Hz)
10^4
10^3
10^2
10^1
10^0
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}


Microwave drying/heating
electric field strength (V/m)
10^4
10^3
10^2
10^1
10^0
10^5
10^6
10^7
10^8
10^9
10^10
10^11
frequency (Hz)


Radar
power density
(W/m2)
10-1
100
101
102
103
105
106
107
108
109
1010
1011
frequency (Hz)

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Review

Manmade Electromagnetic Fields and Oxidative Stress—Biological Effects and Consequences for Health

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Abstract: Concomitant with the ever-expanding use of electrical appliances and mobile communication systems, public and occupational exposure to electromagnetic fields (EMF) in the extremely-low-frequency and radiofrequency range has become a widely debated environmental risk factor for health. Radiofrequency (RF) EMF and extremely-low-frequency (ELF) MF have been classified as possibly carcinogenic to humans (Group 2B) by the International Agency for Research on Cancer (IARC). The production of reactive oxygen species (ROS), potentially leading to cellular or systemic oxidative stress, was frequently found to be influenced by EMF exposure in animals and cells. In this review, we summarize key experimental findings on oxidative stress related to EMF exposure from animal and cell studies of the last decade. The observations are discussed in the context of molecular mechanisms and functionalities relevant to health such as neurological function, genome stability, immune response, and reproduction. Most animal and many cell studies showed increased oxidative stress caused by RF-EMF and ELF-MF. In order to estimate the risk for human health by manmade exposure, experimental studies in humans and epidemiological studies need to be considered as well.

Keywords: oxidative stress; ROS; electromagnetic field; extremely low frequency; radiofrequency; environment and public health; environmental exposure; animal study; cultured cells

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1. Introduction

Reactive oxygen species (ROS), as well as related reactive nitrogen species (RNS), are involved in many biological processes; nonetheless, they pose a hazard to the biological material and physiology of cells [1–3]. Protective mechanisms, such as antioxidants and antioxidative enzymes, maintain physiological concentrations of ROS in cells, while external and internal stimuli affect the amount of ROS by altering the activity of involved ROS-forming and -degrading enzymes [4]. For example, an increased energy requirement during physical activity leads to a temporary state of oxidative stress, and many environmental risk factors such as ionizing radiation in ultraviolet (UV) light or the radioactivity spectrum partly act via the formation of ROS. Pathophysiological levels of ROS interfere with many vital cellular processes and functions, such as inflammation, cell proliferation and differentiation, wound healing, neuronal activity, reproduction, and behavior by altering biochemical and signaling processes or even resulting in oxidative damage to DNA, RNA, and proteins or to the peroxidation of fatty acids [5,6]. If this unfavorable state persists over a long period or occurs repeatedly, it can lead to changes in the biological material, as well as the genetic and epigenetic information, and it can lead to health-related malfunctions. Accordingly, altered ROS levels and changes in biomarkers of oxidative stress as cause or consequence have been observed in many diseases, such as cancer, diabetes, congenital malformations, or neurodegenerative syndromes [1,3].

The influence of electromagnetic fields (EMF), as a manmade environmental factor with increasing importance, on ROS formation, triggering oxidative stress, has been repeatedly discussed. Corresponding hypotheses and experimental findings have been summarized and discussed in previous reviews on this topic [7–16]. Although there is consistent evidence for EMF-induced ROS formation in experimental studies, a complete picture and a scientific consensus have not yet emerged with regard to epidemiological association and possible negative and long-term consequences for health.

In this review, recently published relevant animal and cell studies were identified and evaluated with the aim toward providing an updated assessment of a causality between oxidative stress and exposure to magnetic and electromagnetic fields and their possible effects on health. The focus was put on environmentally and technologically relevant frequency ranges: extremely-low-frequency magnetic fields (ELF-MF) typical for 50/60 Hz alternating current (AC) power lines and radiofrequency electromagnetic fields (RF-EMF) in the frequency range from 800 MHz to 2.5 GHz as used for current mobile communication systems. This primarily involved experimental studies in animals and cultured and/or primary cells published in the peer-reviewed literature from 2010–2020 (Supplementary Materials, Tables S1–S4). These studies provided data about the influence of exposure on the formation of ROS, markers of oxidative stress, and changes in protective mechanisms that counteract oxidative stress.

Some studies are purely descriptive or contain mechanistic aspects that specifically track and investigate correlations and influenced processes. In animal experimentations, the balance of ROS and the antioxidant counterparts in the whole organism can be studied. In addition, functional changes, which are mostly based on a permanent imbalance and are, therefore, important for health, can be evaluated in animal studies. In addition to investigations on biomarkers of oxidative stress, molecular, morphological, or functional changes, such as induced DNA damage, impaired learning and memory, organ abnormalities, and decreased sperm count or motility are more conclusive for estimating possible adverse health effects. Therefore, studies showing functional changes are considered particularly important for estimating the impact of EMF on human health.

In the following chapters, we summarize important findings from animal and cell studies on oxidative stress and EMF exposure by organ system and related cell types, and we assess their relevance for human health. Furthermore, general aspects are included, which are independent of cell type and/or organ/tissue but need to be considered for such an assessment.

For this narrative review, a subset of animal and cell studies published in the last 10 years in English language that were considered relevant for the research question were assessed and included, in order to provide an overview of the current research. The included studies were extracted from databases available at BERENIS (https://www.bafu.admin.ch/bafu/en/home/topics/electrosmog/newsletter-of-the-swiss-expert-group-on-electromagnetic-fields-a/beratende-expertengruppe-nis-berenis.html, accessed on 10 June 2020), EMF Portal (https://www.emf-portal.org/en, accessed on 25 June 2020), and PubMed (https://pubmed.ncbi.nlm.nih.gov, accessed on 30 June 2020).

2. Background Information on Oxidative Stress

The chemical processes of oxidation and reduction are the basis for all biochemical reactions that make biological actions and life possible. The relatively reactive molecular oxygen in our atmosphere plays a central role in the production of energy from sunlight, as well as in the conversion of this energy by cellular respiration in the mitochondria, making it available for other biological processes. It is important for the function of cells and organisms that the reducing and oxidizing molecules are roughly in balance. This is known as redox balance. It is referred to as oxidative stress if this balance is disturbed, usually by an increase in oxidative processes [2,3]. The oxidative state is controlled and maintained by the cell's own sensors, signaling pathways, and defense mechanisms, in which the transcriptional regulation of many antioxidative and cytoprotective enzymes by the NRF2–KEAP1 system, consisting of the redox state-sensing Kelch-like ECH-associated protein 1 (KEAP1) and the transcription factor nuclear factor erythroid 2 related factor 2 (NRF2), plays a central role [17,18].

2.1. Origin of ROS and Oxidative Stress

Oxidative stress occurs primarily when the amount of reactive oxygen species (ROS) exceeds the neutralization capacity. In addition to the superoxide ($\bullet O_2^-$) and hydroxyl ($\bullet$OH) radicals, these include hydrogen peroxide (H_2O_2) and singlet oxygen ($^1O_2$), as well as organic compounds [2,3]. A major source of ROS is the mitochondria, which are present in every cell and play a central role in the energy supply. ROS are formed during metabolic processes of the mitochondrial electron transport chain ("respiratory chain"), in particular the superoxide anion radical $\bullet O_2^-$, H_2O_2, and the hydroxyl radical $\bullet$OH. It is estimated that, in the mitochondrial respiratory chain, about 2% of the oxygen consumed is not converted to water but to superoxide radicals. Persistent oxidative stress may lead to the destruction of mitochondria, microfilaments, and proteins, which lose their function through oxidation, resulting eventually in an impairment of their function in metabolic processes.

Other important sources of ROS include the nicotinamide adenine dinucleotide phosphate (NADPH) oxidases (NOX) and metabolic processes involving, for example, heme-containing cytochromes such as detoxifying enzyme cytochrome P450 [1,3,4,19]. NOX enzyme complexes consist of several subunits and occur in several forms in different cell types [20]. They produce the superoxide radical from molecular oxygen, which, depending on the cell type or organ, is used not only to defend against pathogens but also as a signaling molecule. Accordingly, the NADPH oxidases are either located at cell membranes or at the membranes of specific organelles (phagosomes) of macrophages, neutrophil granulocytes, and dendritic cells of the immune system, where trapped microorganisms are killed [21].

In immune cells, as well as in many other cell types, reactive nitrogen-containing molecules, the gaseous free radical nitric oxide ($\bullet$NO), play a role in addition to ROS. This is produced by three types of ubiquitously expressed nitric oxide synthases (NOS), which exist as endothelial (eNOS), neuronal (nNOS), and inducible (iNOS) isoforms [1,2]. While eNOS and nNOS are calcium/calmodulin-regulated enzymes, iNOS represents a cytokine-inducible form, which leads to a strong nitric oxide (NO) synthesis in immune cells (macrophage and microglia cells), as well as in other cell types, and it is involved in immune processes and controlled cell death. NO itself is an important messenger substance that, for instance, is involved in the regulation of blood circulation by vasodilation, neuronal functions, and immune defense. While it is not cytotoxic per se at normal concentrations, NO can react spontaneously with superoxide to form highly reactive peroxynitrite, which can damage the DNA and proteins, while it is also used in macrophages, for example, to defend against infections. In addition to the Fenton chemistry pathways, the peroxynitrite pathway poses a major oxidative stress-related threat to biological material.

Superoxide radicals can be converted to hydrogen peroxide (H_2O_2) by superoxide dismutases (SODs). This family of enzymes is, thus, the first antioxidative line of defense to control the superoxide radical ($\bullet O_2^-$), a byproduct of oxygen metabolism or specifically produced in immune cells by NADPH oxidases [22]. With the participation of metal ions, they convert superoxide radicals to the less reactive H_2O_2. Superoxide dismutases occur in different variants in most living organisms and cell types and act in the cytoplasm, in the mitochondria, and in the extracellular space.

2.2. Protective Mechanisms

Although these reactive molecules can potentially cause damage to biological material and impede functionality, their presence and production should not generally be considered harmful. As indicated in some examples in the previous chapter, they are even indispensable for some biological functions and mechanisms [1,2,19,23]. For example, $\bullet$NO and H_2O_2 are not only involved in the immune response, but also play a central role in the regulation of the redox state. H_2O_2 is also required for wound-healing processes or the correct formation of protein structures. It is important for the organism to keep ROS concentrations at a tolerable level, which is achieved through the cooperative action of antioxidants and enzymatic protection mechanisms, controlled by the NRF2–KEAP1 pathway, the key regulator of oxidative state and xenobiotic detoxification [17,18]. For example, provitamin A, vitamins C and E, and glutathione (GSH) act as antioxidants.

In addition, a number of enzymes play essential roles in controlling ROS. Peroxidases are able to process different forms of reactive peroxides, with H_2O_2 and lipid peroxides being the most relevant biologically in mammals. Different strategies and cofactors are used to neutralize these radicals by the addition of electrons. The peroxidase named catalase (CAT) plays a key role in the antioxidative defense system of many living organisms. It breaks down H_2O_2 to water and oxygen and, thus, neutralizes it [1,3]. CAT occurs in virtually all cell types and fulfils its function in specialized cell organelles, the peroxisomes, or in the cytoplasm and mitochondria. Peroxiredoxins (PRDx) also degrade H_2O_2, as well as organic peroxides [24]. Among other functions, for example, they regulate the cytokine-mediated signaling cascades and occur as antioxidant enzymes in mitochondria and in red blood cells. Glutathione peroxidases (GPx) and the GSH system are also vital. In humans and mammals, several types of glutathione peroxidases with preferences for either lipid peroxides or H_2O_2 have been identified [25]. The variants of GPx occur in specific cell types, as well as extracellularly or in the plasma. These enzymes can remove peroxides in a multistep process, converting reduced GSH into oxidized glutathione disulfide (GSSG). By the action of the glutathione reductase (GR), GSSG is then converted back to GSH, which is the predominant form of glutathione and an important antioxidant under physiological conditions.

2.3. Detection of Oxidative Stress

Intracellular ROS concentrations depend on the balance between ROS generation and its elimination. In general, fluctuations in ROS production and the rapid response of the related protective mechanisms can be measured. Several experimental approaches have been described to detect ROS generation, with dyes turning fluorescent upon contact with ROS being the one that is most commonly used [26]. However, it has to be noted that specificity and sensitivity for a particular ROS species are limited, depending on the method and compound applied. The activity or amount of superoxide dismutases (SODs), catalases (CATs), or peroxidases can also be used as an indicator of oxidative stress. An important and frequently used biomarker for oxidative stress is the availability of GSH or, rather, the ratio of reduced to oxidized glutathione (GSH/GSSG). The activity of glutathione reductase also provides information on the redox state.

In addition to direct measurements of ROS production and the antioxidative defense process, damage to biomolecules or their degradation products can be detected, especially as indicators for sustained oxidative stress. An increase in oxidized bases in the DNA (i.e., 8-oxo-G/8-OHdG) and the carbonylation of proteins serve as surrogate markers for ROS. Malondialdehyde (MDA), a degradation product of unsaturated fatty acids, is also a frequently analyzed biomarker for oxidative stress [27]. Malondialdehyde is formed during normal enzymatic reactions, as well as by ROS-induced peroxidation of membrane lipids (lipid peroxidation). MDA itself is highly reactive and can lead to structural changes and damage to DNA and proteins. Elevated MDA levels are observed in many chronic diseases, and such pathological levels may contribute to a variety of long-term health impairments.

3. Impact of EMF on the Nervous System

Due to their longevity and limited renewal, neurons are considered particularly sensitive to oxidative stress. Oxidative stress caused by chronic inflammation may result in substantial cell damage. Thus, ROS formation and consistent oxidative stress have been associated with neurodegenerative diseases and aging [1,20,23], whereby—among many other factors and environmental influences—an involvement of EMF-induced oxidative stress is conceivable. On the other hand, many aspects of neuronal development, plasticity, and signal processing rely fundamentally on the formation of ROS to establish and ensure normal functionality [19,23,28]. Thus, temporal changes of ROS formation in brain cells do not necessarily have to result in negative and health-relevant effects.

3.1. Observations in EMF-Exposed Animals

After short- or long-time EMF exposure, ROS production and the related antioxidant defense systems have mostly been investigated in laboratory animals, namely rats and mice (Supplementary Materials, Tables S1 and S3). In addition to the basic question of whether EMF exposure causes oxidative stress, in some cases, information about its transient or permanent nature, requiring ROS measurements in several animal groups with different exposure durations, provided additional data with respect to health impact. However, well-founded conclusions on health impact are only possible if additional functional investigations, such as learning behavior or the occurrence of DNA damage, are also measured. Small group sizes, from five animals upward, are considered meaningful studies with experimental animals.

In the last decade, about 50 original studies in laboratory animals have been published on EMF exposure and oxidative stress in the brain. In a comprehensive work with Sprague-Dawley rats, increased ROS activity or formation of MDA, 8-OHdG, and serum nitrite was observed after 6 months of RF-EMF exposure at different frequencies (900, 1800, and 2100 MHz) for 2 h per day [29]. The whole-body specific absorption rate (SAR) of 0.174–0.638 W/kg was below the existing regulatory limits and recommendations. Concurrently, indications for increased DNA damage were found in the brain, which correlated with the applied frequency but was only significantly different from the sham controls at 2100 MHz. At the same time, the capacity of the antioxidative protection system was exhausted as the measured antioxidative markers were significantly lower compared to sham-exposed animals [29]. These results indicate that oxidative stress induced by RF-EMF can lead to DNA damage in neurons during prolonged exposure of the animals. Virtually identical results were also found in several other studies [30–34]. In the study by Megha et al., Fischer-344 rats were exposed to RF-EMF with frequencies of 900, 1800, and 2450 MHz at whole-body SAR values of 0.59, 0.58, and 0.66 mW/kg, respectively, for 60 days (2 h/day and 5 days/week) [32]. Biomarkers for oxidative stress (including MDA) and various inflammatory markers were augmented correlating with the increasing frequency, while the antioxidative activity (SOD, GSH) decreased [32]. Similar observations were reported by Sahin et al., who measured increased ROS production in the brain of Wistar rats after universal mobile telecommunications system/third generation (UMTS/3G)-modulated RF-EMF exposure (2100 MHz, whole-body SAR: 0.4 W/kg; 6 h/day and 5 days/week) [33]. However, this ROS increase occurred only after 10 but not after 40 days of exposure, correlating with DNA damage but decreased lipid peroxidation in brain cells [33]. The absence of DNA damage after 40 days may indicate adaptation to exposure or enhanced capacity of DNA repair. Evidence for adaptation to or recovery from induced oxidative stress by 900 MHz RF-EMF (2.5 mW/cm^2, 1 h/day) was also observed in male Sprague-Dawley rats. ROS levels were elevated in the brain after 60 days of irradiation. However, ROS levels were not different from controls after a regeneration phase of 30 days without irradiation [35]. Correlating with exposure duration, changed levels of DNA damage were also found in hippocampal cells after 900 MHz RF-EMF exposure [34]. RF-EMF exposure for 90 days (1–4 h/day, 5 days/week at 0.231 W/kg) increased ROS formation, reduced antioxidative markers (SOD and CAT), and induced the formation of inflammatory cytokines. In addition, neuronal cell degeneration and other morphological changes in the brain were observed [34]. In contrast, an increase in oxidative stress was induced by RF-EMF exposure without affecting DNA damage levels in some other studies [36–39].

Adding to the studies with functional aspects, descriptive studies including analyses of ROS with and without measurements of antioxidative biomarkers were also published. With respect to health effects, they are less conclusive, especially if no data are available on whether the observed effects are temporary or persistent. Nevertheless, most of the studies indicate changes in ROS formation and/or oxidative stress biomarkers [35,40–46], examining and demonstrating morphological changes of the brain tissue in some cases [35,42,43,46–48]. The study by Kesari et al. described an increase in ROS formation and an elevation of oxidative stress markers, a marked reduction of antioxidative markers, and increased apoptosis rates in the brain of Wistar rats exposed daily for 2 h to 900 MHz RF-EMF for 45 days (pulsed at 217 Hz; SAR: 0.9 W/kg) [49]. The effects of exposure on this readout were measured once after an exposure period of 45 days, suggesting that prolonged RF-EMF exposure did not lead to exhaustion of ROS production and/or adaptation in this case. Similarly, RF-EMF (915 MHz, 0.79 mW/cm^2) exposure of male Wistar rats for 1 h/day for 1 month resulted in increased oxidative stress and NO formation and reduced antioxidant markers [50]. These purely descriptive studies have limitations, especially when a cell phone was used for exposure, dosimetry was missing, and/or no SAR value or dose was provided. The marker for ROS-related DNA damage, 8-oxo-G, was also increased after RF-EMF exposure (2.45 GHz, whole-body SAR: 0.2 W/kg for 30 days and 1 h/day) in rat brains, while oxidative protein products were not altered [44]. Again, this is a descriptive study, which focused on possible antioxidant effects of garlic extracts, similar to a second study by another group [41], in which RF-EMF (1.8 GHz, whole-body SAR: 0.4 W/kg, 1 h) after 3 weeks of exposure showed an increase in protein oxidation, as well as more NO in the brain. Lipid peroxidation in the brain was found at whole-body SAR values in the range of 0.1–0.3 W/kg [48].

Shahin et al. (2017) also found an increase in ROS and associated changes in the antioxidative defense system in the hypothalamus of female Swiss mice exposed to 1800 MHz RF-EMF for 100 days with no SAR value reported [51]. The same group reported changes in stress-related hormones and associated markers in the hippocampus of male Swiss mice exposed to 2.45 GHz RF-EMF at 0.0146 W/kg SAR for 15, 30, or 60 days [52]. This stress, probably associated with induced NO production and signaling, led to reductions in learning and spatial memory performance of these mice. Long-term exposure for 8 months at 1950 MHz (SAR: 5 W/kg, 2 h/day for 5 days/week) revealed no remarkable differences in programmed cell death, oxidative stress, apoptosis, genotoxicity, and motor activity in 14 month old female mice (C57BL/6J) compared to controls [37]. An increase in oxidative stress was observed in the animals due to age, but RF-EMF exposure did not induce oxidative stress, and the movement behavior of the animals was not affected.

An increase of ROS markers compared to sham-exposed and cage controls was also seen in the spinal cord of very young and middle-aged Sprague-Dawley rats after 900 MHz RF-EMF exposure (1 h/day, calculated whole-body SAR: 0.01 W/kg) for 25 days [53]. Interestingly, biomarkers for antioxidative activity were elevated, indicating that the capacity of the antioxidant system was not yet exhausted and presumably able to counteract ROS formation. Nevertheless, morphological alterations of the spinal cord, such as tissue loss, vacuolation, and changes in myelin integrity, were observed, which might compromise proper neural signal transmission. Such changes, particularly demyelination and scarring of the myelin sheath, occur, for example, in multiple sclerosis. Changes in neurochemical parameters, as well as pathophysiological damage caused by inflammatory processes in various brain regions (i.e., hippocampus and cortex), are usually associated with reduced memory performance, DNA damage, and/or apoptosis. Correlating with the frequency of the radiation, such effects were reported by Megha et al. upon low-intensity RF-EMF exposure (whole-body SAR: about 0.6 mW/kg) [32]. They provided scarce information on the dosimetry, and the actual exposure in the brain is likely to be different from the estimated whole-body SAR values. However, an increased ROS production was found in the brain of rodents at higher SAR values (>1 W/kg) [35,43,54,55]. Ertilav et al. reported an increase in ROS in hippocampal neurons as well as in dorsal root ganglia after RF-EMF exposure of young female Wistar rats [43]. Rats were exposed to 900 or 1800 MHz RF-EMF with 217 Hz pulses for 12 weeks (1 h/day, 5 days/week) at an average whole-body SAR of 0.1 W/kg (local SAR ranging from 0.01–1.1 W/kg with the highest values for the head region). Transient receptor potential cation channel subfamily V member 1 (TRPV1) currents, intracellular calcium concentrations, mitochondrial membrane depolarization, and apoptosis were also significantly enhanced in neuronal cells of exposed animal in a frequency-dependent manner [43]. These observations are potentially relevant due to the role of spinal ganglia the hippocampus in pain transmission and behavior, as well as cognitive functions, although no functional experiments on pain or memory performance have been performed. Neither measurements nor calculations of SAR levels in the brain and spinal cord have been presented and, therefore, the level of exposure of these tissues remains unclear.

An impairment of learning behavior and memory performance by exposure was observed in other studies [56–58]. Tang et al. reported a reduction in memory performance in male Sprague-Dawley rats after 900 MHz RF-EMF exposure (whole-body SAR: 0.016 W/kg, brain SAR: 2 W/kg) for 28 days, associated with changes in the activity of the mitogen-activated protein kinase signaling pathway (mpk-1, external signal-regulated kinase (pERK)) [57]. Similarly, cognitive performance of Fischer-344 rats was decreased after a 900 MHz RF-EMF exposure for 30 days (whole-body SAR: 0.0058 W/kg), which was associated with increased oxidative stress and inflammatory markers in the brain [56]. Exposure to 1500 MHz RF-EMF decreased SOD levels in the brain of Wistar rats, correlating with neural toxicity and changes in learning and memory performance [58]. Thus, the findings of these studies suggest that increased formation of ROS by RF-EMF exposure is associated with an impairment of cognitive abilities.

There have been only a few studies in Wistar rats exposed to a Wireless Fidelity (WiFi) signal (2.45 GHz) [50,59–61]. Othman et al. found impaired neurodevelopment in offspring during the first 17 postnatal days, an increase in cerebral ROS and lipid peroxidation on postnatal day 28 but not 43 after prenatal exposure for 2 h/day, and decreased antioxidant levels (CAT, SOD) [61], indicating an exhaustion of the antioxidative capacity in the brain. In a study from the same group, prenatal WiFi exposure in combination with physical constraint was associated with increased anxiety behavior, motor deficits, and impaired exploratory behavior in adult male rats. Restrained animals, WiFi-exposed rats, and a combination of both resulted in increased oxidative stress in the brain in both sexes [60]. WiFi exposure of adult male Wistar rats alone or with physical constraint impaired the learning behavior and memory performance accompanied by an oxidative stress response in the brain. [59]. Albeit having some methodological shortcomings, the study by Asl et al. also showed increased ROS and NO production in rats exposed to RF-EMF/WiFi (2450 MHz; 0.98 mW/cm^2) [50].

In the context of neurological disorders, the immediate response to short-term RF-EMF exposure was also assessed. In a mouse model with chemically induced epilepsy, the influence of RF-EMF on oxidative stress caused by epilepsy was investigated, exposing them (900 MHz, SAR: 0.3 W/kg) for 15 and 30 min before and/or after induction of the epileptic seizures [62]. While the antioxidant activity was significantly reduced, markers for ROS and lipid peroxidation in the brain were induced, whereby the time-point of RF-EMF exposure was not pivotal for the observed effects. In an Alzheimer's disease model, the stress marker cortisone and markers for oxidative stress in the brain of rats after RF-EMF exposure for 15 min (1.5, 6 W/kg) and for 45 min (6 W/kg) were measured, coincidental with the assessment of memory performance. While oxidative stress in the brain increased, cortisone levels and memory performance of RF-EMF-exposed Alzheimer's animals decreased markedly, an effect that was not observed in wildtype (devoid of Alzheimer) animals [63]. This study indicates that animals with a prior neurodegenerative condition might be more sensitive to RF-EMF exposure.

Compared to neuronal effects of RF-EMF, fewer studies have been published for the low-frequency range in the last decade. A dose-dependent increase in ROS, lipid peroxidation, and decreased antioxidant defense were observed in different brain regions of young male Wistar rats continuously exposed to 50 Hz ELF-MF (50 and 100 µT) for 90 days [64]. More pronounced at the higher field strength, the production of ROS was also increased and the antioxidant response decreased after ELF-MF exposure (100 and 500 µT, 50 Hz) of male Sprague-Dawley rats for 2 h/day for a total duration of 10 months [65]. Similar results were obtained in a study with shorter exposure duration. In male rats exposed to ELF-MF (500 µT, 50 Hz) for 7 days, ROS was increased in various areas of the brain and increased lipid peroxidation and activity of the protective antioxidative mechanisms were observed [66].

At higher magnetic field strengths (2.3 mT), increased ROS production was observed in the cerebellum of male mice (Balb/C) after a short exposure (3 h) with 60 Hz ELF-MF, while some antioxidative markers were elevated (SOD, ascorbic acid) and others remained unchanged (GSH, GPx) [67]. Apparently, antioxidative processes are initiated after such a short exposure period. However, it is not expected that the antioxidative system is already exhausted or impaired, indicating a state of oxidative stress as in studies with longer exposure. For example, ROS production, as well as lipid peroxidation, in the brain of young male Sprague-Dawley rats was altered after 40 Hz ELF-MF exposure (7 mT), depending on the duration of daily exposure (30 versus 60 min) for 10 days [68]. In this situation, 30 min of daily exposure was sufficient to increase lipid peroxidation, while detectable ROS formation required 60 min exposure, suggesting a threshold for exposure duration or cumulative dose.

As mentioned before, confinement stress caused by animal exposure in tubes can lead to systemic oxidative stress. In the study by Martinez-Samarano et al., an alteration of various biomarkers for oxidative stress (SOD, CAT, NO) and increased ROS levels were measured in the brain of male rats after acute 60 Hz ELF-MF exposure for 2 h (2.4 mT), whether in cages or in tubes [69]. SOD levels were significantly lower in restrained ELF-MF-exposed animals compared to animals in cage controls and the respective sham controls. CAT levels were reduced in ELF-MF-exposed animals in cages when compared to the sham control, but a difference in CAT levels was found when the rats exposed in tubes were compared to the corresponding sham control. NO levels were significantly lower in rats exposed to ELF-MF in tubes compared to all other groups. These data show that ELF-MF induces an adaptive response even at short-term exposure, leading to activation of protective antioxidative measures. The stress hormone cortisone was elevated only in control animals that spent time in tubes, while ELF-MF exposure did not alter the outcome [69]. There are also indications of inflammatory response in the brain. NO was elevated in various brain regions of male Sprague-Dawley rats exposed to a 60 Hz ELF-MF (2 mT) for 5 days, which was supported by an increased level of nNOS [70]. Nevertheless, the number of neurons remained unchanged and ultrastructural examinations of the mitochondria did not reveal any differences compared to the controls. As NO can react with superoxide, this could then lead to damage of DNA and proteins, depending on its extent. However, no further investigations in this direction were performed, precluding a firm statement about damage to both biomolecules by ELF-MF.

In addition to duration and dose of exposure, the age of the animals is also a factor influencing the defense mechanisms against stress factors since defense and counter-regulatory mechanisms decrease with age [71]. In line with that notion, Falone et al. showed that the extent of antioxidative defense mechanisms in the cerebral cortex of female Sprague-Dawley rats depended on age, regardless of exposure [72]. The antioxidative capacity was less efficient in 19 month old animals compared to 3 month old animals, yet an influence of 50 Hz ELF-MF exposure (100 μT) for 10 days on the antioxidative activity was observed overall. CAT activity was significantly decreased and SOD and GSH reductase were increased in the young rats after ELF-MF exposure. In young animals, this was accompanied by signs of increased neuromodulation (elevated levels of nerve growth factor NGF and tropomyosin receptor kinase A TrKA). Such neurotrophins cause targeted connections between neurons and lead to activation of cellular signaling pathways, which may ultimately result in an antiapoptotic effect. In contrast, older rats were not able to stimulate such protective processes, and a marked reduction in antioxidative parameters was found in the brain [72,73]. These results suggest that EMF might be a risk factor in older individuals due to their reduced capacity of antioxidative defense.

Environmental cofactors may also modulate the occurrence and response of oxidative stress. In the brain of Kumming mice, the effect of aluminum with and without 50 Hz ELF-MF irradiation (2 mT) for 6 days/week and 8 weeks on the occurrence of oxidative stress, as well as Tau and phosphorylated Tau proteins, was investigated. The Tau protein is important in neurodegenerative syndromes such as Alzheimer's disease, as it binds to microtubules in cells, regulating their cohesion. ELF-MF exposure caused an increase in ROS and a reduction in the measured antioxidative biomarkers, while the additional administration of aluminum did not promote any further impairment [74]. Structural abnormalities, a reduction in the number of neurons, and changes in the phosphorylated form of Tau at S404 and S396 indicated neurodegenerative effects of subchronic ELF-MF exposure, which was supported by the impairment of learning and memory performance in ELF-MF-exposed animals.

Overall, the studies related to RF-EMF and ELF-MF show that various factors are influencing the response to EMF exposure. In addition to duration and dose of exposure, adaptive processes and age-related capacities to respond to oxidative stress are of central importance.

3.2. Observations in EMF-Exposed Cultured Neuronal Cells

In support of the findings in animals, EMF-induced oxidative stress was also most frequently investigated in cultured cells of neuronal origin (Supplementary Materials, Tables S2 and S4). In the last 10 years, more than 30 manuscripts have been published, in which, among other endpoints, the influence of EMF on the formation of radicals and ROS or biomarkers for oxidative stress was analyzed, about half in the low- and half in the radio-frequency range. The cell models used were largely tumor cells of neuronal origin (neuroblastoma: SH-SY5Y, NB69, Neuro-2a; glioma: U-87MG, C6; pheochromocytoma: PC12), in addition to established cell lines (HT22) and primary neurons of the brain, as well as astrocytes from humans and rodents.

The influence of ELF-MF was mainly investigated in tumor cell lines, where exposure was frequently found to influence ROS formation or markers of oxidative stress and to lead to changes in the antioxidative defense system. It is important to note that tumor cells often have an intrinsically disturbed oxidative balance and may, therefore, react differently to EMF or other treatments than a normal cell. However, primary neurons from the brain also reacted to repeated 50 Hz ELF-MF exposure at a flux density of 2 mT by an increased production of ROS, an upregulation of the NADPH oxidase NOX2, and faster neuronal cell death, especially pronounced in older cell cultures [75]. This indicates that the findings from the experiments with tumor cells are at least partially transferable to normal and immortalized cells. For example, slightly elevated values for superoxide and H_2O_2 were found in SH-SY5Y neuroblastoma cells [76–78] when exposed to a 1 mT field for 1–3 days. In addition, the increase in ROS was attenuated by SOD administration [79] and changes in various markers of oxidative stress (CAT activity, oxidative protein modification) were observed. On the other hand, the increase in ROS appeared to be more pronounced when acute cell responses, about 1 to 6 h after exposure start, were evaluated [78,80]. Simultaneously, an increased activity of the NO synthase was observed, which might indicate a function of ROS and NO as a signaling molecule in this context. In fact, there is evidence for ROS-mediated alteration of cellular signaling pathways by ELF-MF exposure from studies with neuroblastoma cells [77,81]. In addition, it was found in PC-12 tumor cells that a short ELF-MF exposure of 30 min (0.1 and 1 mT) induced a differentiation process mediated by a rapid increase in ROS formation [82]. This increase in ROS did not occur when the cells were advanced in the differentiation process or exposed for a longer period of time [82,83]. Similar mechanisms involving ROS formation as a signaling molecule seemed to work when mesenchymal stem cells from human bone marrow were differentiated into neural cells under 50 Hz ELF-MF exposure (1 mT) [84,85]. Here, the efficiency and proportion of differentiation to the distinct neural cell types was altered by exposure, most likely because the increased ROS formation triggered or modified signaling cascades.

It is possible that a constant stimulation of ROS formation cumulatively boosts the antioxidative defense systems. Therefore, after short exposures, little or no evidence of antioxidative stress markers, such as the ratio of GSH/GSSG, can be detected [86], while, after longer exposure, increases in these markers, as well as changes in cell response to additional stress, were observed [76,87]. In this context, it is also worth mentioning that similar observations were also made for weaker ELF-MF ($\leq$100 µT) in combination with other triggers of oxidative stress, whereby the cellular adaptations and consequences were still detectable for a prolonged time [88–91]. Hence, there is quite consistent evidence that exposure to 50 Hz ELF-MF leads to increased formation of ROS in cultured cells of neuronal origin. As a consequence, activation of a variety of cellular regulatory mechanisms triggers corresponding cell responses, whereas it may also lead to persistent oxidative stress situations.

Similar observations were made in RF-EMF-exposed neuronal cells, although the findings were less consistent and partly even contradictory. This could also be due to the technically and dosimetrically more demanding implementation in this frequency range and the diversity of the investigated RF-EMFs with respect to dose, carrier frequencies, inclusion of signal modulation, etc. For example, in isolated rat neurons exposed to a 1.8 GHz global system for mobile communications/second generation (GSM) signal for 24 h, increased ROS formation, in addition to signs of DNA damage and reduced functionality of mitochondria, was found at 2 W/kg SAR [92], whereas this increase was only significantly detectable at 4 W/kg SAR in another study [93]. In isolated astrocytes of humans, mice and rats, however, there was no evidence of an increase in ROS by 900 MHz GSM signals for 24 h, and there was even less ROS produced in the mitochondria (SAR: 0.2 W/kg) [94]. Similarly, no signs of inflammation, such as more iNOS or NO formation, were found in astrocytes after exposure to 1.8 GHz RF-EMF for 1–24 h (SAR: 1 W/kg) [95], although an acute increase in ROS after 20 min of exposure to modulated but not unmodulated 900 MHz RF-EMF was found [96]. On the other hand, in a mouse neuronal cell line, exposure to a 1.95 GHz RF-EMF (UMTS/3G signal) showed marginal effects on ROS formation and other parameters on its own, but differentially modulated signaling pathways and cytotoxicity when ROS formation was triggered by glutamate or β-amyloid [97,98].

A series of studies have been conducted with neuronal tumor cells. No increase in ROS formation was found in SH-SY5Y neuroblastoma or U-87MG glioma cells after acute exposure to 872 MHz RF-EMF (GSM signal or carrier wave, SAR: 5 W/kg) [99,100], a 900 MHz GSM signal (SAR: 4 W/kg, 2 min on/off) [101], a combination of modulated 867/1950 MHz RF-EMFs (SAR: 4 W/kg) [102], and a 1.8 GHz GSM signal (SAR: 2/10 W/kg) [103]. In short-term co-exposure experiments, the effect of an ROS-triggering substance such as menadione and H_2O_2 was amplified by these RF-EMFs [99,102]. In contrast, these cell types reacted to a non-modulated 1.8 GHz RF-EMF and comparable exposure duration with the formation of ROS, oxidative protein modification, lipid peroxidation, and alteration of the antioxidative defense system (GSH) [104,105]. Similar to the observations for ELF-MF, the ROS increase seems to be more prominent after short rather than after continuous ($\geq$12 h) RF-EMF exposure [94,103,105]. For prolonged exposure, there are once more indications for a boost of the antioxidative defense system, an impact on mitochondrial function and autophagy activity [101,106], and even an accumulation of DNA damage and cell death [92,105,107].

3.3. *Assessment of EMF-Induced Oxidative Stress in the Nervous System*

In general, a distinction must be made between studies that are purely descriptive and those that simultaneously investigate functional effects, such as learning and memory performance. The latter ones provide more information on a possible health-relevant impact on the animals due to increased oxidative stress caused by EMF exposure. It is also important to note that, for the assessment of health relevance, ROS formation and temporary oxidative stress are not harmful per se [1,3,4,23]. These reactive molecules are also part of physiological processes and fulfil functions, for example, in the immune response or the correct formation of protein structures. Damage with possible health relevance only occurs if the redox equilibrium, which is controlled and maintained by sensors, cellular signaling pathways, and protective antioxidative mechanisms, is disturbed over a long period of time, either permanently or repeatedly. If the latter is the case, various physiological processes such as cell proliferation, neuronal differentiation and activity, and development are affected. ROS formation and decreased antioxidative counter-regulation also occur in aging processes. Therefore, models investigating the influence of EMF exposure on the redox system are of interest and importance for a possible impairment of old individuals or those with pre-existing damage (neurodegeneration). Oxidative stress is the cause and/or consequence of neurodegenerative syndromes such as Alzheimer's and Parkinson's disease, which are accompanied by reduced learning and memory performance.

An increased occurrence of ROS, as well as the burdening and exhaustion of antioxidative mechanisms after exposure to different EMF in the radiofrequency range and SAR, even at values below the recommended regulatory limits, and damage to the DNA were associated with prolonged exposure over weeks or months, applied in many cases only for a few hours per day [29–34]. However, one study also reported that recovery and a return to normal values after the end of exposure occurred [35].

Studies on mechanisms such as those related to calcium channels are particularly informative as calcium concentration-dependent cellular responses may result in a multitude of pleiotropic effects [9]. Voltage-gated calcium channels were shown to be activated by nonthermal pulse-modulated 27 MHz RF-EMF, leading to an increase in NO [108] while nonselective calcium channels such as transient receptor potential (TRP) channels are activated by oxidative stress [109,110]. For instance, the TRPV1 channel, belonging to the calcium-permeable TRP superfamily, can be activated not only by stimuli such as heat and capsaicin, but also by oxidative stress. Activation of TRPV channels by oxidative stress/EMF was demonstrated to result in an increase in neuronal calcium concentrations that may lead to physiological changes and pathological processes such as apoptosis [43,111,112]. The occurrence of TRPV1 is particularly high in neurons of the hippocampus and in spinal ganglia, where it is probably involved in the transmission of pain, which is impaired in neurodegenerative processes [109,110].

In part, the changes in redox balance were accompanied by morphological changes that resemble those in neurodegenerative diseases [34,35,42,43,46–48,53]. In general, studies, in which ROS, antioxidative markers, learning behavior, and memory performance were examined, suggest an impairment of neuronal functions of the animals. Thus, there is evidence that, at least in animal models, increased ROS production by EMF is associated with an impairment of cognitive abilities [51,52,56–60]. Notably, RF-EMF exposure affected the memory performance of animals with neurodegenerative pre-damage of the brain (i.e., Alzheimer's disease model) more than in control wildtype animals [63], indicating an enhancement of conditions of impaired learning behavior by RF-EMF. In addition to such pre-existing conditions, other environmental or risk factors may also play a role in whether and to what extent oxidative stress due to EMF exposure occurs. There is evidence that age is such a risk factor [72]. Due to their reduced antioxidative capacity in the brain, older individuals are less efficient in compensating for increased ROS formation, and adaptive processes are exhausted more quickly than in young individuals [71]. Newborns are also more vulnerable to oxidative stress, as antioxidative protection mechanisms are not fully developed in the first days or weeks of life, depending on the species.

Methodological factors must also be taken into consideration when evaluating experimental studies. Often, RF-EMF exposure was performed in carousel exposure systems, in which the animals are placed into narrow tubes during exposure, facilitating a homogeneous and defined exposure. However, this procedure provides a source of error if the animals are not trained in advance, since restraint stress can also lead to oxidative stress [69]. In these experiments, sham controls and prior training of the animals to the conditions of exposure are important. In addition to increased ROS production, a change in the anxiety behavior, but not in memory performance, was found after WiFi exposure of rats exposed in tubes, which was enhanced by the exposure [59,60].

ROS formation and impairment of antioxidative protection measures by EMF were demonstrated in cell studies with neurons or neural cells, which aim at understanding the mechanisms underlying the observations in animal models. There is consistent evidence that cellular signaling pathways regulated by ROS are affected [77,81,82,97,98]. The extent of induction, as well as the possibility of counter-regulation has to be considered, presumably requiring a threshold level or persistence to translate to health impairment. It seems that the degree of cell differentiation or age is critical; cells that were further differentiated generally were less sensitive compared to undifferentiated cells or cells in an early stage of differentiation [75,82,84,85]. It is noteworthy that the induction of ROS and signs of oxidative stress appear to be more reproducible in neural cells exposed to ELF-MF than to RF-EMF [75–82,92–94,96–105,113]. Higher doses of RF-EMF exposure mostly resulted in more pronounced effects, although not consistently, and a temperature increase or other confounders cannot always be excluded [92,93,96,99–103]. Other methodological factors, such as keeping sham controls in a separate incubator, pose a risk of false-positive findings [114,115]. For example, vibrations, as well as EMF of the incubator or its inadequate shielding, come into play, and it cannot be excluded that these factors influenced the measurement parameters recorded in some studies. The duration of exposure seems to play a role, whereas a shorter exposure for few hours rather than prolonged ones led to increased ROS production and a temporal reduction in antioxidative processes [78,80,94,96,103,105].

4. EMF Effects on the Blood and Immune System

The influence of technology-related EMF on cells of the immune system has also been a frequent topic of investigation in recent years [8,11,12]. The functioning of the immune system is inseparably connected to the formation of ROS and NO. ROS and NO play a vital role in the elimination of foreign or damaged cells by phagocytosis and are involved in the inflammatory reaction and activation of the immune response [2,21]. In this respect, it is conceivable that suppression, as well as a constant activation, of these processes by EMF could lead to impairment of health. Therefore, the influence of EMF on various aspects of immune responses and the development of hematopoietic cells and the microglia cells as a functional equivalent in the central nervous system have been studied (Supplementary Materials, Tables S1–S4).

While several publications on oxidative stress and EMF exposure in isolated and cultured blood and immune cells are available, the number of animal studies is limited, whereof only some of them provided information on ROS markers in blood.

4.1. Oxidative Stress in EMF-Exposed Animals

Exogenous influences, such as stress, can alter the organism's response to subsequent stimuli. In a short-term study, mice were exposed to 900 MHz RF-EMF (SAR: 0.5 W/kg) 4 h/day for 1 week before treating them with the cancer medication bleomycin [38]. This substance acts by oxidation of molecules, leading to oxidative stress, and causes DNA damage among other implications. Interestingly, leukocytes of RF-EMF-exposed animals were less damaged by bleomycin compared to controls, and ROS was decreased in the plasma and some tissues, while SOD was increased in the lung [38]. These findings suggest that RF-EMF exposure may cause systemic changes, which in turn affects the cellular response to other stressors. This phenomenon is known as "adaptive response", which is likely to play an important role in real life situations where many stress and environmental stimuli occur simultaneously. Related findings were obtained in young and adolescent Wistar rats after 900 MHz RF-EMF exposure (SAR: 0.28–0.78 W/kg) [116]. ROS and oxidative stress markers were measured directly after 45 days of exposure for 2 h per day or following a recovery period of 15 days [116]. This approach facilitates the determination of postexposure persistence and the ability of the organism to counteract the oxidative stress. RF-EMF increased the antioxidative activity in all lymphoid organs regardless of the age, and that the recovery period was insufficient to return to normal SOD levels when exposure was started at 2 weeks compared to the animals at 10 weeks of age. As oxidative stress biomarkers were elevated in all animals after RF-EMF exposure, this difference may originate from the fact that the enzymes of the protective antioxidative defense system are not yet fully developed or present in the very young rats. Depending on the marker, the normalization in the recovery phase was more successful in the 10 week old rats. In most of the lymphoid organs, as well as in plasma and lymphocytes, increased lipid peroxidation was seen directly after exposure and at the end of the recovery phase [116]. This comprehensive and well-documented study shows, on the one hand, that the oxidative stress situation may persist for a longer period of time and, on the other hand, that very young individuals are less able to compensate for the increase in ROS.

In Wistar rats, similar results were demonstrated, including increased lipid peroxidation due to exposure to 2.45 GHz WiFi-like signals for 35 days (50 Hz pulses, whole-body SAR: 0.14 W/kg) in the spleen [48] and for 28 days (217 Hz pulses, SAR: 0.143 W/kg, 45 min/day) in plasma and erythrocytes [117], accompanied by a reduced activity of antioxidative markers. Furthermore, oxidative DNA (8-oxo-G) and protein products, indicating oxidative stress, were elevated in plasma cells of rats after a daily 1 h exposure to 2.45 GHz RF-EMF (whole-body SAR: 0.2 W/kg) for 30 days [44]. Signs of oxidative stress were described in RF-EMF-exposed mice. Changes in ROS and enzymes of antioxidative defense (SOD, CAT, glutathione *S*-transferase (GST)) were found in blood, as well as in the liver, kidneys, and ovaries, of pregnant Parkes mice exposed to 2450 MHz RF-EMF (SAR: 0.023 W/kg) for 45 days [118]. The same group also reported changes in stress-related hormones and associated markers in the blood of Swiss mice exposed to 2450 MHz RF-EMF (SAR: 0.0146 W/kg) for 15, 30, or 60 days [52]. In contrast, no effects on oxidative stress, lipid peroxidation, or elevated NO levels were measured in the blood serum of Wistar rats upon exposure to 1.8 GHz RF-EMF (whole-body SAR: 0.4 W/kg) daily for 1 h for 3 weeks [41]. Likewise, lipid peroxidation and reduced GSH were not increased in the blood of rats that were exposed to UMTS-modulated RF-EMF daily for 40 min for 2 weeks [119]. However, the animals were exposed using a cell phone in talk mode in their cages, which is associated with large fluctuations and uncertainty regarding exposure dose.

Recent animal studies on oxidative stress induced by exposure to 50 Hz ELF-MF are scarce. Exposure for 10 months at a field strength of 100 μT to male Sprague-Dawley rats resulted in modifications of DNA bases (8-oxo-G and others) in white blood cells, which are produced by oxidative processes and may be mutagenic [120]. Interestingly, these effects were no longer observed at a higher field strength of 500 μT. However, no direct conclusions can be drawn, since DNA damage was not investigated. Increased ROS production and lipid peroxidation were measured in the plasma of female rats after ELF-MF (50 Hz, 100 μT) exposure for 3 h/day. These effects seemed to be cumulative with duration of exposure, being stronger for 100 days than for 50 days of exposure [121].

4.2. Radical Formation in EMF-Exposed Cells of the Blood and Immune System

Cancer cell lines were used as a model system in the majority of in vitro studies, e.g., various myeloid leukemic cells such as THP-1 monocytes, K562 myelocytes, NB-4 and HL-60 promyelocytes, and RAW 264.7 macrophages. In addition, established microglia cells (human: HMO6, CHME-5; mouse: N9) and isolated hematopoietic stem cells, monocytes, macrophages, and T cells from humans and mice were employed (Supplementary Materials, Tables S2 and S4).

An increase in superoxide formation was observed in K562 leukemic cells after 50 Hz ELF-MF exposure for 1 h with relatively low flux densities (25, 50, 100 μT) [122]. In this cell system, the time of analysis also seems to play a role. A transient stimulation of CAT activity and a time window for increased production of superoxide and iNOS were found for ELF-MF exposure (1 mT) [123]. In this case, the superoxide was generated by cytochrome P450 enzymes, which are phase I enzymes that play an important role in biotransformation of substances, including food components and pharmaceuticals. Exposure also altered the cell response to the tumor promoter phorbol-12-myristate-13-acetate (PMA) that triggers cell differentiation processes involving ROS. Prolonged or repeated ELF-MF exposure, however, provided little evidence for oxidative stress and ROS formation, although here an influence of exposure on cell responses to other factors was also found [124,125]. Accompanied by stimulation of ROS formation, on the other hand, prolonged 50 Hz ELF-MF exposure (2 mT) enhanced the differentiation of NB-4 promyelocytic leukemia cells by all-*trans*-retinoic acid (ATRA) but not PMA [126].

There have also been some studies, which looked at effects of ELF-MF on phagocytosis and immune function. For example, it was found in the THP-1 human monocyte leukemia cell line that ELF-MF exposure (1 mT) led to increased iNOS activity and NO production, whereas the activity of the antioxidative enzymes SOD and CAT were reduced [127,128]. In both cases, additional exposure led to changes in the immune response triggered by staphylococci or lipopolysaccharides (LPS). In this regard, 50 Hz ELF-MF exposure modulated the cellular response to the LPS treatment and underlying signaling cascades, involving the antioxidative heme oxigenase-1 (HO-1) that counteracts the induced ROS formation and changes in oxidative status [129]. An enhancing effect of 60 Hz ELF-MF (0.8 mT) on the induced immune response and NO production was found in RAW246.7 mouse macrophage tumor cells [130], whereas a reduction in NO production by LPS was reported in the same cell line exposed to 50 Hz ELF-MF (0.5 mT) [131]. These contrasting effects may be due to the different sequence of treatments. In isolated mouse macrophages, a slightly increased ROS production was observed, resembling to some extent an induced immune response, but the signaling pathways superimposed only partially [132]. This could indicate that ELF-MF does not trigger a genuine immune response, nevertheless creating a cellular situation that leads to a change in the response to further stimuli or stress situations. For example, previous exposures to 10 and 50 Hz, but not to 100 Hz, ELF-MF (1 mT) had a protective effect, reducing apoptosis and ROS formation in human microglia cells when they were metabolically stressed by deprivation of oxygen and sugar, i.e., conditions similar to those that occur in brain ischemia [133].

Evidence for an inflammatory cell response regarding iNOS activity and NO production was found in mouse microglia cells exposed to a GSM signal (SAR: 2 W/kg) [95] for 24 h or for a short time (20 min) to pulsed 2.45 GHz RF-EMF [134,135]. In both situations, activation of STAT3 (signal transducer and activator of transcription 3) and mitogen-activated protein kinase (MAPK) signaling pathways was observed, as well as changes in the production of cellular messengers and a reduction in microglial phagocytosis. It should be noted that exposure to pulsed 2.45 GHz RF-EMF with 6 W/kg SAR is a situation or signal type that would hardly occur as an environmental factor [134,135]. On the other hand, exposure of this cell type to a 900 MHz GSM signal (SAR: 4 W/kg) temporarily altered the activity of the mitochondrial cytochrome c oxidase without leading to oxidative stress [101]. A decrease in phagocytosis was also observed in RAW264.7 macrophages cells, accompanied by an RF-EMF-induced increase in NO synthesis [136]. This effect increased with the duration of exposure, regardless of whether 900 MHz, 2.45 GHz, or a combination (SAR: 80–400 mW) was applied. On the other hand, 2.45 GHz RF-EMF (SAR: 0.4 W/kg) promoted phagocytosis of co-exposed black carbon particles, changed the immune response, and increased NO production and cell toxicity [137].

In this regard, it is worth mentioning that an increase in oxidative stress by RF-EMF was observed in populations of immune cells from human blood enriched by flow cytometry [138–140]. However, it should be noted that, in contrast to cultured cells/cell lines, this does not necessarily reflect an immune reaction, but possibly an enhancement of the cell aging or cell death process because of a strong stress situation due to the removal from their normal environment. Furthermore, leukemic HL60 cells and differentiating $CD34^+$ (surface marker "cluster of differentiation 34") human blood stem cells (HSCs) were also investigated for effects of RF-EMF exposure on the oxidative balance. In both cell types, no evidence was found that exposure to 900 MHz GSM, 1.95 GHz UMTS, and 2.53 GHz LTE signals at SAR values of 0.5–4 W/kg led to increased ROS formation after either short (4 h) or prolonged exposure [141]. In another study with stem and other blood cells, a temporary increase in ROS formation was observed after 1 h of UMTS exposure

(SAR: 40 mW/kg) [142]. This was also the case in leukemic HL60 cells, in which 900 MHz RF-EMF at a calculated SAR value of 0.25 mW/kg triggered an increase in ROS formation, which was prominently detectable after 30 min, attenuated after 4 h, and vanished after 24 h of exposure [143]. ROS levels correlated well with a temporary increase in oxidative DNA damage, as well as the energy production of the mitochondria. In the same cell line, signs of increased lipid peroxidation (MDA) were also observed when the cells were exposed to 2.45 GHz RF-EMF with 217 Hz pulses at estimated 0.1 W/kg SAR, whereas no change in GSH and GPx activity was evident [144].

4.3. Assessment of EMF Effects on Blood and Immune Organs

ROS play an important role in the elimination of foreign or damaged cells, while they are also involved in inflammatory reactions and the activation of the immune response [21]. Long-term inhibition and repeated activation of ROS are likely to cause health effects.

There is evidence that EMF affects the response to other (stress) factors [38,124–126,129,130,137]. Such a crosstalk between cell responses is important in real life, since humans and animals are exposed to different and changing stress and environmental factors, in contrast to experimental studies. For example, chemically induced oxidative stress reduced the production of ROS in animals after subsequent exposure to RF-EMF, indicating an adaptive response [38]. Observations in this direction have also been made in cell studies. For instance, it was shown that immune responses and phagocytosis were altered by RF-EMF exposure [95,134–137].

Similar to the findings reported for the central nervous system, there are indications that effects of EMF exposure are age-dependent in the lymphoid system. Very young animals could not compensate for oxidative stress, even after a recovery period, whereas this was possible in older animals after complete development of the antioxidative protective system [116]. Moreover, in cultured cells, the time of analysis of oxidative stress seems to play a role, and short-term exposure led to an increase of oxidative stress in lymphoid and leukemic cells [123,143]. This increase was mostly temporary, and the triggered processes were partly similar to a genuine immune response [132].

Overall, however, only a few animal and cell studies on the influence of EMF exposure on oxidative stress and defense of the immune system are available. At present, the data available do not allow a conclusive assessment of possible health effects. Nevertheless, dependencies on preconditions, age, and exposure duration are likely similar to the nervous system.

5. EMF Exposure and Oxidative Stress: Effects on Reproduction

5.1. In Animals

Influences of EMF on male reproductive organs and sperm, as well as their precursors, were investigated in more than 30 animal studies (Supplementary Materials, Tables S1 and S3). In Sprague Dawley rats exposed to 900 MHz RF-EMF (whole-body SAR: 0.0067 W/kg) for 1 h/day for 21 days, testicular weight decreased and various morphological changes were observed, including mitochondrial integrity, apoptosis, and increased antioxidative activity [145]. In adult Wistar rats, significant changes in sperm count and vitality, morphological changes, and increased ROS levels and lipid peroxidation in sperm and their precursor stages were found after RF-EMF exposure with a 3G/UMTS signal (SAR: 0.26 W/kg) for 45 days (2 h/day), concomitantly with a decrease in sperm with active mitochondria [146]. Similar results were reported by Shahin et al. [55]. Yet again, significant decreases in sperm count and vitality were found, which were associated with an increase in various oxidative stress markers (ROS, NO, MDA) and a decrease in antioxidative activities (SOD, GST, CAT). In addition, the amount of iNOS was increased in the precursors of sperm and in Leydig cells [55]. These findings indicate functional and morphological impairment of spermatozoa by RF-EMF exposure, associated with an increase in ROS. Liu et al. reported ROS formation and oxidative stress in rat sperm, as well as tissue changes and increased apoptosis, after exposure to 900 MHz RF-EMF (SAR:

0.66 W/kg) for 2 h/day and 50 days [147]. An increase in ROS, resulting in histological and morphological changes of testes and germ cells, as well as DNA damage, was found in Swiss mice after exposure to 900 MHz RF-EMF (SAR: 0.0054–0.0516 W/kg) twice for 3 h/day for 35 days [148].

Increased lipid peroxidation after 2.45 GHz RF-EMF exposure (50 Hz pulses, whole-body SAR: 0.14 W/kg, 2 h/day) for 3 weeks was found in testes of rats [48]. Exposure to 2.45 GHz RF-EMF (217 Hz-pulsed, whole-body SAR: 0.143 W/kg) of male Wistar rats for 30 days at 1 h/day did not change GSH levels and increased lipid peroxidation in testicular tissue, which could be counteracted by melatonin treatment [149]. Analogous findings were reported for male Wistar rats exposed to 900 MHz (pulsed, whole-body SAR: 1.2 W/kg) for 2 h/day for a total of 3 weeks. Lipid peroxidation and NO production were enhanced and GSH levels were decreased [150]. Pandey et al. reported mitochondrial damage, cellular damage, and DNA damage in spermatocytes of male Swiss mice exposed for 35 days to 900 MHz RF-EMF (SAR: 0.0045–0.0056 W/kg, attributing them to oxidative stress [151]. Exposure to a 900 MHz RF-EMF (SAR: 1.075 W/kg) for 2 h/day for 8 weeks resulted in changes in levels of MDA and the ROS scavenger GST in male Wistar rats [152]. The same authors also reported a significant increase in ROS, alterations of oxidative stress markers, DNA damage, increased apoptosis, inflammation, and tissue toxicity in testes of Swiss mice exposed to 1.8 GHz RF-EMF (SAR: 0.05 W/kg) for 120 days [153]. RF-EMF exposure of male Wistar rats at 900 MHz, 2 h/day for 35 days (SAR: 0.9 W/kg) [154], as well as 4 h/day for 20, 40, and 60 days (SAR: 0.043–0.135) [155], revealed alterations in various oxidative stress markers in the testes, with one study also demonstrating DNA damage [154]. Similar findings were obtained in male Wistar rats after exposure to a 900/1800 MHz dual-band mobile phone (no fields measured or SAR calculated) for 1, 2, or 3 h/day [156]. In one study, combined 900/1800/1900 MHz RF-EMF exposure for 15, 30, and 60 min/day for 14 days (SAR: 0.9 W/kg) resulted in changes in oxidative stress markers and tissue toxicity in testes of Wistar rats [157].

Previous insults or existing diseases, such as diabetes, can make the organism more sensitive to exogenous stressors [158]. Increased lipid peroxidation, NO production, and a decrease in GSH were found in the testicular tissue of male Wistar rats after exposure to 50 Hz ELF-MF (8.2 mT) and 2.1 GHz RF-EMF (SAR: 0.23 W/kg) for 20 min/day for 4 weeks. These effects were more pronounced in rats with diabetes than in healthy animals [158].

RF-EMF effects on female reproduction were also performed. For instance, RF-EMF exposure for 1 h/day, 5 days/week for 52 weeks at all investigated frequencies (900, 1800, 2450 MHz, SAR: 0.1 W/kg) resulted in an increase in lipid peroxidation but no significant changes in other oxidative stress markers in the uteri of female Wistar rats [112]. In the endometrium of Wistar rats, increased lipid peroxidation (MDA), NO production, and decreased measured antioxidative biomarkers (GSH, GPx, CAT) were found after exposure to a 217 Hz-pulsed 900 MHz RF-EMF, with a whole-body SAR of 0.014–4 W/kg for 30 min/day for 30 days [159]. However, the large SAR fluctuations with potential temperature increases entail some uncertainty whether the observed morphological changes, apoptosis, and immune modulation occurred due to the oxidative stress and/or by tissue warming. Similarly, increased ROS production and associated changes in oxidative stress markers were found in the uterus and the ovaries of female Swiss mice exposed to 1.8 GHz RF-EMF for 100 days. However, no SAR values were reported [51]. Another study in female mice demonstrated increased oxidative stress and morphological alterations of the implantation sites of the embryos in the placenta when female Parkes mice were exposed to 2.45 GHz RF-EMF (SAR: 0.023 W/kg) for 2 h/day for 45 days [118]. This resulted in impaired reproduction, measured as implantation failure or resorption of the embryos, which might have been caused by increased formation of ROS. This affects a very early stage of pregnancy (corresponding to days 7–8 in humans) when the blastocyst attaches to the uterine wall.

Regarding development, it is also of relevance whether exposure of dams causes oxidative stress in the fetuses and whether this results in any kind of impairments in the offspring. In the study by Özorak et al., Wistar rats were exposed to 217 Hz-pulsed 900 MHz, 1800 MHz, or 2.45 GHz RF-EMF (whole-body SAR: 0.18 W/kg; 10 V/m) for 60 min/day in the uterus and up to 6 weeks after birth [160]. For all three frequencies, lipid peroxidation in the newborns was initially decreased (week 4 after birth), while it was significantly higher at 6 weeks. Antioxidative markers in RF-EMF-exposed rats were significantly lower than those of the control animals at all three time-points measured (4, 5, and 6 weeks postpartum) and at all frequencies [160]. ROS were not analyzed, but the increased lipid peroxidation in RF-EMF exposed animals at 6 weeks of life and the decrease in antioxidative markers suggest an oxidative stress situation. Increased ROS production was also found in ovaries of female Wistar rats after 2.45 GHz RF-EMF exposure (SAR: 0.1 W/kg) for 1 h/day in utero and/or 1 h/day from postnatal day 21 to puberty [161].

5.2. In Cultured Cells

The functionality of cells of the reproductive system was also examined for effects of EMF (Supplementary Materials, Tables S2 and S4). Due to their temperature sensitivity, developmental characteristics, and availability, mainly male germ cells and cells from the reproductive organ were employed. Among them, two mouse cell lines, GC-1 and GC-2, representing two stages of sperm development, were used most frequently, but sperm and spermatogonia from humans and mice, as well as the testosterone-producing Leydig cells from testicular tissue, were also assessed.

The majority of studies published in the last 10 years focused on investigations of RF-EMF effects, such that hardly any recent data are available on the influence of 50 Hz ELF-MF on oxidative balance. In spermatogenic GC-1 but not in GC-2 mouse cell lines, a consistent increase in superoxide was found after exposure to 50 Hz ELF-MF (2.5 mT) for 2 h, while NO levels remained unchanged [162,163]. Here, however, changes after a recovery period of 2 days and nonimmediate responses were measured; thus, these effects are rather indications of long-term or secondary effects. The influence of prolonged ELF-MF exposure for 24 h (1, 2, 3 mT) on the genome was investigated in another study with GC-2 cells, with a marginal increase in DNA damage at the highest dose, which was interpreted as a consequence of oxidative stress [164], but data about ROS formation or oxidative stress were not provided.

Ex vivo investigation yielded ambivalent observations and conclusions in a few studies with human sperm on the influence of RF-EMF with respect to oxidative stress and quality, although similar exposure durations (45–90 min) and doses (SAR: 1–6 W/kg) were applied [165–168]. Two studies reported no signs of increased ROS, no oxidative DNA damage, or any other negative effects such as induced cell death and reduction in sperm quality, when sperm was exposed to a 900 MHz GSM or a 1.95 GHz UMTS signal [166,167]. In contrast, oxidative stress and, in some cases, massive DNA damage and loss of sperm vitality were observed after exposure to 900 MHz GSM or 2.45 GHz WiFi signal [165,168]. However, it has to be noted that the two studies without significant effects were conducted under controlled temperature and exposure conditions, while user devices were applied in the other two. It needs to be considered that exposure of cells with commercial user devices (e.g., cell phones) often entail many uncertainties, confounders, and/or fluctuations in exposure.

After 24 h of exposure with a 1.8 GHz RF-EMF (GSM signal, continuous, or intermittent), an increase in oxidative DNA damage, ROS production, and autophagy activity was observed in GC-2 cells at the highest SAR dose of 4 W/kg [164,169–171]. Hence, there is evidence that the increase in ROS production does not occur immediately but with increasing exposure time (>12 h) or cumulative dose [170]. Nevertheless, an increase in mitochondrial superoxide production was observed in the same cell line after 2–6 h of exposure to unmodulated 1.8 GHz RF-EMF at lower doses (SAR: 0.15 W/kg), accompanied by lipid peroxidation [172]. In this comprehensive study, these observations were confirmed in GC-1 cells and freshly isolated spermatogonia, and the origin of observed RF-EMF effects was attributed to the mitochondrial respiratory chain. Even at higher exposure intensities (SAR: 1.5 W/kg), no increase, but rather a decrease, in mitochondrial ROS formation and no change in global ROS and lipid peroxidation levels were measured in mouse spermatozoa [172]. Hence, the mouse sperm reacted differently to RF-EMF exposure than the preliminary stages of sperm development, represented by the GC-1 and GC-2 cells. The exposed sperm cells exhibited indications for oxidative DNA damage and reduced quality despite the lack of indicators of oxidative stress.

Additional evidence for an influence of RF-EMF on reproduction was obtained from studies in Leydig cells from mice, in which exposure to a 1.8 GHz GSM signal (SAR: 0.116 W/kg) or a 1.95 GHz RF-EMF (SAR: 3 W/kg) led to reduced testosterone production [173,174]. While there was evidence for oxidative stress (i.e., CAT and MDA) [173] after a short exposure for 1–3 h, an increased ROS formation was not detected after the 24 h of exposure [174]. Lastly, effects on a model system for female reproduction were investigated in cultured murine preantral follicles upon developmental induction. The exposure to 2.45 GHz RF-EMF (SAR: 0.77–0.88 W/kg) for 1 h/day negatively affected the growth and development of follicles, which was associated with increased lipid peroxidation and oxidative stress markers [175].

5.3. Assessment of EMF Effects on Reproduction and Fertility

The influence on fertility and the development of fetuses is an important topic, as developing organisms and cells are particularly sensitive to external stress factors. Effects of EMF on reproduction, predominantly after RF-EMF exposure, were studied in male reproductive organs and sperm and their precursor stages. In addition, dams were exposed to EMF, and possible damage in early and late stages of pregnancy, as well as in the offspring, was investigated [51,112,159].

The majority of the findings from the animal studies indicate a functional and morphological impairment of testes and spermatozoa by EMF exposure (predominantly for RF-EMF), which was associated with an increase in ROS, a reduction in the antioxidative capacity, and lipid peroxidation [48,55,146–151,153,154]. A previous insult or pre-existing disease (i.e., diabetes) was shown to be a risk factor that enhanced oxidative stress, which could not be compensated for [158]. After in utero exposure, age-dependent effects on oxidative stress markers were seen in the offspring, differing, depending on the assessed organ system [160,161]. A study on impairments at early stages of pregnancy revealed indications of reduced blastocyst implantation [118].

In cell studies, mainly male germ cells and cells from male reproductive organs were used. These are very temperature-sensitive and, therefore, temperature fluctuations must be excluded during irradiation; otherwise, false-positive findings influence the evaluation [114,115]. This was not the case in many cell studies and, therefore, it cannot be excluded that some findings are false-positive. Overall, the few cell studies do not provide any reliable evidence for an impairment of sperm cells and their precursors by EMF-induced oxidative stress, although some of them reported indications for ROS formation and oxidative stress [164,169–172].

6. Further Observations of Oxidative Stress Induced by EMF

In addition to the extensive literature on effects of EMF on the nervous, immune, and reproductive systems, a number of studies on oxidative stress in other organ system and cell types have been published (Supplementary Materials, Tables S1–S4).

6.1. Oxidative Influences on Other Organs

Evidence of adaptation to oxidative stress and antioxidant processes induced by 900 MHz RF-EMF exposure (2.5 mW/cm^2) for 1 h/day was found in the liver and kidney of male Sprague-Dawley rats. ROS formation was increased in both organs after 60 days of RF-EMF exposure, which was associated with changes in markers of liver and kidney function. However, these changes were no longer present after 30 days of regeneration, indicating adaptation [35]. Examinations of oxidative stress in the liver of adolescent

Sprague-Dawley rats after 900 MHz RF-EMF (SAR: 0.0096 W/kg) exposure for 1 h/day during postnatal days 35–59 did not result in a significant induction of ROS but led to some changes in oxidative stress markers [176]. In contrary, analyses of liver tissue at postnatal day 60 showed changes in ROS, oxidative stress markers, and tissue toxicity after in utero exposure to a 1.8 GHz (SAR: 0.12 W/kg) for 20 days and 6, 12, 24 h/day [177]. RF-EMF exposure (950 MHz) of rats, dams, and their offspring of different ages (neonates up to 30 days after birth) for up to 51 days resulted in some changes in oxidative stress and DNA damage in the liver. These effects were dependent on age, exposure duration, and dose (whole-body SARs: 0.51, 0.18, 0.18, and 0.06 W/kg for neonates, day 6, day 15, and day 30 after birth, respectively) [178]. Reduced lipid peroxidation was found only in the neonates, after RF-EMF exposure in utero, while no differences between groups were observed for protein oxidation and CAT. DNA damage was only increased in 30 day old exposed animals while it was reduced in 15 day old animals. Thus, the results on DNA damage are inconclusive and might be random due to a large variability.

Whether a pre-existing condition or disease, such as diabetes, influences the extent of oxidative stress or modulates its defense was investigated in male Sprague-Dawley rats in a diabetes model [179]. Rats with diabetes, when compared to healthy rats, showed a more pronounced production of ROS and increased lipid peroxidation in the liver after 28 days of 900 MHz RF-EMF exposure (E-field: 25 V/m) for 4 h/day. Unfortunately, no SAR value was reported in this study, and the observation of diverging activity of SOD and CAT is somewhat counterintuitive as both are markers for the antioxidative defense [179]. In the study by Esmekaya et al., lipid peroxidation and NO production were increased in the liver, as well as in the lung, heart, and kidney, of male rats after exposure to pulsed 900 MHz RF-EMF (whole-body SAR: 1.2 W/kg) for 2 h/day for 3 weeks, whereas GSH levels were decreased [150]. Shahin et al. reported changes in ROS and the oxidative stress markers SOD, CAT, and GST in the liver and kidney of pregnant Parkes mice exposed for 45 days to 2450 MHz RF-EMF (SAR: 0.023 W/kg) [118]. The same group found an increase in ROS and associated indications for oxidative stress in the liver and kidney of male Swiss mice exposed to 2450 MHz RF-EMF (SAR: 0.018 W/kg) for 30 days [55].

Increased lipid peroxidation, as well as a decrease in antioxidative markers, was observed in the kidney of rats exposed to 217 Hz-pulsed 900, 1800 MHz, or 2450 MHz RF-EMF (whole-body SAR: 0.18 W/kg; 10 V/m) for 5 days/week and 60 min/day from in utero until 6 weeks after birth [160]. Interestingly, lipid peroxidation was decreased in exposed animals at the fourth week of life, while the antioxidative biomarkers were consistently lower than those of the corresponding controls at all three time-points assessed (4, 5, and 6 weeks after birth). Applying a 2450 MHz RF-EMF, a study in Wistar rats found changes in both ROS and oxidative stress markers in the kidney [180], while no alterations were found for ROS [181]. Similarly, four studies examining oxidative stress in the kidney of Sprague-Dawley rats using 900 MHz RF-EMF signals yielded ambivalent results. Two of them reported changes in ROS formation, oxidative stress, and tissue toxicity [35,182], one demonstrated increased ROS, tissue toxicity, and apoptosis without assessing antioxidative markers [183], and one found no indication for oxidative stress although seeing kidney toxicity [184]. Other investigations in the kidney revealed changes in ROS, oxidative stress, tissue toxicity, and apoptosis, applying 2.1 GHz RF-EMF [185].

In the heart of Wistar rats, 2.45 GHz RF-EMF exposure for 5 min (50, 100, 150, 200 mW/cm^2) or 30 days (SAR: 0.1 W/kg) resulted in changes in ROS and oxidative stress markers and increased tissue toxicity and apoptosis [186] or in more lipid peroxidation and reduced SOD, respectively [187]. Two studies in Sprague-Dawley rats examined oxidative stress in the heart applying laboratory-generated 900 MHz RF-EMF signals. After in utero exposure during gestational days 13–21 at 0.025 W/kg SAR for 1 h/day and examination at postnatal day 21, there were clear indications of oxidative stress, tissue toxicity and apoptosis in the heart [188]. In another study using young rats, increased ROS and increased apoptosis but no changes in antioxidative defense or tissue toxicity were found after 900 MHz RF-EMF exposure (SAR: 0.0093 W/kg) for 1 h/day on postnatal days 21–59 [189].

Lastly, there are some sporadic reports about oxidative stress related to RF-EMF exposure in other tissue types. For instance, 2.45 GHz WiFi exposure (whole-body SAR: 0.1 W/kg) of male Wistar rats caused increased lipid peroxidation in the mucosa of the vocal tract, while no differences in antioxidative biomarkers were measured [190]. Increased lipid peroxidation, apoptosis, and pathological tissue changes were found in the bladder of young rats exposed to 900 MHz RF-EMF (SAR: 0.0067 W/kg) [183]. Two animal studies on possible oxidative stress on the eyes have been published [119,191], both indicating no increased ROS production. Exposure to 2.45 GHz RF-EMF, pulsed at 217 Hz (whole-body SAR: 0.1 W/kg), for 1 h/day and 30 days had no marked effect on lipid peroxidation in the eye, while antioxidative biomarkers (GPx and GSH) were significantly decreased [191]. In combination with melatonin treatment, these effects were reverted, which was explained by the antioxidant effect of melatonin. In contrast, no evidence for increased oxidative stress and NO production by 1.8 GHz RF-EMF (whole-body SAR: 0.4 W/kg) was found in Wistar rats exposed 1 h/day for 3 weeks [119]. However, the exposure of animals in the cages was performed using a cell phone in talk mode, which is inevitably associated with large uncertainty and variability of the SAR.

For ELF-MF exposure, only a few animal studies with readout concerning oxidative stress have recently been published. No evidence for increased lipid peroxidation (MDA) in the liver was found by Erdal et al., in which Wistar rats of both sexes were exposed to 50 Hz ELF-MF (1 mT) for 4 h/day and 445 days [192]. The results of a study in male Wistar rats exposed to 60 Hz ELF-MF (2.4 mT) for 2 h indicated an impairment of the antioxidant defense in the heart and kidneys [193]. However, rats kept in tubes of a carrousel setup for exposure without ELF-MF showed similar levels of ROS and antioxidative markers, indicating that the stress situation caused by a containment in tubes also triggered oxidative stress. These findings demonstrate the need for appropriate sham-exposure controls for such experimentations to exclude confounding factors resulting in oxidative stress. However, this study did not indicate whether the animals were previously trained to go into the tubes to exclude this stress factor.

6.2. Experimental Data on the Effect of EMF on Skin, Epithelial, and Cancer Cells

Because of their function as a barrier and first line of defense against the environment, skin and epithelial cells are of interest for possible EMF effects. However, only experimental studies with cultured cells and none with animals have been performed in the last decade. A number of cell types with different functions and properties were used such as fibroblasts from the skin of rats (Rat-1), mice (NIH/3T3, McCoy), and humans (HSF) or human gingival fibroblasts. In addition, there are experimental data from human keratinocytes (NCTC-2544, HaCaT), specialized epithelial cells of the mammary gland (MCF10A), pulmonary fibroblasts from human (IMR-90, MRC-5) and hamster (V79), Chinese hamster ovary cells (CHO), cells of the human retina (RPE-1), and lens (HLE-B3) of the eye and human amniotic cells (FL, HTR-8/SV40neo).

Due to the use of a wide range of cell types and the limited number of directly comparable studies, the current picture regarding the effects of EMF exposure on skin and epithelial cells is patchy. Nevertheless, there is some evidence that EMF can lead, at least temporarily, to an increase in ROS production and oxidative stress in these cell types, whereby the majority of the data originate from cell studies in the ELF-MF range. A transient increase in ROS was observed in human keratinocytes (NCTC-2544) and in mouse embryonic fibroblasts (MEF) upon continuous exposure to 50 Hz ELF-MFs [194,195]. In keratinocytes, an increase in ROS formation was found after 1–2 h of exposure, concurrent with changes in oxidative stress markers (GSH, GPx, SOD) [194]. After 4 h of exposure, ROS measurements no longer showed any differences to control cells, but there were signs of building up the antioxidative defense. It is also remarkable that this exposure-related increase in ROS was found at low (50 and 100 μT) but not at higher field strengths, i.e., not in the range used in many other studies.

Nevertheless, increased ROS formation was also found in mouse fibroblasts after exposure to an ELF-MF (2 mT) in a time window of 2–6 h, correlating with an increase in autophagy [195]. As the exposure period progressed, the cells adapted to the exposure and no longer reacted with increased ROS production. In IMR-90 pulmonary fibroblasts exposed to strong 60 Hz ELF-MF (6 mT) for 3 days, this prolonged exposure even led to reduced ROS formation [196]. Together with fluctuations of antioxidative markers, a transient reduction of superoxide, H_2O_2, and NO level was reported for MRC-5 lung fibroblasts daily exposed for 1 h to strong 50 Hz ELF-MF (10 mT) for days 1–3, while a prominent increase was found after 7 days [197]. In the context of investigating the influence of 50 Hz ELF-MF on processes of wound healing and inflammation, a similar exposure duration (3–6 h) in gingival fibroblasts and in HaCaT keratinocytes showed increased iNOS expression and activity, whereas CAT activity and superoxide formation were reduced [198,199]. Similar observations were made in two other cell types, breast (MCF10A) and retinal epithelial cells (RPE-1), in which no signs or even a tendency to reduced oxidative stress were observed after ELF-MF exposure [200,201]. However, some of the measurements were performed after a longer recovery period and, therefore, presumably do not represent direct effects of exposure but rather a secondary cell response.

One research group conducted a series of studies in FL cells derived from the epithelium of the amniotic sac [202–205]. They found a slight increase in ROS in the cytoplasm and, with some delay, superoxide production in the mitochondria in the time period of 5–30 min after the beginning of exposure to a 50 Hz ELF-MF (0.4 mT) exposure [202]. In this case, however, it is likely that the exposure led to the activation of cellular signaling pathways rather than to canonical oxidative cell stress [203–205]. For instance, ELF-MF exposure alters the activity/excitability of epidermal growth factor (EGF) receptors in the cell membrane, thereby remodeling the MAPK pathway and subsequent cell responses.

The function of EMF-induced production of radicals as signal molecules for the activation of the MAPK signaling pathway was previously postulated for RF-EMF in a pioneering study [206]. In Rat-1 rat skin fibroblasts, a short exposure to unmodulated 875 MHz RF-EMF stimulated NADH oxidase and ROS production, thereby increasing the sensitivity of the EGF receptor and activating the MAPK pathway. Applying RF-EMF, there is further evidence of transient ROS formation and oxidative stress provided by a few studies. In murine NIH/3T3 embryonic fibroblasts, an increase in ROS was found, most pronounced after exposure to a 1.8 GHz GSM signal (SAR: 2 W/kg, 5/10 min on/off) for 1–2 h or a combination of a 837 Hz GSM and a 1.95 GHz UMTS signal (SAR: 4 W/kg) [102,207]. In contrast, the combined exposure to these two signals in MCF10A breast epithelial cells did not result in an increase in ROS and changes in oxidative stress markers [208]. Likewise, no increase of mitochondrial superoxide formation was observed for exposure to 1.8 GHz RF-EMF (SAR: 0.15 W/kg) for 2–6 h in another mouse fibroblast cell line [172]. Thus, the temporary increase in ROS does not seem to be a general cell response but specific to certain cell types.

Performed again in mouse fibroblasts, an unusually high cell mortality was found upon continuous 1.8 GHz RF-EMF exposure (1.2 W/m^2) for 2 days [105]. In contrast to most other comparable investigations, ROS formation was not temporary and detectable shortly after the start of exposure, instead it became obvious only after 6 h and increased with exposure duration. This finding suggests that ROS formation might not be a direct result of exposure but a secondary effect, due to apoptosis. Similar mechanisms may have played a role in the ROS increase after exposure of CHO cells to a GSM-modulated 900 MHz RF-EMF (SAR 2 W/kg) for 12 and 24 h [209]. This notion is further supported by observations made in hamster (V79) and human (HSF) fibroblasts. Without having a negative effect on viability or leading to cell damage, exposure to 1.8 GHz RF-EMF (SAR: 1.6/3 W/kg, GSM signal or carrier wave) led to an early transient increase in ROS formation which ceased after 24 h of exposure [113,210,211]. In accordance with these conclusions, no evidence for oxidative DNA damage was found in pulmonary fibroblasts, regardless of the exposure duration (1, 4, 24 h) with different doses (SAR: 0.5, 2, 4.9 W/kg) and modulations of 1.95 GHz RF-EMFs (GSM, UMTS, WiFi) [212]. However, a slight reduction in cell vitality after 6–24 h of exposure to a 1.8 GHz GSM signal (SAR: 2.3 and 4 W/kg) was observed in HLE B3 lens epithelial cells, accompanied by an increase in the lipid peroxidation marker, MDA [213]. Gene expression and protein levels for key antioxidative enzymes (SOD, CAT, GPx1) were lowered. Hence, the authors concluded that the higher ROS levels measured after 30–90 min of exposure were due to a reduced activity of the antioxidant defense system, which is in contrast to other cell types, in which ROS production was attributed to stimulation of oxidizing enzymes such as the NADH oxidases by EMF.

In addition to the studies with cultured cells that could be assigned to one of the above biological functions or organs, there are also some experimental results that were generated in various primary or tumor cells of different origin. Although it is hardly possible to derive a uniform picture and comprehensive conclusions, these results provide additional information about the influence of EMF on the oxidative balance of cells. For instance, 50 Hz ELF-MF (100 μT) did not cause any change in ROS formation or GSH levels in heart muscle cells, whether after continuous or after interval exposure for a short time [214]. In contrast, in a murine squamous cell carcinoma line (AT478), exposure at 1 mT for 16 min resulted in an increase in ROS formation and in the activities of SOD and GPx, while MDA concentrations decreased [215]. However, other cancer cell lines reacted differently to 50 Hz ELF-MF exposure (6 mT) for 2 h. ROS levels remained unchanged in Gist-T1 gastrointestinal stromal tumor cells, increased in HCT-116 colorectal cancer cells, and tended to be lower in HEK293T embryonic kidney cells [201]. Continuous 60 Hz ELF-MF exposure (6 mT) of the HeLa cervical cancer cells resulted in lower ROS and better cell viability [196], whereas, in breast cancer cells, an increase in ROS formation after 2 h was found, accompanied by induced apoptosis upon prolonged exposure to the ELF-MF (1 mT) [216]. Notably, ROS formation after exposure to 200 Hz rather than 50 Hz ELF-MF was considered here, as the former generally showed stronger effects on apoptosis.

In the RF-EMF range, analogous observations were made in MDA-MB-231 breast cancer cells exposed to a 900 MHz GSM-like signal (SAR: 0.36 W/kg). RF-EMF exposure for 1 h resulted in an increase in ROS formation and induced cell death [217]. Apoptosis and more ROS was also seen in MCF-7 breast cancer cells after exposure to 217 Hz pulsed 900, 1800, and 2450 MHz RF-EMF (average SAR: 0.36 W/kg) for 1 h [111]. RF-EMF-induced cell death was also observed in embryonic kidney cells (HEK293, HEK293T) exposed to an unmodulated 940 MHz carrier wave (SAR: 90 mW/kg) [218] or 2.45 GHz (E-field: 2 V/m) [219,220] for about 1 h. However, the results from the analyses of the markers for oxidative stress differed. While the 2.45 GHz RF-EMF resulted in higher MDA levels and reduced activities of SOD and GPx, exposure to the 940 MHz RF-EMF decreased MDA values over time while increasing SOD, with maximal changes observed at 30–45 min after the exposure started. In similar time windows, a transient increase in ROS formation, accompanied by changes in oxidative stress markers, was reported after exposure of HEK293 cells to 940 MHz RF-EMF (SAR: 90 mW/kg) [218] or MC3T3-E1 osteoblastic cells to a 2.45 GHz WiFi signal (SAR: 0.16/0.85 W/kg) [221]. The reason for a reduction in cell numbers may not always be induced apoptosis but could result from the promotion of cell senescence [222]. This was observed in the population of various cancer cells, as well as in stem cells from adipose tissue, after exposure to a 1.7 GHz long-term evolution/fourth generation (LTE) signal (SAR: 1 and 2 W/kg) for 3 days. Depicted for HuH7 liver cancer cells and the adipose stem cells, the increased formation of mitochondrial and total ROS by exposure played a role in the promotion of senescence, as more cells with stronger ROS signals were present. On the other hand, exposure to 900 MHz RF-EMF (SAR: 80 or 170 mW/kg) in isolated thyroid cells neither affected cell vitality nor provided indications for oxidative stress or an increase in ROS formation [223].

In summary, EMF exposure of cultured cells does not to induce an universal cellular reaction, but a variety of mechanisms and stress responses including ROS formation and oxidative stress might be triggered, depending on cell type and experimental conditions. In this regard, it needs to be noted that established cell lines and especially cancer cells, representing the majority of the cell lines studied, might react more strongly and more variably than normal cells, likely attributed to their altered metabolism and regulatory mechanisms.

7. Conclusions

The majority of recent animal studies on increased ROS production and oxidative stress caused by EMF were aimed at investigations of the nervous system and reproduction. Analogously, in cell studies, neurons or neuron-like cells were most frequently used. Animal studies on oxidative stress and possible impairment of reproduction at different stages (sperm maturation, very early stages of pregnancy such as implantation, and effects in newborns and after a few weeks of EMF exposure to the mother animals during pregnancy) follow in second place. These animal studies were supported by some cell studies, mainly in mouse cell lines of the male reproductive system and in sperm. Overall, more cells than animal studies were published, using, in addition to the abovementioned cell types of the nervous and reproductive system, immune and cancer cells, as well as isolated cells from the skin and epithelia. For this report, animal and cell studies were included, according to their quality and research question, in order to give an informative overview of the available studies; however, this is not a systematic review.

In summary, indications for increased oxidative stress caused by RF-EMF and ELF-MF were reported in the majority of the animal studies and in more than half of the cell studies. Investigations in Wistar and Sprague-Dawley rats provided consistent evidence for oxidative stress occurring after RF-EMF exposure in the brain and testes and some indication of oxidative stress in the heart. Observations in Sprague-Dawley rats also seem to provide consistent evidence for oxidative stress in the liver and kidneys. In mice, oxidative stress induced by RF-EMF was predominantly demonstrated in the brain and testes, as well as in liver, kidneys, and ovaries. These observations were made with a variety of cell types, exposure times, and dosages (SAR or field strengths), within the range of the regulatory limits and recommendations. Certainly, some studies were subject to methodological uncertainties or weaknesses or are not very comprehensive regarding exposure time, dose, number, and quantitative analysis of the biomarkers used, to name a few. A trend is emerging, which becomes clear even when taking these methodological weaknesses into account, i.e., that EMF exposure, even in the low dose range, may well lead to changes in cellular oxidative balance. Organisms and cells are able to react to oxidative stress, and many observations after EMF exposure point to an adaptation after a recovery phase. Adverse conditions, such as diseases (diabetes, neurodegenerative diseases), compromise the body's defense mechanisms, including antioxidant protection mechanisms, and individuals with such pre-existing conditions are more likely to experience health effects. The studies show that very young or old individuals can react less efficiently to oxidative stress, which of course also applies to other stressors that cause oxidative stress. Further investigations under standardized conditions are necessary to better understand and confirm these phenomena and observations.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/ijms22073772/s1: Table S1. Animal studies with RF-EMF exposure; Table S2. Cell studies with RF-EMF exposure; Table S3. Animal studies with ELF-MF exposure; Table S4. Cell studies with ELF-MF exposure.

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Abbreviations

8-OHdG	8-Oxo-2′-deoxyguanosine, 8-oxo-G
AC	Alternating current
ATRA	All-*trans* retinoic acid
CAT	Catalase
ELF-MF	Extremely-low-frequency magnetic field
EMF	Electromagnetic field
eNOS	Endothelial nitric oxide synthase
ERK	External signal-regulated kinase
GPx	Glutathione peroxidase
GSH	Glutathione
GSM	Global system for mobile communications, 2G
GSSG	Glutathione disulfide
GST	Glutathione *S*-transferase
GR	Glutathione reductase
HSC	Hematopoietic stem cell
IARC	International Agency for Research on Cancer
iNOS	Inducible nitric oxide synthase
LPS	Lipopolysaccharide
LTE	Long-term evolution, 4G
MAPK	Mitogen-activated protein kinase
MDA	Malondialdehyde
NADPH	Nicotinamide adenine dinucleotide phosphate
nNOS	Neuronal nitric oxide synthase
NO	Nitric oxide
NOS	Nitric oxide synthase
NOX	NADPH oxidase
PMA	Phorbol-12-myristate-13-acetate
PRDx	Peroxiredoxin
RF-EMF	Radiofrequency magnetic field
ROS	Reactive oxygen species
SAR	Specific absorption rate
SOD	Superoxide dismutase
TRPV1	Transient receptor potential cation channel subfamily V member 1
UMTS	Universal mobile telecommunications system, 3G
UV	Ultraviolet
WiFi	Wireless Fidelity, WLAN standard

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Review Article

Martin L. Pall*

Millimeter (MM) wave and microwave frequency radiation produce deeply penetrating effects: the biology and the physics

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Abstract: Millimeter wave (MM-wave) electromagnetic fields (EMFs) are predicted to not produce penetrating effects in the body. The electric but not magnetic part of MM-EMFs are almost completely absorbed within the outer 1 mm of the body. Rodents are reported to have penetrating MM-wave impacts on the brain, the myocardium, liver, kidney and bone marrow. MM-waves produce electromagnetic sensitivity-like changes in rodent, frog and skate tissues. In humans, MM-waves have penetrating effects including impacts on the brain, producing EEG changes and other neurological/neuropsychiatric changes, increases in apparent electromagnetic hypersensitivity and produce changes on ulcers and cardiac activity. This review focuses on several issues required to understand penetrating effects of MM-waves and microwaves: 1. Electronically generated EMFs are coherent, producing much higher electrical and magnetic forces then do natural incoherent EMFs. 2. The fixed relationship between electrical and magnetic fields found in EMFs in a vacuum or highly permeable medium such as air, predicted by Maxwell's equations, breaks down in other materials. Specifically, MM-wave electrical fields are almost completely absorbed in the outer 1 mm of the body due to the high dielectric constant of biological aqueous phases. However, the magnetic fields are very highly penetrating. 3. Time-varying magnetic fields have central roles in producing highly penetrating effects. The primary mechanism of EMF action is voltage-gated calcium channel (VGCC) activation with the EMFs acting via their forces on the voltage sensor, rather than by depolarization of the plasma membrane. Two distinct mechanisms, an indirect and a direct mechanism, are consistent with and predicted by the physics, to explain penetrating MM-wave VGCC activation via the voltage sensor. Time-varying coherent magnetic fields, as predicted by the Maxwell–Faraday version of Faraday's law of induction, can put forces on ions dissolved in aqueous phases deep within the body, regenerating coherent electric fields which activate the VGCC voltage sensor. In addition, time-varying magnetic fields can directly put forces on the 20 charges in the VGCC voltage sensor. There are three very important findings here which are rarely recognized in the EMF scientific literature: coherence of electronically generated EMFs; the key role of time-varying magnetic fields in generating highly penetrating effects; the key role of both modulating and pure EMF pulses in greatly increasing very short term high level time-variation of magnetic and electric fields. It is probable that genuine safety guidelines must keep nanosecond timescale-variation of coherent electric and magnetic fields below some maximum level in order to produce genuine safety. These findings have important implications with regard to 5G radiation.

Keywords: 5G modulating pulses; coherent electronically generated EMFs; EMF pathophysiological and therapeutic effects; increased [Ca2+]i and calcium signaling; modulating pulses and biological EMF effects; penetrating effects via time-varying magnetic field penetration.

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Introduction

Electronically generated electromagnetic fields (EMFs) are highly coherent, being generated at specific frequencies, with specific vector direction, with a specific phase and specific polarity. The special physics properties of such coherent EMFs have been discussed [1–5]. Similarly, biological impacts of coherent EMFs have also been discussed [6–10]. Such coherent EMFs generate much stronger electrical forces and magnetic forces than do natural incoherent EMFs. Most but not all natural EMFs are incoherent. The much stronger forces produced by electronically generated EMFs are of great importance with regard to EMF causation of biological effects and also with respect to our ability to use such EMFs for wireless communication. A study where coherence is central to wireless communication is the article of Geffrin et al. [5] which discusses many examples where coherence is essential for wireless communications and also discusses how antenna design is greatly influenced by the need to maintain such coherence. The biological importance of coherence was discussed in two contexts by Panagopoulos et al. [9]. The coherence of the polarity is required for maximum force generation. In addition, the coherence of phase is also important because identical phase produces constructive interference and supra-additive effects, whereas phase shifts lead to high amounts of destructive interference and much lower effects [9]. Golant [7] discusses how coherent MM-wave EMFs may produce resonance interactions with specific biological targets. Strong electrical forces produced by coherent electronically generated EMFs are an important feature of the Fröhlich [6] theoretical model of biological activity of EMFs. While it is clear from this, that there is a substantial literature that electronically generated EMFs are coherent and that such coherence is important for their acting in wireless communication and in producing non-thermal biological effects, this literature is not widely known nor is its importance appreciated among the vast majority of scientists studying EMF effects.

EMF propagation in a vacuum or in very low dielectric constant media, such as air, is characterized by a fixed relationship between the electric field and the magnetic field, as described by Maxwell's equations [11]. However electric fields are much more susceptible to absorption than are magnetic fields by many media, producing a breakdown of that fixed relationship (Keller and Karal [2]). Because the dielectric constant of intracellular and extracellular biological aqueous phases is estimated to be about 120 [12], such differential absorption is relevant to the issue of biological effects. However, as also discussed in ref. [2], the magnetic field penetration is determined by the magnetic field permeability which in essentially all biological tissues is very high, producing very high magnetic field penetration. Strong absorption of electric fields but not magnetic fields are found with MM-wave or microwave radiation traversing biological tissues and also many other media including building materials [13–15]. Electric field absorption is a function of both the dielectric properties of materials and also of the EMF frequency, such that the electric fields of MM-wave EMFs are almost completely absorbed in the outer 1 mm of the body, as shown in ref. [13–15]. The impedance of biological tissues is also likely to have roles in limiting electric field penetration. The rapid electric field absorption in biological tissues has lead telecommunications industry-associated and other scientists to predict that MM-wave biological effects will be limited to the outer 1 mm of the body and that lower microwave frequency effects, in the 400 MHz to 5 GHz range, are suggested to be limited to the outer 1–3 cm of the body. Various definitions are used to define microwave frequency radiation. In this paper, that term refers to 400 MHz to 5 GHz radiation, the range most commonly used for wireless communication.

Other scientists such as in many articles cited in Betskii and Lebedeva [16] have found deeply penetrating effects of MM-waves in human and animal bodies, but have interpreted these as possibly caused by effects near the surface of the body indirectly producing penetrating effects. Similar views are expressed in the Pakhomov et al. [17] review as follows: On p. 393, Pakhomov et al. [17] state that "The term millimeter waves (MMW) refers to extremely high frequency (30–300 GHz) electromagnetic oscillations. Coherent oscillations of this range are virtually absent from the natural electromagnetic environment." Further down [17] continues "Indeed, MMW have been reported to produce a variety of bioeffects, *many of which are quite unexpected from radiation penetrating less than 1 mm into biological tissues*" (italics added). It can be seen from this that although Pakhomov et al. [17] are aware that these MM-waves are coherent, they fail to consider that the MM-wave magnetic fields are highly penetrating and may, therefore, produce highly penetrating effects. On p. 400 of ref. [17], states that "It is clearly understood that MMW penetration into biological tissues is rather shallow, and any primary response must occur in skin or subcutaneous structures, or at the surface of the eye." This review will discuss towards its end, two distinct probable mechanisms by which highly penetrating time-varying MM-wave magnetic fields can produce highly penetrating effects reported in ref. [16, 17] and elsewhere.

Gaiduk [18] showed that when most of the water molecules are hydrogen bonded to solutes or when such solutes otherwise greatly determine water hydrogen bonding structures, as is often the case within living cells, the electric field absorption is lowered. This may be minor part of the mechanism leading to greater penetration of effects, shown below but time varying penetrating magnetic field effects are argued here to be much more important.

Penetrating effects of MM-wave and microwave radiation

Penetrating effects of non-thermal, non-pulsed, continuous wave MM-wave exposures have been reported in a large number of studies. Zalyobokskaya [19] reported that such exposures in rodents produced pathophysiological structural, functional and biochemical changes in each of the following internal organs: the brain, the myocardium, liver, kidney and bone marrow. These are each deeper in the body that 1 mm and therefore provide evidence for deeper MM-wave effects than the industry claims is possible.

Betskii and Lebedeva [16] reviewed large numbers of studies, both human and animal studies of highly penetrating nonthermal MM-wave effects. I will concentrate here on some of the human studies cited in that paper, although animal studies such as discussed in Zalyobokskaya [19] were also reviewed. When that review [16] was published, the voltage-gated calcium channel mechanism, discussed below, was not known so that their interpretation of the various findings discussed was very different from the interpretation discussed below.

We will be discussing here MM-wave effects impacting human brain function as well as a number of other penetrating effects of MM-wave radiation. References [20–24] each show that low intensity, non-thermal non-pulsed MM-wave EMFs produce changes in the EEGs in the human brain which are a measure of the electrical activity of the brain. The citations [21–24] each also find other neurological effects in addition to EEG effects are produced such MM-wave EMFs. The shortest path from outside the body into the human brain is through the skin, skull and meninges surrounding the brain, usually circa 6–7 mm in adults.

Such findings should not be surprising for two different reasons discussed in this paragraph and the following two paragraphs. Pikov et al. [25] and also Siegel and Pikov [26] at Caltech each find that stunningly low intensities of non-pulsed MM-wave EMFs produce strong impacts on brain derived neurons. Pikov et al. [25] in their abstract state that: "The applied levels of MMW power are three orders of magnitude below the existing safe limit for human exposure of 1 mW/cm^2. Surprisingly, even at these low power levels, MMWs were able to produce considerable changes in neuronal firing rate and plasma membrane properties. At the power density approaching 1 $\mu W/cm^2$, 1 min of MMW exposure reduced the firing rate to one third of the pre-exposure level in four out of eight examined neurons. The width of the action potentials was narrowed by MMW exposure to 17% of the baseline value and the membrane input resistance decreased to 54% of the baseline value across all neurons."

Consequently, Pikov et al. [25] are seeing large, repeated impacts on neuronal cell activity at exposure levels of 1 $\mu W/cm^2$, one one-thousandth of the normal safety guideline allowable levels. They are seeing large effects at exposure levels of 1/1,000th of allowable levels. Normally, safety guideline allowable levels are set at no more than 1% of the lowest level found to produce any effects. By that standard, safety guidelines for MM-wave radiation should be *more than* 100,000 times lower than the current safety guidelines. Siegel and Pikov [26] found effects at still lower level exposures, 300 mW/cm^2, which argues that safety levels should be *more than* 330,000 times lower than current safety guidelines. It should be noted that these are cells in culture, with no shielding from tissues above the cells, other than that produced by the culture medium. Each of the findings, discussed above, are effects produced by non-pulsed, continuous wave MM-wave EMFs, not the extraordinarily highly pulsed 5G radiation, which is predicted to have vastly stronger effects than do these non-pulsed MM-wave, continuous wave EMFs, as discussed below. The US FCC and other regulatory agencies are pushing to change safety guidelines to allow much higher exposures than currently allowed by the current safety guidelines!

There is a second reason why these MM-wave, brain-related findings are not surprising. Reference [27] cited multiple primary literature studies and also review articles which show that EEGs are influenced by low intensity, non-thermal microwave frequency EMFs and also cited many primary literature studies showing that such microwave frequency EMFs also produce widespread human neurological and neuropsychiatric effects. Reference [28] cited 15 review articles showing that such microwave frequency EMFs produce neurological/neuropsychiatric effects.

The remaining human highly penetrating MM-wave effects discussed here, from Betskii and Lebedeva review [16], are apparent therapeutic effects. There are genuine therapeutic effects produced by microwave and other frequency EMFs, so it should not be surprising to find that MM-waves can produce therapeutic effects. There are multiple studies reporting that non-thermal, non-pulsed MM-waves produce improved bone marrow function in humans [29–32]. Other therapeutic effects of MM-waves include increased healing of gastric and duodenal ulcers [33] and improved cardiac function [34, 35]. Two other types of penetrating effects documented by the Pakhomov et al. [17] review, will be discussed later in this paper.

The studies outlined in the previous paragraphs of this section, are all highly penetrating effects produced by non-thermal, non-pulsed MM-wave EMFs. 5G radiation, however, uses extraordinarily high levels of modulating pulses in order to carry extraordinarily high amounts of information per second [36]. Reference [28] cited 10 different reviews each showing that EMFs with modulating pulses produce, in most cases, much higher levels of biological effects than do non-pulsed (continuous wave) EMFs of the same average intensity. If follows that 5G may be predicted to produce very damaging highly penetrating effects because of its extraordinary level of modulating pulsation. The relationship between therapeutic effects and pathophysiological effects produced by EMFs is discussed below.

The recent publication of Kostoff et al. [37] came to similar conclusions to those stated in the previous paragraphs, that MM-waves produce highly penetrating effects: “These results reinforce the conclusion of Russell (quoted above) that *systemic results may occur from millimeter wave radiation*” (italics added). Continuing from ref. [37] “To re-emphasize, for Zalyubovskaya’s experiments, the incoming signal was unmodulated carrier frequency only, and the experiment was single stressor only. Thus, the expected real-world results (when human beings are impacted, the signals are pulsed and modulated, and there is exposure to many toxic stimuli) would be far more serious and would be initiated at lower (perhaps far lower) wireless radiation power fluxes.”

Much deeper effects than predicted by the industry are not limited to millimeter waves but also occur with microwave radiation. Microwave radiation, as discussed above, has been argued to produce effects limited to the outer 1–3 cm in the body. However, Hässig et al. [38, 39], in Switzerland, find that pregnant cattle grazing near a cell phone tower (also known as a mobile phone base station) produce large numbers of newborn calves with cataracts. The fetus’s deep location in the mother’s body should protect it from cell phone tower radiation but does not. Switzerland has safety guidelines for cell phone tower radiation that are 100 times more stringent than the U.S. or EU guidelines so that these are quite low intensity EMFs by most standards, but they produce effects very deeply in the mother’s body.

The rest of this paper focuses on how such highly penetrating effects can be produced. Both the biology and the physics are essential to this discussion.

The primary mechanism of action of low intensity EMFs in producing biological effects is activation of voltage-gated calcium channels (VGCCs) via its voltage sensor

The most important type of evidence for the EMF-voltage gated calcium channel (VGCC) activation mechanism, is that effects produced by EMF exposures can be blocked or greatly lowered by calcium channel blockers, drugs that are specific for blocking voltage-gated calcium channels [VGCCs) [12, 27, 28, 40]. Five different types of calcium channel blockers have been used in these studies, each of which is thought to be highly specific for blocking VGCCs [40]. Diverse EMFs produce effects which are blocked or greatly lowered by the calcium channel blockers, ranging from millimeter wave frequencies, microwave, radiofrequencies, intermediate frequencies, extremely low frequencies (including 50 and 60 Hz), all the way down to static electric fields and even static magnetic fields [12, 28, 40]. Following EMF exposure, the exposed cells and tissues have large, rapid increases in calcium signaling [12, 27, 28, 40], produced by increases in intracellular calcium [Ca2+]i levels. This overall interpretation has been confirmed by patch-clamp studies, studies using calcium-free medium, and studies measuring [Ca2+]i levels [28]. This mechanism has been widely recognized in the scientific literature with the first publication on this [40] being cited 305 times according to the Google Scholar database, at this writing. New scientific paradigms are usually only very slowly recognized in the scientific literature such that the widespread interest in and acceptance of this mechanism is very unusual. That does not, of course, mean that everyone accepts it.

The direct target of the EMFs is the voltage-sensor, which, in the normal physiology, controls the opening of the VGCCs in response to partial depolarization across the plasma membrane. Four distinct classes of VGCCs are activated in response to low level EMF exposures, L-type, T-type, N-type and P/Q-type VGCCs [40]. Voltage-gated sodium, potassium, and chloride channels, each controlled by a similar voltage sensor are also activated by low intensity EMF exposures, although these have relatively minor roles in producing effects compared with those of VGCC-produced [Ca2+]i elevation [28]. Plant TPC channel activation via a similar voltage sensor also produce plant calcium-dependent EMF effects [41]. Each of these channels is controlled by a similar voltage-sensor, suggesting that the voltage-sensor is the direct EMF target.

The electrical forces produced by even weak electronically generated EMFs on each of the 20 positive charges in the VGCC voltage sensor are thought to be very strong due each of three distinct mechanisms, which act multiplicatively: 1. Electronically generated EMFs are highly coherent, as discussed above, being emitted with a specific frequency, in a specific vector direction, with a specific phase and specific polarity. This high-level coherence causes the electrical and magnetic forces produced by these to be vastly higher than are forces produced by incoherent natural EMFs. 2. The electrical forces on these charges in the voltage sensor are thought to be approximately 120 times higher than forces on charges in the aqueous phases of our cells and bodies, as predicted be Coulomb's law, due to the difference of the dielectric constant in the two locations [12, 28]. 3. The forces on the charges in the voltage sensor are also thought, to be approximately 3,000 times higher because of the high electrical resistance of the plasma membrane and therefore the high level of amplification of the electric field across the plasma membrane [12, 28]. This helps us to understand how VGCCs and other voltage-gated ion channels can be activated by what are considered to be very weak EMFs. The important finding here is that EMFs activate the VGCCs and other voltage-gated ion channels not via depolarization of the plasma membrane but rather via the direct forces they produce on the circa 20 charges in the voltage sensor. One puzzle discussed in ref. [40] and also below in this paper is how can static magnetic fields activate the VGCCs when physics shows that static magnetic fields cannot put forces on static electrical charges. These magnetic field effects are discussed in the next section.

How then does EMF-produced VGCC activation produce biological effects? Our best understanding of this is outlined in Figure 1 [12, 28, 40]. The main pathophysiological effects seen going to the bottom of Figure 1, are produced through excessive calcium signaling produced by [Ca2+]i elevation and by the peroxynitrite pathway, with the latter involving increases in reactive free radicals, oxidative stress, NF-kappaB activity and inflammatory cytokine levels and also mitochondrial dysfunction. There is also a pathway by which VGCC activation, acting via increased nitric oxide (NO), NO signaling and Nrf2 stimulation can produce therapeutic effects that also helps explain EMF effects. The therapeutic pathway is thought to be produced by modest [Ca2+]i elevation whereas the pathophysiological pathways are produced by higher level [Ca2+]i elevation.

MM-waves have been shown to act via activation of the VGCCs and also voltage-gated potassium channels [42–44]. Therefore it seems likely that MM-waves act via such channel activation as do lower frequency EMFs. This interpretation is confirmed by findings that MM-waves raise [Ca2+]i levels, calcium signaling and also nitric oxide (NO) [42] (compare with Figure 1). It is also confirmed by findings that MM-waves raise peroxynitrite [45] and by findings, discussed above, that MM-waves can produce similar pathophysiological effects and therapeutic effects to those produced by lower frequency EMFs. There is an additional channel that is probably activated by MM-waves acting on voltage sensors, the Ca2+-activated potassium channel as shown by Geletyuk et al. [46]. It was shown in ref. [46] using patch-clamp studies, that closed Ca2+-activated potassium channels are opened by exposures to low intensity non-pulsed MM-waves. This same channel has also been shown to be activated by both 50 Hz and microwave frequency EMFs [47]. Ca2+-activated potassium channels have been shown to be activated by a voltage sensor similar in structure to the voltage sensors discussed above acting synergistically with increases in [Ca2+]i. It follows that EMFs may act to activate Ca^{2+}-activated potassium channels via the voltage sensor in that channel and also via the VGCC voltage sensors.

Can Nrf2 activation (see Figure 1) produce the therapeutic responses reported to occur following MM-wave exposures [16], as discussed in a previous section? Garkavi et al. [48] showed that MM-waves produced antistress responses and such antistress responses have been shown to be produced by therapeutic Nrf2 elevations (see, for example [49, 50]). Consequently, it is plausible that the therapeutic mechanism outlined in Figure 1 can produce the penetrating therapeutic effects, discussed above to be found following non-pulsed MM-wave exposures.

What mechanisms produce highly penetrating effects of MM-waves?

With the electrical parts of MM-wave radiation largely absorbed in the outer 1 mm of the body, how, can we get these highly penetrating effects through impacts on the voltage sensor of the VGCCs produced by these highly coherent electronically generated EMFs?

Two explanatory mechanisms are proposed here, each as a consequence of the very highly penetrating, time-varying magnetic forces produced by the highly coherent electronically generated EMFs including MM-wave EMFs. Let's consider each these two explanatory mechanisms, one at a time.

The discussion on Maxwell's equations in Wikipedia [11] states that "The Maxwell–Faraday version of Faraday's law of induction describes *how a time varying magnetic field* creates ('induces') an electric field" (italics added). Coherent highly penetrating time-varying magnetic fields will produce strong forces on ions dissolved in the aqueous phases in our bodies, moving those ions in both the extracellular medium and also in intracellular aqueous phases and therefore regenerating a highly coherent electric field similar to but of lower intensity to the original electric field of the EMF before entering the body. The regenerated EMF can, then act to put forces on the charges of the voltage sensor thus activating the VGCCs. The

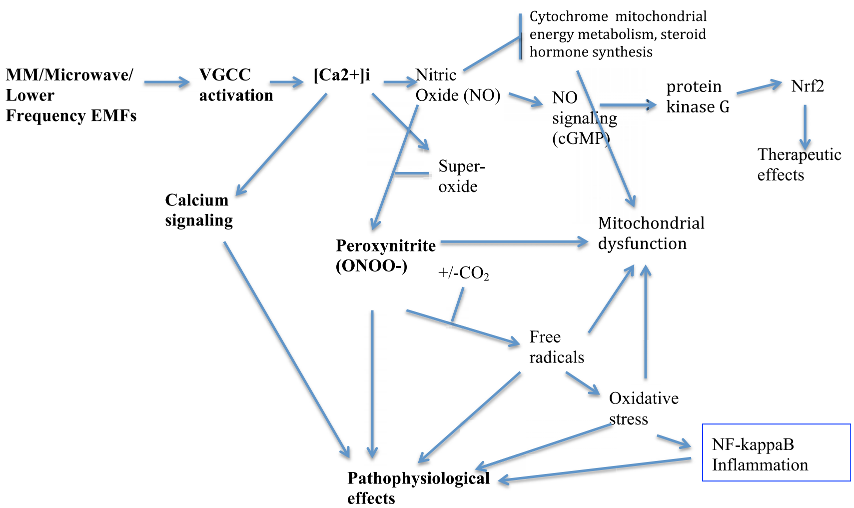

Figure 1: Diverse frequency EMFs act via activation of voltage-gated calcium channels (VGCCs) producing increased intracellular calcium [Ca2+]i. [Ca2+]i is defined as the calcium ion concentration in the cytoplasm which is distinct from the calcium concentration in the endoplasmic reticulum or the mitochondria, which are regulated separately. This leads to production of pathophysiological effects mainly via excessive calcium signaling and activation of the peroxynitrite/free radical/oxidative stress, NF-kappaB and inflammation pathway. Therapeutic effects are produced primarily via nitric oxide (NO) signaling leading to increased Nrf2 activity. Because the therapeutic pathway produces effects that are almost exactly opposite the effects produced by the peroxynitrite pathway, different EMF exposures may produce almost opposite effects. Copied from ref. [28] with permission.

physics here is essentially identical to the physics of electrical generation. In electrical generators, time-varying magnetic fields put forces on mobile electrons in copper wires, moving those mobile electrons and generating, in turn, an electrical current. In our bodies, the highly penetrating time varying magnetic fields put time-varying forces on dissolved mobile ions in aqueous phases in our bodies, generating a coherent electric field which can act on the voltage sensors to activate the VGCCs, as discussed above. A study providing support for this mechanism is the study of Deghoyan et al. [51] which found that non-thermal effects on cells in culture were produced through MM-wave irradiation of the medium surrounding these cells. This may or may not be the primary mechanism by which MM-waves produce highly penetrating effects.

There is second highly plausible mechanism by which highly penetrating magnetic fields can put forces on the charges in the voltage sensor activate voltage-gated ion channels. In ref. [40] it was shown that static magnetic fields also act, as do EMFs, via VGCC activation to produce biological effects that can be blocked with calcium channel blockers, so that the biological effects must have been produced via VGCC activation. Specifically, in Table 1 of ref. [40] and refs. [10], [12] and [24] in that paper each showed that effects produced by static magnetic fields can be blocked by calcium channel blockers, drugs specific for blocking VGCCs. Consequently, static magnetic fields produce effects via VGCC activation. That conclusion has been confirmed by the findings from patch-clamp studies, showing that static magnetic fields produced VGCC activation and also activation of voltage-gated sodium channels [52]. Those findings that static magnetic fields can act via the voltage sensor to activate VGCCs and apparently other voltage-gated ion channels created a puzzle that was discussed in ref. [40]. That puzzle is that static magnetic fields do not produce forces on static electrically charged objects. The answer to that puzzle, as discussed in ref. [40], is that the plasma membranes of cells are constantly moving and therefore the voltage sensors of the VGCCs located in the plasma membrane are also moving, so that static magnetic fields can produce time-varying forces on the charges of the VGCC voltage-sensor. These findings clearly raise the possibility that the highly penetrating time-varying magnetic fields derived from MM-wave or other frequency EMFs, including the extraordinarily high densities of modulating pulses of 5G, can have very high activity when acting directly on the 20 positive charges in the voltage sensor of the VGCCs to activate the VGCCs.

Both modulating EMF pulses and pure EMF pulses can act via each of the two mechanisms discussed here to produce large, very short term, penetrating changes in the forces on electrical charges including the voltage gated ion channel voltage sensor charges. Modulating and pure pulses inevitably produce vastly greater maximum time-variation and are, therefore, predicted to produce vastly greater maximum forces on the voltage sensor charges.

Because each of the two mechanisms proposed in this section for the generation of penetrating effects are dependent upon time-varying magnetic fields, together they provide a new understanding of the great importance of both modulating and pure pulsation in producing high level EMF effects.

Pakhomov et al. [17] reviewed findings with regard to non-pulsed MM-Waves: cardiac effects and electromagnetic hypersensitivity (EHS)

There are important findings on both animal cardiac effects and on animal tissue and human EHS-like effects produced by non-pulsed MM-wave exposures that were reviewed in Pakhomov et al. [17]. These are discussed here, in contrast, other MM-wave studies including those reviewed by Zalyobokskaya [19] and by Betskii and Lebedeva [16] which were discussed much earlier.

There are two important reasons for the author choosing to discuss the Pakhomov et al. [17] review on cardiac effects and also EHS-like effects here, as opposed to much earlier. Each of these require comparing animal studies with human studies. When highly penetrating MM-wave magnetic fields produce highly penetrating effects in animals and in humans, the difference in body size between humans and rodents is of little importance in predicting effects. A second reason for discussing these parts of ref. [17] here, is that the VGCC activation mechanism discussed above is predicted to be central to our understanding of both cardiac effects and EHS.

Chernyakov et al. [53], as discussed on p. 399 of ref. [17], reported on 990 experiments where very low intensity MM-wave EMFs changed the membrane function of the pacemaker cells of the sinoatrial node of the frog heart. In most cases, there was an almost instantaneous (less than 2 s) decrease in the interspike interval of these cells which in an intact heart would produce tachycardia. These occurred with intensity ranges of 20–500 $\mu W/cm^2$ and were, therefore, clearly non-thermal effects. Furthermore, as discussed on p.400 of ref. [17], Chernyakov et al. [53] showed that very low intensity MM-wave EMFs could produce changes in heart rate in anesthetized frogs, including both tachycardia (increase heartbeat) and bradycardia (slow heartbeat) and also arrhythmias. These also occurred when the hearts had been completely denervated although the severity of these changes decreased with denervation. The studies in this paragraph show that low intensity MM-wave EMFs produce direct effects on the membrane activity of the pacemaker cells in the sinoatrial node of the frog heart, influencing the heartbeat, but that the responsiveness of these cells can be influenced by neurological activity.

Other important cardiac studies of low intensity MM-waves were reported by Potekhina et al. [54] in the rat. They [54] showed that MM-waves produced changes in heartbeat including arrhythmias, tachycardia and bradycardia. Longer term (circa 3 h) exposures produced large numbers of animals who died of apparent sudden cardiac death. It is the author's opinion that most if not all of these EMF cardiac effects are produced by the direct impacts of diverse EMFs impacting the pacemaker cells in the sinoatrial node of the heart. One additional set of observations supporting that view are the findings of Liu et al. [55] showing that pulsed microwave EMFs produce heart failure-like changes in the sinoatrial node of the heart. The reason the pacemaker cells of the sinoatrial node of the heart may be particularly sensitive to EMFs is because they contain particularly high densities of T-type VGCCs, with both T-type and L-type VGCCs having essential roles in producing the pace making activity [56, 57]. These findings suggest that penetrating EMF effects can produce commonly observed cardiac effects via direct impacts on the pacemaker cells in the sinoatrial node of the heart.

Pakhomov et al. [17] also reviewed findings showing that non-pulsed MM-wave EMF exposures produce EHS-like effects in animal nerve tissue, and in humans. EHS is characterized by long term sensitivity responses to electromagnetic or electric fields [17] describes three studies where non-pulsed MM-wave exposures produced fairly long-term sensitivities in animal tissues and three additional studies of long term neurological/neuropsychiatric sensitivity in humans.

Burachas and Mascoliunas [58] described changes in the compound action potential (CAP) in the frog sciatic nerve following MM-wave exposures. They found that "CAP decreased exponentially and fell 10-fold within 50–110 min of exposure at 77.7 GHz, 10 mW/cm^2. CAP restored entirely soon after exposure, but the nerve became far more sensitive to MMW. CAP suppression due to the next exposures became increasingly steep and finally took only 10–15 min. This sensitized state persisted for at least 16 h" CAP is a measure of the overall electrical activity of the nerve. These findings may be interpreted in terms of MM-wave EMF exposures producing long-term EHS-like sensitivities in the frog sciatic nerve.

A second study by Chernyakov et al. [53] also reported sensitivity changes using a different frog nerve and also different MM-wave exposure protocols. “The exposures lasted 2–3 h, either with a regular frequency change of 1 GHz every 8–9 min or with a random frequency change every 1–4 min (53–78 GHz band, 0.1–0.2 mW/cm^2). The latter regimen induced an abrupt CAP ‘rearrangement’ in 11 of 12 exposed preparations: the position, magnitude and polarity of the CAP peaks (the initial CAP was polyphasic) drastically changed in an unforeseeable manner. The other exposure regimen altered the CAP peaks components in 30–40 min”

Akoev et al. [59] found EHS-like effects following low intensity MM-wave exposures on the activity of electroreceptors of skates (the article cited here is an English language study, published in an international journal that appears to be similar or identical to the Russian language article cited in ref. [17]). “When a power intensity of 1–5 mW/cm^2 was used at a distance of 1–20 mm from the duct opening only excitatory responses were observed in receptors with electrical thresholds of 4–20 nA”, p. 15 in ref. [59]. Reference [59] states further (p. 17) “It is of interest that at low EMR intensity, the electroreceptors (have) prolonged excitatory responses which differ from responses to the d.c. electrical stimuli (where) the ampullae of Lorenzini completely adapt within a few minutes. Thus it is the long-lasting slow adapting excitatory response that may reflect the peculiarity of the low-intensity millimeter-wave EMR effect on biological tissues.” These results show that low intensity MM-wave EMFs produce long-term hypersensitivity of the electroreceptors. There are similar electroreceptors in sharks, skates and rays and given that the target producing hypersensitivity here is that receptor, it is important to identify the identity of electroreceptor. Bellono et al. [60] showed that the electroreceptor is the VGCC Ca(V)1.3. Other studies implicate excessive [Ca2+]i in electroreception and VGCC activation was also implicated in the Zhang et al. [61] study of the skate electrosensor. We have, therefore, VGCCs implicated as the direct EMF target involved in producing EHS-like responses.

Is there other evidence implicated excessive VGCC sensitivity in producing EHS? One such study was published by Dr. Cornelia Waldmann-Selsam [62]. She studied an EHS patient who showed high sensitivity to extremely low intensity EMFs and who also had a profound parathyroid deficiency. This patient showed very large rapid drops in extracellular Ca^{2+} concentration, including in the blood plasma, following extremely low intensity EMF exposure. Because the only possible mechanism that can produce such a large rapid drop in extracellular Ca^{2+} concentration is a large influx of Ca^{2+} ions into cells of our bodies, this argues strongly for EHS producing large increases in activity of one or more calcium channels in the plasma membranes of cells. Because VGCC activation is known to be the major mechanism of EMFs, all of these findings argue that the VGCCs in EHS become hypersensitive to EMF activation.

The parathyroid deficiency of this patient [62] is of great importance because in people with normal parathyroid function, large drops in extracellular calcium levels produce a rapid increase in parathyroid hormone secretion, which mobilizes calcium from the bones to help restore normal extracellular calcium levels, thus making drops of extracellular Ca^{2+} concentrations in exposed EHS patients with normal parathyroid function more difficult to document. However, these considerations suggest a simple clinical test for EHS patients. Such patients should have large increases in parathyroid hormone following low intensity EMF exposures to which they report sensitivity, whereas normal people should not show such large increases to the same exposures. Because parathyroid hormone can be measured by clinical testing laboratories, this prediction can be easily tested and possibly used as a simple, inexpensive test of EHS.

A fourth MM-wave animal study, discussed above in this section, also suggests possible EHS-like effects in animals. This is the Potekhina et al. [54] study in the rat which found that non-pulsed MM-wave exposures for 3 h or more started to produce apparent sudden cardiac death in these exposed rats. These findings suggest cumulative effects of EMF exposure. However, their relevance to EHS must be viewed as more questionable than are the three studies discussed more immediately above, because there were no measurements which demonstrated that exposures produced increased sensitivity following MM-wave exposures in Potekhina et al. [54].

Three human studies, cited in ref. [17] each showed apparent EHS effects following low intensity non-pulsed MM-wave exposures, including neurological/neuropsychiatric sensitivities [21, 63, 64]. The sensitivities shown in each are brain-related neurological/neuropsychiatric sensitivities that are commonly reported in EHS.

EHS causation by EMF exposures is not only documented by the studies cited above. They are also documented by the largest occupational exposures ever performed, as shown in the Hecht review of such exposures [65]. Reference [65] also documents EMF causation of neurological/neuropsychiatric effects and cardiac effects.

In addition the much earlier US Government (NASA) document [66] also documents EMF occupational exposure causation of neurological/neuropsychiatric effect and cardiac effects [28] lists 15 different published reviews each of which provide substantial bodies of evidence that neurological/neuropsychiatric effects are caused by low-intensity, non-thermal EMF exposures. Lamech [67] showed that smart meter radiation exposure was associated with large increases in EHS, neurological/neuropsychiatric effects and cardiac effects and similar findings were reported in the Conrad study of smart meter radiation.

Four reviews on EHS each report that among the most common sensitivities in EHS patients are neurological/neuropsychiatric sensitivity and cardiac sensitivity [65, 68–70].

It follows from the findings discussed in this section, that EMFs with substantial impacts on our bodies will produce many cases of EHS with the consequent sensitivity responses often including neurological/neuropsychiatric effects and cardiac effects. The next question to be considered here is whether 5G radiation is likely to be among the EMFs that may produce substantial impacts.

Earlier in this paper we discussed two important findings that are important for assessing the probable impacts of 5G radiation. 5G radiation, however, uses extraordinarily high levels of modulating pulses in order to carry extraordinarily high amounts of information per second [36]. Reference [28] cited 10 different reviews each showing that EMFs with modulating pulses produce, in most cases, much higher levels of biological effects than do non-pulsed (continuous wave) EMFs of the same average intensity. If follows that 5G may be predicted to produce very damaging highly penetrating effects because of its extraordinary level of modulating pulsations.

Is there any evidence that 5G radiation produces high human impacts including EHS, neurological/neuropsychiatric effects and cardiac effects?

There has been no biological safety testing of highly pulsed 5G radiation despite calls from many scientists for such testing before any 5G rollout should occur. There have also been no scientific studies of 5G radiation effects after any 5G rollouts, to my knowledge. Consequently, the only evidence we have is from reports of 5G effects in the media. These reports are not, of course, scientific studies but rather are derived from what may be viewed as questionable observations. Nevertheless, due to the lack of any other 5G information, it is important to look at what little information we do have.

Reference [71] is a German news article about protests of German physicians in Stuttgart Germany following a 5G rollout. The physicians report seeing substantial apparent effects on their patients including neurological/neuropsychiatric effects, cardiac effects and EHS. These observations can be seen to be similar to the predicted 5G effects in the previous section. German physicians may be more aware of EHS than are physicians in other countries because the European environmental medicine organization, EUROPAEM, has been headquartered in Germany for many years – [69] is a EUROPAEM-related paper.

There are also reports of neurological/neuropsychiatric effects, cardiac effects and possibly also EHS in Switzerland following 5G rollout in parts of that country [72–74]. These reports may be somewhat less reliable than those from Stuttgart because they come from lay people.

There was much concern about three suicides over an 11 day period of emergency medical technicians working in the first 5G ambulance [75]. This occurred in Coventry, UK. The idea was that 5G could be used to transmit much medical information from the hospital to the ambulance and could also be used to transmit much electronic patient information from the ambulance to the hospital. The first EMT suicide occurred approximately two weeks after the EMTs started working in the 5G ambulance. Among the more common neuropsychiatric effects produced in humans by EMF exposures are depression and anxiety [27], both of which when severe can cause suicide. It is possible that EHS may play a role in the approximate two week time period between the beginning of service of the 5G ambulance and the first suicide. Development of progressively more severe EHS over that two week period may be predicted to produce progressively more severe depression and anxiety.

Again, these are not scientific studies but given the lack of any contrary information, they need to be taken seriously and should be the subject of serious scientific study rather than massive rollout of untested and possibly very dangerous 5G systems. One thing that should be pointed out is that any initial effects on rollout of 5G, are likely to be dwarfed by effects of any full-fledged 5G system communicating with billions of devices on the ‘internet of things." Of course, the effects of such massive amounts of pulsed EMF communication may be further amplified through the action of EHS in the victims.

Search strategies

Articles on important physical or biological properties of coherent electronically generated EMFs were found using two search strategies: The EMF Portal database was searched using coherent or coherence. The Web of Science database and Google Scholar were each searched using electromagnetic fields and coherent.

Reviews on biological including human effects of millimeter waves were searched for in the EMF Portal database searching with the words millimeter waves and limiting responses to review articles. Similarly, reviews were searched in the EMF Portal database using EHS to identify EHS reviews.

The work on EMFs acting primarily via the voltage sensor to activate VGCCs is limited to my own work where only highly cited peer-reviewed articles were cited.

Two specific questions were answered as follows

When it was shown that millimeter wave exposures produced increased sensitivity of the skate electroreceptor, it was important to determine whether the electroreceptor is a VGCC, the most important direct target of EMFs. A Web of Science search using electroreceptor and voltage calcium channel found two studies each showing that the electroreceptor is a VGCC.

It was shown that millimeter waves act directly on the pacemaker cells of the sinoatrial node of the heart to change the beat frequency. It was important to determine whether microwave frequency radiation also target such cells in the sinoatrial node. A search of the EMF Portal database limited to radiation over 1 MHz for studies on sinoatrial node found a study showing that repeated or prolonged exposures produced heart failure-like changes in the sinoatrial node of the rat heart.

Two of the Russian language articles are available as CIA English translations, as shown in the citation list. All other foreign language documents cited where suitable PDFs of the original documents were available were translated into English using Google Translate.

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Radio-Frequency Electromagnetic Field Exposure of Western Honey Bees

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Radio-frequency electromagnetic fields (RF-EMFs) can be absorbed in all living organisms, including Western Honey Bees (*Apis Mellifera*). This is an ecologically and economically important global insect species that is continuously exposed to environmental RF-EMFs. This exposure is studied numerically and experimentally in this manuscript. To this aim, numerical simulations using honey bee models, obtained using micro-CT scanning, were implemented to determine RF absorbed power as a function of frequency in the 0.6 to 120 GHz range. Five different models of honey bees were obtained and simulated: two workers, a drone, a larva, and a queen. The simulations were combined with *in-situ* measurements of environmental RF-EMF exposure near beehives in Belgium in order to estimate realistic exposure and absorbed power values for honey bees. Our analysis shows that a relatively small shift of 10% of environmental incident power density from frequencies below 3 GHz to higher frequencies will lead to a relative increase in absorbed power of a factor higher than 3.

Wireless communication is a widespread and growing technology. Most of the wireless networks and personal devices operate using Radio-Frequency (RF) electromagnetic fi lds (EMFs). The current networks rely on frequencies between 0.1 GHz and 6 GHz[1]. These EMFs can be absorbed in dielectric media and can cause dielectric heating[2]. Th s dielectric heating can occur in any living organism, including insects.

Absorption of RF EMFs in insects has been studied previously. Wang *et al.*[3] studied absorption of RF EMFs in mashed codling moth larvae at 27 MHz and 915 MHz. Shrestha *et al.*[4] studied dielectric heating of Cryptolestes ferrungineus S. in different stages (eggs, larvae, pupae, and adults) at 27 MHz. Shayesteh *et al.*[5] exposed Tribolium confusum and Plodia interpunctella to RF EMFs at 2450 MHz[6–8]. are reviews of RF heating of insects. Dielectric porperties of insects are measured by Nelson *et al.*[9] from 0.2 to 20 GHz through the determination of loss of RF EMF power in insect samples (rice weevil, red fl ur beetle, saw-toothed grain beetle, and lesser grain borer). Absorption of RF EMFs was studied by Halverson *et al.*[10] in insects between 10–50 GHz. Thi lens *et al.*[11] used numerical simulations to study absorption of RF EMFs from 2–120 GHz in four insect models. The main conclusions from the aforementioned studies are that (i) RF EMFs can be absorbed and can cause dielectric heating in insects and (ii) this absorption of RF-EMFs is frequency dependent. Th s frequency dependency is important since 5th generation (5 G) networks are expected to partially operate at higher frequencies (up to 300 GHz)[12,13]. Th s shift might induce a change in RF EMF absorption for insects[11].

Western Honey Bees (*Apis Mellifera*) are particularly important insects because of the environmental and economical importance of this species. Therefore, previous studies have focused on the potential effects of EMF exposure of Western Honey Bees. Low-frequency EM properties and exposure of honeybees was studied in[14]. The influence of Low-frequency magnetic fi lds on honey bee orientation has been studied in[15]. There have also been some studies on effects of RF EMF on honey bees. Potential effects of RF EMF exposure on reproduction of honey bee queens were investigated in[16]. Behavioral effects potentially caused by exposure to RF EMFs in honey bees have been investigated in[17–19]. A disadvantage is that these studies are lacking a quantifi ation of the amount of power that is absorbed in the studied honey bees, so called RF dosimetry[20]. On the other hand, this absorption has been determined for a single honey bee worker in[11]. However, Thi lens *et al.*[11] do not provide any coupling of this absorption to a real RF-EMF exposure situation and only study a single honey bee, which provides no

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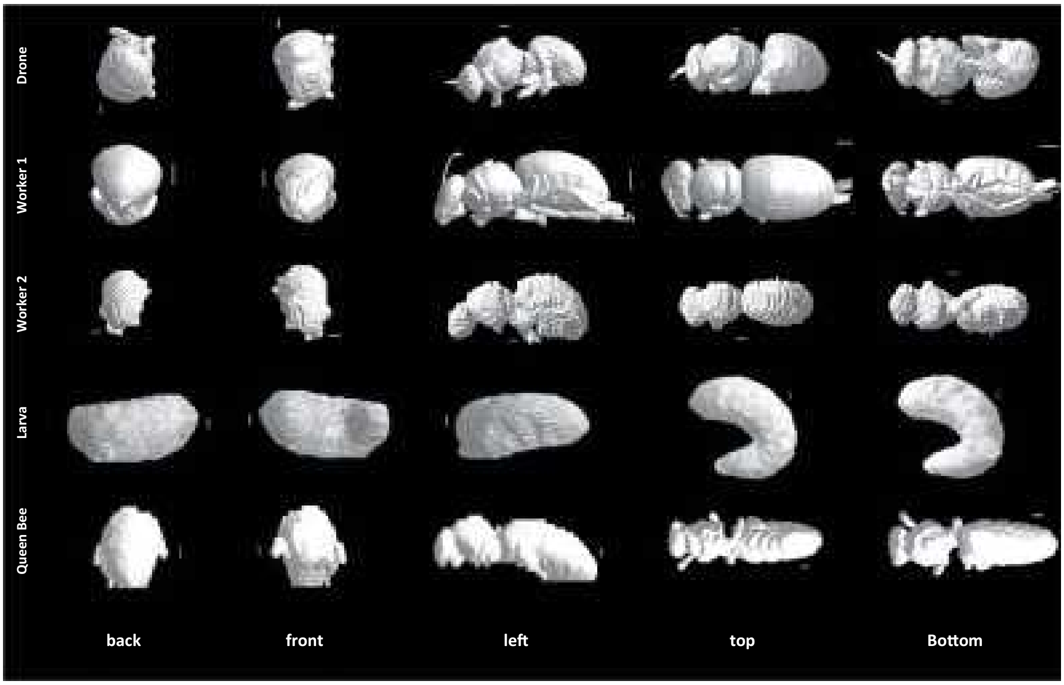

Figure 1. Studied Honey Bee Models, from top to bottom: Male Drone, Worker Bee 1, Worker Bee 2, Worker Larva and Queen Bee. Columns show different perspectives: back, front, left, top, and bottom view, respectively. The white lines show a 1 mm scale for reference.

information on the evolution of such absorption as a honey bee goes through different developmental stages. Nor is it clear whether this RF absorption is realistic for other castes, such as drones or queens, in a bee colony.

Therefore, the aims of this study were to numerically evaluate RF-EMF absorption in western honey bees and validate the frequency dependency of this absorption during various developmental stages and experimentally quantify real-life exposure of bees. To this aim, numerical simulations were executed to determine the absorption of RF-EMFs in five different honey bee models: a larva, a queen, two workers, and one drone, obtained using micro-CT imaging. These simulations were implemented as a function of frequency in a broad band, 0.6 GHz up to 120 GHz, that can be used to model both current and future telecommunication frequencies. In parallel, RF-EMF exposure measurements were executed near five bee hives in Belgium, in order to quantify the real exposure of such honey bees. Finally, these measured values were used to rescale the numerical simulations in order to quantify real honey bee absorption and assess a potential change in absorption in case a shift in operation frequencies in future telecommunication networks would occur.

Methods

Studied honey bees, imaging technique, and model development. Images of the studied insects are shown in Fig. 1. All studied insects are western honey bees (*Apis mellifera*), which is the most commonly used honey bee worldwide. Honey bees within a colony are subdivided into different castes. An active viable honeybee colony contains only one queen bee who spends most of her time laying 2,000 to 3,000 eggs per day. The queen is the only reproductive female within the colony and her health is vitally important to the survival of her colony. Damage to her ovaries has the potential to effect the function and survival of her progeny. A queen typically lives between approximately three and five years. From early spring time to mid-summer the queen lays unfertilized "haploid" eggs which develop into drone bees. All drones are males. Their specific role is to mate with a virgin queen so that she can initiate the propagation of a new colony. During this mating season, there are approximately 3,000 to 5,000 drones within any given colony. Drones typically live between one to two months.

A healthy honey bee colony can contain approximately 50,000 individuals. Most of these are sterile, female, worker bees. Worker bees perform all the tasks within a colony to keep it full of provisions and free from disease. Th s involves feeding and nursing larvae, foraging for nectar and pollen, storing nectar and pollen, guarding the entrance, tending to the hygiene of the queen-workers-drones and maintaining a clean hive environment. Workers live for three to four weeks during the active seasons (spring-summer-autumn) and approximately three months during the colder inactive season (winter). There are approximately 3,000 (winter) to 10,000 (summer) larvae present at any given time.

We chose representatives from all three castes within a honeybee colony, one queen bee, two worker bees, one drone bee and one worker larva. All honey bees were scanned at the Western Sydney University National Imaging Facility (Sydney, Australia) using a bench-top MicroCT scanner (Quantum GX MicroCT Imaging System, PerkinElmer, Hopkinton, MA, USA). The parameters used during this scanning depended on the scanned bee. Such scans are made using different projections, at different time intervals on the scanners settings.

The rotation between projections also depends on the scanner's settings and the studied honey bee (see below for full description).

Worker 1. The insect named 'Worker 1' is the same bee studied in[11], which had a full body length of approximately 11.0 mm long, is 5.0 mm wide, and had a mass of approximately 900 mg. During the scanning of Worker 1, the Micro-CT scanner was operated using the following parameters: 50 kVp, 80 mA, and a 2048 $\times$ 2048 pixels image matrix. This resulted in scans with a 20 μm isotropic voxel size. Each projection had a scanning time of 3.0 s, with 3.0 s rotation time in between projections. The total scan time for Worker 1 was approximately 18 min.

Worker 2. The second honey bee worker (Worker 2) has a full body length of 13 mm with cross sectional dimensions of 6.8 mm and 5.4 mm and a mass of approximately 900 mg. For Worker 2, the scanner was operated using the following parameters: 40 kVp, 70 mA, and a 2048 $\times$ 2048 pixels image matrix. The isotropic voxel size was 100 μm. Each projection had a scanning time of 1.5 s. There was a 3.0 s rotation time in between each projection. The total scan time for the whole bee was approximately 10 min.

Larva. Larvae of this age (three weeks) are typically approximately 16 mm long with an approximate mass of 900 mg. The scanned larva was curled up, which made estimating its full body dimensions difficult, but the sample fitted within a $14 \times 7 \times 15$ mm^3 box. Th s scanning of the larva was done using the following parameters: 50 kVp, 80 mA, and a 2048 $\times$ 2048 pixels image matrix. Th s resulted in scans with a 20 μm isotropic voxel size. Each projection had a scanning time of 3.0 s. and with a 3.0 s rotation time this resulted in a total scan time for the larva of 18 min.

Male drone. The drone has a full body length of 18 mm with cross sectional dimensions of 7.2 mm and 9.4 mm and an approximate mass of 1 g. During the scanning of the drone, the Micro-CT scanner was operated using the following parameters: 40 kVp, 70 mA, and a 2048 $\times$ 2048 pixels image matrix. The isotropic voxel size was 100 μm. Each projection had a scanning time of 1.5 s. The full scan took 180 projections and there was a 3.0 s rotation time in between each projection. The total scan time for the whole bee was approximately 10 min.

Queen bee. The QB has a full body length of 19 mm and cross sectional dimensions of 7.5 times 7.1 mm^2 and an approximate mass of 1100 mg. The queen was scanned was using the following parameters: 40 kVp, 70 mA, and a 2048 $\times$ 2048 pixels image matrix. The isotropic voxel size was 250 μm. Each projection had a scanning time of 1.5 s. There was a 1.5 s rotation time in between each projection. The total scan time for the queen bee was approximately 10 min.

Development of 3D models. The software running on the Quantum GX, bench-top MicroCT scanner was used for all honey bees to reconstruct the 180 projection images. Those were then converted into a 2D rendered image stack of 512, 16 bit bitmap images. Finally, the BeeView volume rendering software (DISECT Systems Ltd, Suffolk, UK) was used to acquire Bee volume data from the image stack. All 3D models of the insects were created using the software TomoMask (www.tomomask.com). We used the same approach as in[11]. The image stack for each honey bee was imported into TomoMask, which also required the pixel and slice spacing. The software generated a 3D model using a marching cubes algorithm[21]. Th s model was then exported as an STL (STereo Lithography)[22] file. Th s is a commonly used format to describe surface geometry. The models were also smoothed using the Taubin λ/μ smoothing scheme[23] implemented in MeshLab[24]. The dimensions of the models and mesh integrity were checked (and corrected if necessary) before simulations using Netfabb (Autodesk, San Rafael, CA, USA).

Numerical simulations and RF EMF exposure conditions. Electromagnetic, numerical simulations were executed to estimate electromagnetic fi lds in and around the honey bees under far-field exposure. Far-field exposure is in this manuscript defi ed as RF-EMF sources being more than $2D^2/\lambda$ away from the insects, with D the largest dimension of the RF source and λ the wavelength of the RF-EMFs. Th s is often referred to as the Fraunhofer far-fi ld limit[25]. In general, far-fi ld RF-EMF sources can be located in any direction from the honey bees. Therefore, different approaches exist to model such far-fi ld exposure to RF-EMFs: a stochastic method where far-fi ld exposure is decomposed in sets of plane waves according to certain statistics is used in[26,27], while a more limited set of plane-wave exposures coming from six predefi ed directions along the main axis of the exposed subject or animal are considered in[11,28]. In this study, we have chosen to work with the latter method. We have modeled exposure of the studied honey bees by a set of 12 incident plane waves traveling along six directions defined by a Cartesian coordinate system, see Fig. 2. For each direction, two orthogonal incident electric field polarizations were chosen, since any other free-space E-fi ld polarization can be obtained using a linear combination of both. All incident plane waves have a root-mean squared electric fi ld strength of 1 V/m. Th s value is chosen to facilitate renormalization to any potential value of incident fi ld strenght.

Numerical simulations were executed using the Finite-Difference Time-Domain (FDTD) method implemented in Sim4life (ZMT, Zurich, Switzerland). Th s is a common technique used to determine RF-EMF in and near homogeneous and heterogeneous dielectric objects[11,26,28], such as the honey bees studied in this paper. In this method, the simulation domain is divided in cubes using a three-dimensional rectilinear grid. Depending on the wavelength, feature sizes of the objects in the simulations, and the desired spatial accuracy, a different spatial step is used to discretize the simulation. The FDTD algorithm requires a grid step smaller than one tenth of the smallest wavelength in the simulation domain in order to return stable solutions[29]. Since this is a time-domain technique, it requires a predefi ed simulation time in order to reach a steady-state solution, which will again depend on the chosen spatial resolution, the wavelength, and the size of the simulation domain.

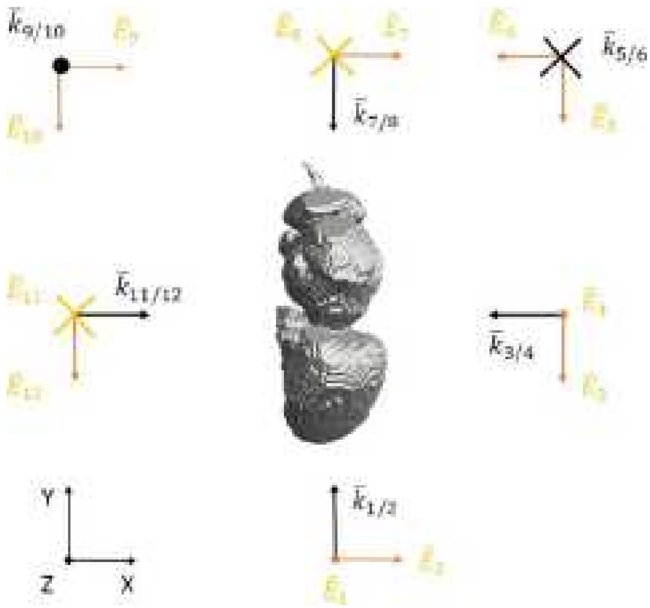

Figure 2. Configur tion of the RF-EMF plane-wave simulations. Twelve potential RF plane waves incident from six directions are incident on the insect (honey bee drone shown here in grey, top view). Orange arrows indicate the electric fi ld $\overline{E}_i$ polarizations, while the black arrows indicate the direction of propagation with wave vector $\overline{k}_{i/j}$ of the plane waves. *i* and *j* indicate the simulations' configur tion number, from 1 to 12.

	0.6 GHz	1.2 GHz	2 GHz	3 GHz	6 GHz	12 GHz	24 GHz	60 GHz	120 GHz
Maximal grid step (mm)									
Larva	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Others	0.1	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Simulated Periods									
Worker Bee 1	20	30	60	30	30	30	30	40	40
Others	10	20	20	30	30	30	30	30	30
ε_r	45.6	44.2	39.9	38.8	38.0	28.6	14.9	7.018	5.46
σ (S/m)	0.688	0.924	1.35	2.05	5.05	12.0	21.1	27.9	29.2

Table 1. Simulations Settings and Dielectric Properties of the Honey Bees.

We executed numerical simulations at nine harmonic frequencies from 0.6–120 GHz (sinusoidal waves at a single frequency). The lower and upper frequency limits were chosen because they correspond to the current limits in terms of simulation size and length that can realistically be supported by our simulation hardware. The simulated frequencies are listed in Table 1 alongside the chosen grid steps in the simulation domain and the number of periods used for every simulation. These settings were the same for each of the five studied honey bee models. The studied insects have certain dielectric properties, quantifi d using the relative permittivity (ε_r) and conductivity (σ). We did not measure the dielectric properties of the studied insects. Instead, we assigned dielectric parameters obtained from[11]. The value at 1 GHz is obtained using the same literature database and interpolation presented in[11]. Table 1 lists these properties. All insects were modeled as homogeneous objects. These configur tions resulted in 12 (plane waves) × 9 (frequencies) × 5 (honey bees) = 540 simulation results.

After each simulation, the internal electric fi ld in the insect model was extracted and used to calculate the total absorbed RF-EMF power (P_{abs}) in the honey bee. P_{abs} is calculated as the integrated product of the conductivity and the squared internal electric fi ld strenght ($\overline{E}_{int}$) over the total volume (V) of the insect:

$$P_{abs} = \int_V \sigma \times |\overline{E}_{int}|^2 .\, dV \tag{1}$$

We report P_{abs} rather than specific absorption rate (SAR) values since we did not measure the mass and density of all the simulated honey bees. P_{abs} is an important quantity since dielectric heating of an insect is proportional to absorbed RF-EMF power[2].

In order to validate our simulations we tested the influence of four simulation settings on the RF-EMF P_{abs}: grid step size, dielectric parameters, angle of incidence, and number of simulated periods. The influence of the grid step is expected to be the most signifi ant at the highest simulated frequency (120 GHz), since the chosen maximal grid step of 0.05 mm is closest to the smallest wavelength in the simulation domain at that frequency in the tissue ($0.05\,mm = 0.045\,\lambda$). Therefore the maximal grid step was set to 25 μm for exposure configur tion number 2 in Fig. 2 for both the Larva and Worker 2 phantoms. In[11], it was demonstrated that the maximal uncertainty on the dielectric parameters occurs between 2 and 3 GHz, with maximal relative deviations of 40%. In order to test the dependency of our simulation results on the chosen dielectric parameters, we executed four additional FDTD simulations in exposure configur tion number 2 shown in Fig. 2 using the Worker 2 phantom. In these simulations the dielectric parameters (ε,σ) were changed to: (1.5.ε, 1.5.σ), (0.5.ε, 1.5.σ), (1.5.ε, 0.5.σ), and (0.5.ε, 0.5.σ), respectively, allowing for a potential 50% deviation on the dielectric parameters, which should be larger than the uncertainty on the chosen dielectric parameters. We chose to model RF-EMF exposure of the studied honey bees using plane waves incident from 6 directions. However, it is uncertain whether this set of plane waves provides a complete overview of the full range in P_{abs} as function of the angle of incidence. In order to validate our exposure set up, we have executed 20 additional FDTD simulations at 6 GHz using the Worker 2 phantom, where the elevation, azimuth, and polarization angles were generated according to uniform distributions between $[0, \pi]$, $[0, 2\pi]$, and $[0, 2\pi]$, respectively. The settings of these FDTD simulations were the same as those shown in Table 1. Finally, the number of simulated periods was tested at 120 GHz for the Worker 2 phantom in exposure configur tion number 2 shown in Fig. 2 by increasing the number of simulated periods to 120 instead of 30, see Table 1. After each of these validation simulations, the P_{abs} was extracted and compared to the one obtained in the original simulation set.

RF-EMF field measurements. In order to quantify current RF-EMF exposure of honey bees in real exposure scenarios, we executed RF-EMF exposure measurements at five sets of bee hives in Belgium at: Aalter, Merelbeke, Eeklo, Zomergem, and Drongen, see Fig. 3(a). At each measurement site, three different measurements were executed in order to quantify RF-EMF exposure.

First, a spectrum analyzer of the type FSL6 (R&S Belgium, Excelsiorlaan 31 1930 Zaventem Belgium) connected to a triaxial isotropic antenna was used to perform a broad-band RF overview measurement from 80 MHz to 6 GHz. These measurements were executed in two steps: fi st spectral overview measurements were executed from 0.08–3 GHz using a tri-axial antenna TS-EMF (Rhode and Schwartz, dynamic range of 1 mV/m–100 V/m for the frequency range of 80 MHz–3 GHz), followed by measurements from 3–6 GHz using a Clampco AT6000 antenna. At one out of five measurement sites, Drongen, a conical dipole antenna PCD 8250 (Seibersdorf Laboratories, Seibersdorf, Austria) was used for the 80 MHz - 3 GHz measurements. Th s antenna was rotated to obtain three orthogonal polarizations of the electric fi ld. During these overview measurements, the spectrum analyzer measured in maximum-hold modus during 17 and 9 minutes in the lower and higher frequency bands, respectively. The antennas were supported by a plastic tripod and were placed at 1 m in front of the bee hive at a height of 1.5 m from the ground level. Figure 3 shows the studied bee hives and the measurement set up in the field. The 1.5 m height is a typical height at which such EM field measurements[30]. Additionally, this height is mentioned in the ECC(02)04 standard[31]. The purpose of these measurements was to get an overview of which frequency bands were in use at the respective sites. These frequency bands were then investigated further in the second measurements.

Second, the same spectrum analyzer was connected to the tri-axial antenna TS-EMF which was again supported by the same tripod at a height of 1.5 m. The tripod was placed at two distances of 1 and 2 m from the central bee hive. The spectrum analyzer performed root-mean square electric fi ld strength (E_{RMS}) measurements over a measurement period of 6 minutes[2] in each of the telecommunication frequency bands identifi d using the fi st measurement. Each of the three electric field components (E_x, E_y, E_z) were measured individually. E_{RMS} was then obtained as the square root of the sum of squares of the individual components.

$$E_{RMS} = \sqrt{E_x^2 + E_y^2 + E_z^2} \tag{2}$$

The spectrum analyzer measurements in terms of received power on the antenna were then recalculated using the known antenna factor of the tri-axial antenna to incident root-mean-squared electric fi ld strength. The $E_{RMS,i}$ values in each frequency band (i) were then summed quadratically and the square root of that sum is listed as the total instantaneous electric fi ld strength ($E_{RMS,tot}$).

$$E_{RMS,tot} = \sqrt{\sum_i E_{RMS,i}^2} \tag{3}$$

The measurement procedure and measurement settings for these RF-EMF exposure measurements are presented in[32]. The expanded measurement uncertainty (95% confide ce interval) for electric fi ld strength measurements using this set up is $\pm 3\,dB$[30].Th s measurement setup enables the most accurate assessment of *in situ* exposure from various RF-EMF sources[30].

Third, a broadband exposure measurement was executed using a Narda NBM-550 probe (Narda, Hauppauge,NY, USA) connected to an EF 0691 broad-band probe (Narda, Hauppauge, NY, USA) which has a frequency span from 100 kHz to 6 GHz, thus including so-called intermediate frequencies (IF). These IF fi lds are not considered in our numerical simulations. However, we measured those to provide a complete overview of the exposure to electromagnetic fi ld below 6 GHz. The NMB probe was placed on top of the central bee hive and was left there during both RF measurements. The device measured and registered root-mean-squared electric fi ld strengths with a period of 1 s. From those time series of measurements, we obtained the time average and the maximal value.

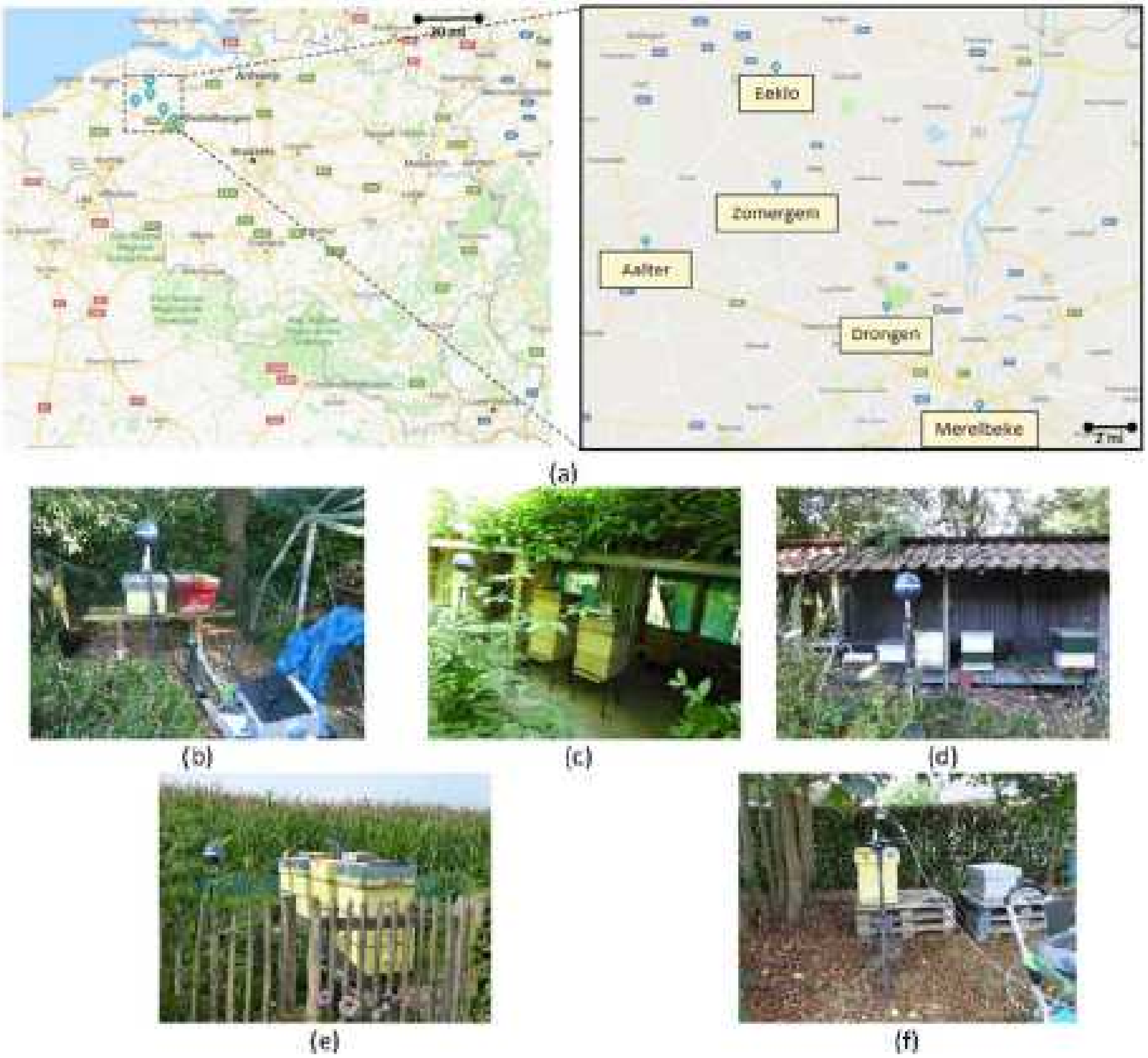

Figure 3. Five measurement locations near bee hives in Belgium: (**a**) Overview of the measrurement locations (source: https://www.google.com/maps, Google Maps, Google, Alphabet inc., Mountain View, CA, USA) Map data: Google, GeoBasis-DE/BKG (**b**) Aalter, (**c**) Merelbeke, (**d**) Eeklo, (**e**) Zomergem, and (**f**) Drongen.

The researchers that executed the RF-EMF fi ld measurements did not use personal devices during the measurements. All wireless devices brought to the measurement site by the researchers were operated in fli ht mode, i.e. any wireless transmissions by those devices were not allowed.

Estimation of realistic RF-EMF absorbed power in honey bees. Realistic P_{abs} absorbed in honey bees can be obtained by rescaling the simulated P_{abs} values using the measured incident fi ld strengths. Therefore, we linearly averaged the total E_{RMS} values measured near the five bee hives at two different positions to obtain an average $E_{RMS,avg}$ value. In order to estimate exposure of honey bees in current wireless networks, we averaged the P_{abs} values using:

$$P_{abs,av}(f < 3\ GHz) = \frac{1}{4}\sum_{i=1}^{4} P_{abs}(f_i) \tag{4}$$

with $f_i = 0.6, 1.2, 2, 3\ GHz$. We only considered P_{abs} values < 3 GHz, since our measurements will show that there are only incident RF-EMFs below 3 GHz in the current environment of honey bees in Belgium. Th s value is then rescaled using:

$$P_{abs,real}(f < 3\ GHz) = \frac{E^2_{RMS,avg}}{1\ V^2/m^2} \times P_{abs,av}(f < 3\ GHz) \tag{5}$$

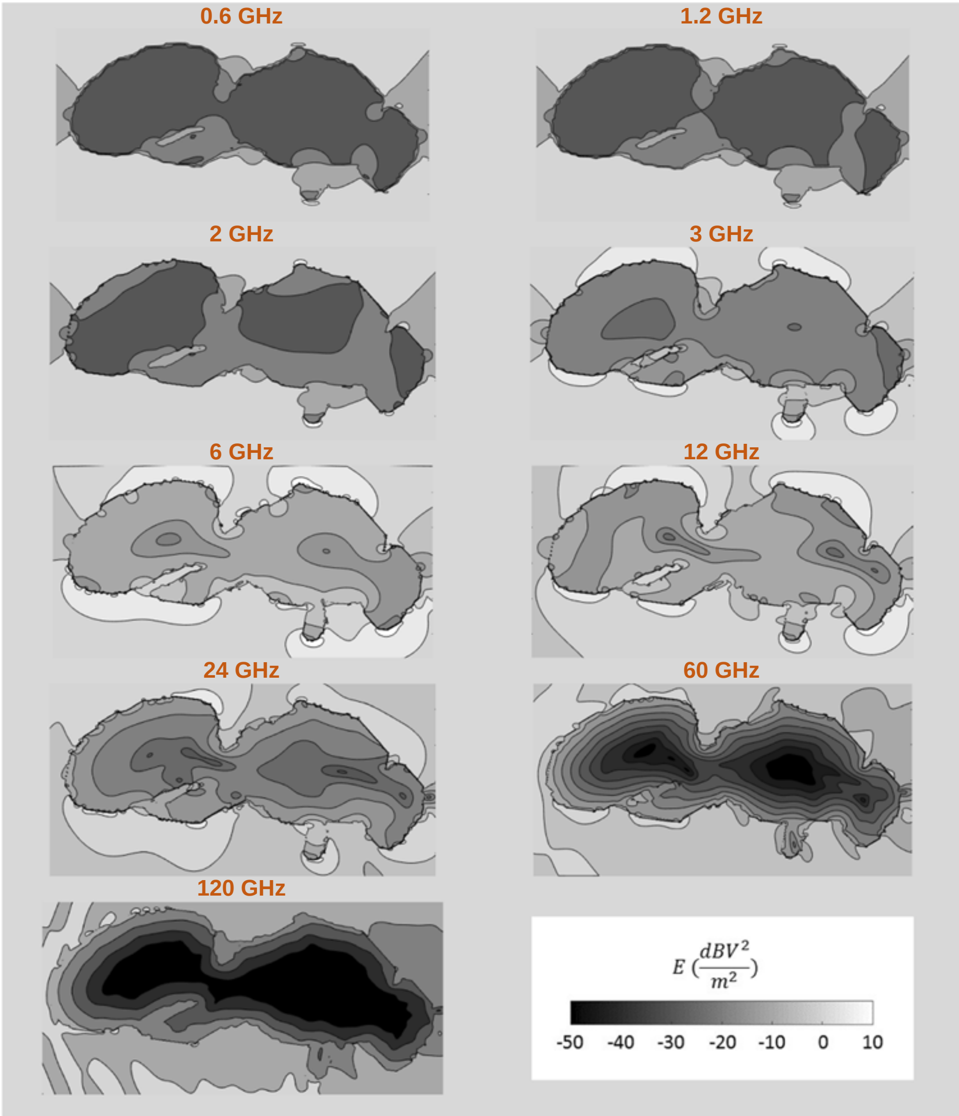

Figure 4. Relative electric fi ld strength in and around a mid-sagittal plane of the Honey Bee Drone at the nine studied frequencies. Grey scale shows the electric fi ld strengths relative to 1 V/m electric fi ld strength.

In order to estimate the effect of a fraction ($p \in [0, 1]$) of the RF-EMF incident fi lds shifting to frequencies higher than 3 GHz we also determine the average P_{abs} for frequencies higher than 3 GHz, using:

$$P_{abs,av}(f > 3\ GHz) = \frac{1}{5}\sum_{j=1}^{5} P_{abs}(f_j) \tag{6}$$

with $f_j = 6, 12, 24, 60, 120\ GHz$. The realistic $P_{abs,real}(p)$ for a fraction p of the power shifted to frequencies higher than 3 GHz is then calculated as:

$$\begin{aligned} P_{abs,real}(p) &= p \times \frac{E^2_{RMS,avg}}{1\ V^2/m^2} \times P_{abs,av}(f > 3\ GHz) + (1 - p) \\ &\times \frac{E^2_{RMS,avg}}{1\ V^2/m^2} \times P_{abs,av}(f < 3\ GHz) \end{aligned} \tag{7}$$

Results

Numerical simulations. Figure 4 shows the relative electric fi ld strength (electric fi ld strength divided by the maximum electric fi ld strength in the simulation domain) in and around the studied drone in a mid-sagittal plane as function of frequency for exposure configur tion number 1 shown in Fig. 2. The internal electric fi lds increase up to 12 GHz and shift towards the outside of the phantom at higher frequencies. At 120 GHz the electric

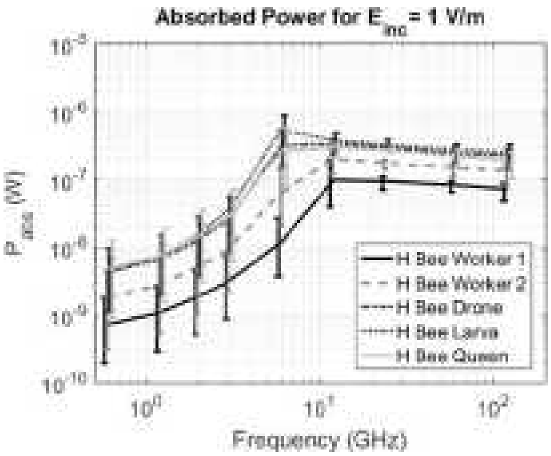

Figure 5. Total absorbed power (P_{abs}) in the five studied honey bees as function of frequency, normalized to an incident plane-wave fi ld strength of 1 V/m at each frequency. The curves indicate the mean values over the twelve plane wave simulations, while the whiskers indicate the maximum and minimum values found at each frequency. The whiskers are slightly off et in order to avoid visual overlap but are all determined at the simulated frequencies described in the Methods Section.

fi ld strengths decreases very rapidly within the phantom and electric fi lds are basically only present in the outer layers of the insect. Th s is caused by a decrease in skin depth that is driven by the increase in conductivity at higher frequencies, see Table 1. Note that the total RF-EMF absorbed power in the insect scales both with the internal electric fi ld strength and the conductivity.

Figure 5 shows the normalized RF-EMF P_{abs} as a function of frequency for the five studied insects from 0.6 GHz up to 120 GHz. The curves connect the linear averages of the 12 P_{abs} values obtained for each honey bee at each simulated frequency, while the whiskers indicate the minimum and maximum P_{abs} values found at those frequencies. All P_{abs} values are normalized to an incident fi ld strength of 1 V/m. Figure 5 shows an increase of P_{abs} over frequency for all studied phantoms up to 6 GHz. When comparing the average P_{abs} at 0.6 GHz and 6 GHz, we found relative increases of factors of 16, 35, 72, 121, and 54 for the Worker Bee 1, Worker Bee 2, Drone, Larva, and queen Bee, respectively. The P_{abs} slightly decreases over frequency beyond 12 GHz for all the studied honey bees. When comparing P_{abs} at 12 GHz and 120 GHz, we found relative decreases of 26%, 34%, 33%, 32%, and 34% for the Worker Bee 1, Worker Bee 2, Drone, Larva, and Queen Bee, respectively. The spread on the P_{abs} values obtained at each individual frequency reduces from up to a factor of 13 below 12 GHz to smaller than a factor 2.5 beyond 12 GHz. Figure 5 shows a general increase of P_{abs} with increasing volume and surface area of the studied insects. Previous studies on whole-body averaged absorbed RF power and specific absorption rate of humans have shown a dependency of these quantities on the absorption cross section, a quantity that scales with volume and/or surface area of an exposed subject. When the diagonals of the smallest rectangular brick that contain the insect phantoms are considered, the honey bee with the smallest diagonal, Worker Bee 1 with a diagonal of 13 mm has the overall lowest average P_{abs}. The Larva, Queen Bee, and Drone all have associated diagonals of 22 mm and have similar average P_{abs} values as function of frequency. The Worker Bee 2 has a diagonal that falls in between Worker 1 and the other insects of 16 mm and also has an average P_{abs} that falls in between the curve for the smaller worker and the other honey bee models, see Fig. 5. We attribute he differences between the two Worker Bee phantoms mainly to the difference in size of both phantoms. The larger Worker Bee 2 phantom has a larger diagonal, surface area, and volume. Th s leads to a higher absorption cross section[33] and higher P_{abs}.

The maximal P_{abs} for the five studied insect models occurs at those wavelengths that are close to the double of this diagonal, which suggests an absorption peak around half a wavelength. The maximum P_{abs} for the Larva model lies in between 3 and 12 GHz, i.e. in between 25 and 100 mm in terms of λ, while the diagonal of said bounding box is 22 mm for the phantom. For the other studied insect models the maximum P_{abs} lies in between 6 and 24 GHz, i.e. in between 23 and 50 mm in terms of λ, with associated phantom diagonals ranging from 16 mm to 22 mm.

As mentioned in the Methods section, the influence of dielectric parameters was studied with simulations using Worker 2 at 2 GHz with altered dielectric parameters. These resulted in P_{abs} values of 6.3×10^{-10} W, 6.3×10^{-9} W, 3.1×10^{-9} W, and 1.8×10^{-9} W, in comparison to 2.0×10^{-9} W for an incident fi ld strength of $1\ V/m$. Th s corresponds to relative deviations of −69%, +210%, +50%, and −10%. These deviations are significant but smaller than the full range of a factor of 5 we observed for the larva at 2 GHz as a function of changing incident angle and polarization. These relative differences are small in comparison to the differences we observe over frequency for the same phantom: a factor of 121 over frequency from 0.6 to 6 GHz.

At 120 GHz we fi d a deviation on P_{abs} smaller than 0.1% when 120 simulation periods are executed in comparison to 30 simulation periods in configuration number 2 shown in Fig. 2 for the Worker 2 phantom. Indicating that the number of simulated periods is sufficient for these simulations. At the same frequency and in the same simulation configur tion, a reduction of the grid step with a factor of 2 resulted in a P_{abs} of 8.6×10^{-8} W and 3.1×10^{-7} W for the Worker 2 and Larva phantoms, respectively, while the regular simulations with 0.1 mm

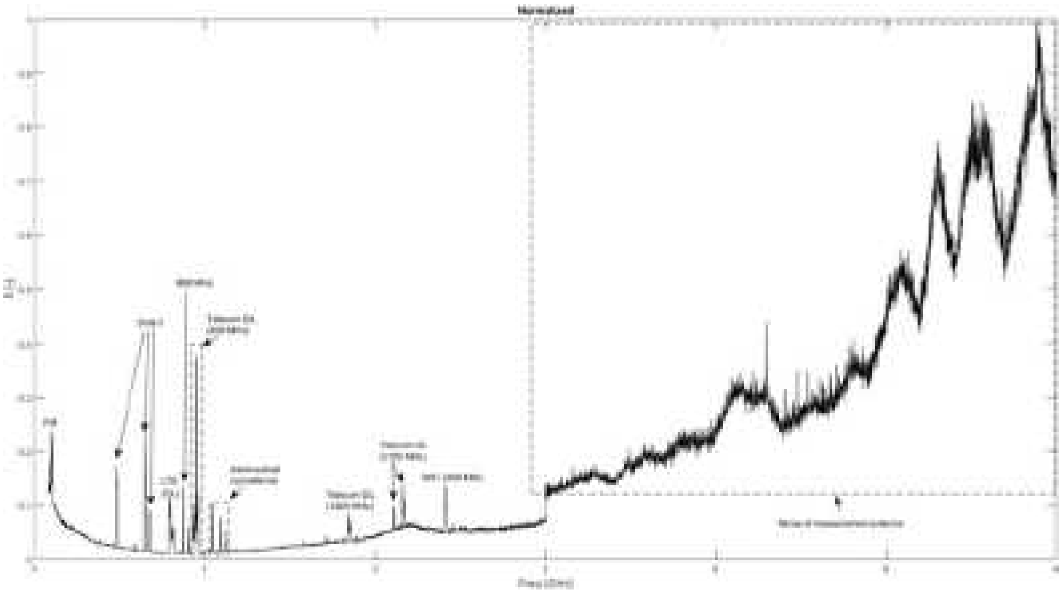

Figure 6. Overview measurement of electric fi ld strength (normalized to maximally measured electric fi ld strength), between 0.8 and 6 GHz, in Aalter. The wireless technologies associated with the different peaks are indicated in the figu e as well.

and 0.05 mm grid steps, respectively, resulted in P_{abs} values of 8.4×10^{-8} W and 3.1×10^{-7} W for an incident fi ld strength of 1 V/m. Th s corresponds to relative deviations of 0.3% and 0.5% for the Worker 2 and the Larva phantoms, respectively, indicating that the chosen grid step was small enough to result in stable numerical results.

The set of 20 incident plane waves with randomized angles of incidence and polarization at 6 GHz using the Worker 2 phantom resulted in an average P_{abs} of $4.5 \times 10^{-8} \pm 1.6 \times 10^{-8}$ W for an incident fi ld strength of 1 V/m, while the set of 12 incident plane waves used to model far-fi ld exposure results in an average P_{abs} of $6.5 \times 10^{-8} \pm 5.3 \times 10^{-8}$ W at the same frequency. The value are fairly close, which indicates that the set of 12 incident plane waves along the main axes is a good proxy for average exposure under a randomized angle of incidence and polarization. The set of twelve plane waves does seem to overestimate exposure at the higher percentiles, since they are signifi antly higher than those obtained using the random set of plane waves.

RF-EMF field measurements. Figure 6 shows an example of an RF-EMF overview measurement at one of the five studied bee hives (Aalter). Figure 6 shows the relative electric fi ld strength, normalized to the maximally measured electric fi ld strength. The different peaks correspond to several individual frequency bands that are used for telecommunication and broadcasting signals. These frequency bands were then measured individually using the same set-up with triaxial antenna and spectrum analyzer at two positions relative to the bee hive on each measurement site using the measurement procedure described in[32].

Table 2 lists the measured E_{RMS} values at the five studied bee hives shown in Fig. 3. As all these measurement sites were rural, private areas, there were no uplink (emissions from a user device to the network) transmissions found. Downlink (DL, this is network to user communication) signals were found at all measurement sites. These signals were generated by three different mobile telecommunications providers in fourteen different frequency bands. The wireless technologies used by the telecommunication operators were: Long Term Evolution (LTE) in frequency bands close to 800 MHz and 1800 MHz, Global System for Mobile telecommunications (GSM) in frequency bands close to 900 MHz, and Universal Mobile Telecommunications Service (UMTS) in frequency bands close to 900 MHz and 2100 MHz. Four other telecommunication bands were identifi d: TETRA (Terrestrial Trunked Radio, 390–395 MHz) which is a technology used by public services (police, fi efi hters, etc.), an Industrial, Scientifi al, and/or Medical (ISM) application around 870 MHz, Digital Enhanced Cordless Telecommunications (DECT) close to 1900 MHz, and Wireless Fidelity (WiFi) at 2400 MHz. Additionally, several frequency bands with RF signals for broadcasting were measured: Frequency Modulated (FM) Radio around 100 MHz, Digital Audio Broadcasting (DAB) around 200 MHz, Digital Video Broadcasting (DVB) at 480–680 MHz. We found one unidentifi d RF wireless transmission at 592 MHz on two measurement sites: Merelbeke and Eeklo. The total E_{RMS} values ranged from 0.016 V/m on both positions in Merelbeke up to 0.226 V/m on position 1 in Drongen. The average E_{RMS} over the ten studied measurement sites was 0.06 V/m. FM Radio was the dominant source of RF exposure on 7/10 measurement positions. In Drongen and in Aalter, GSM 900 DL was the dominant contributor to the RF-EMF exposure. The fi ld strength of WiFi signals depends strongly on the duty cycle used by the wireless technology[34]. The measured E_{RMS} values can be extrapolated to peak values under the assumption of 100% duty cycle. In the case of Aalter, this would result in 0.027 V/m and 0.032 V/m on positions 1 and 2, respectively. In the case of Zomergem, this extrapolation would result in peak E_{RMS} values of 0.059 V/m and 0.016 V/m on positions 1 and 2, respectively. On both measurement sites, a theoretically maximal 90% duty cycle would make WiFi the dominant source of exposure. However, such a network load is unlikely in a rural

$E_{RMS}(V/m)$	Aalter		Merelbeke		Eeklo		Zomergem		Drongen	
Frequency Band	**Pos 1**	**Pos 2**	**Pos 1**	**Pos 2**	**Pos 1**	**Pos 2**	**Pos 1**	**Pos 2**	**Pos 1**	**Pos 2**
FM[a] radio	**0.019**	**0.021**	**0.009**	**0.009**	**0.018**	**0.014**	**0.011**	**0.011**	0.009	0.008
T-DAB	—[b]	—	—	—	—	—	0.004	0.005	0.005	0.004
TETRA (390 MHz-395 MHz)	0.001	0.001	0.002	0.001	0.001	0.001	—	—	0.001	0.002
DVB-T 482 MHz	0.009	0.006	—	—	0.003	0.003	0.008	0.006	0.004	0.002
Freq. 592 MHz	—	—	0.001	0.002	0.002	0.002	—	—	—	—
DVB-T 650 MHz	0.008	0.008	0.003	0.003	0.002	0.003	0.006	0.006	0.006	0.004
DVB-T 674 MHz	0.004	0.008	0.004	0.004	0.002	0.002	0.006	0.005	0.004	0.004
ISM 868 MHz (869.5 MHz)	0.001	0.001	—	—	—	—	—	—	—	—
LTE 800 DL Prov. 1[c]	0.003	0.004	0.001	0.001	0.006	0.004	0.002	0.002	0.002	0.002
LTE 800 DL Prov. 2	0.002	0.002	0.004	0.004	0.002	0.002	0.002	0.002	0.047	0.031
LTE 800 DL Prov. 3	0.003	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.087	0.073
GSM 900 DL Prov. 1	0.005	0.004	0.001	0.002	0.005	0.007	0.003	0.004	0.004	0.004
GSM 900 DL Prov. 2	**0.019**	**0.036**	0.008	0.009	0.002	0.003	0.003	0.004	0.065	0.083
GSM 900 DL Prov. 3	0.004	0.004	0.003	0.002	0.002	0.003	0.003	0.004	**0.180**	**0.137**
UMTS 900 DL Prov. 1	0.001	0.002	0.001	0.001	0.003	0.003	0.002	0.002	0.002	0.001
UMTS 900 DL Prov. 2	0.001	0.001	0.005	0.006	0.001	0.001	0.001	0.001	—	—
UMTS 900 DL Prov. 3	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.055	0.055
LTE 1800 DL Prov. 1	—	—	—	—	0.004	0.005	—	—	—	—
LTE 1800 DL Prov. 3	0.004	0.004	—	—	—	—	—	—	—	—
DECT 1880 MHz	—	—	—	—	—	—	0.002	0.003	0.002	0.001
UMTS 2100 Prov. 1	—	—	—	—	0.006	0.007	—	—	—	—
UMTS 2100 DL Prov. 2	0.003	0.003	0.004	0.004	—	—	—	—	0.039	0.026
UMTS 2100 Prov. 3	0.005	0.006	—	—	—	—	—	—	—	—
WiFi 2400 MHz instantaneous[d]	0.007[e]	0.008[e]	—	—	—	—	0.006[f]	0.002[f]	—	—
Total instantaneous	**0.032**	**0.046**	**0.016**	**0.016**	**0.022**	**0.020**	**0.019**	**0.018**	**0.226**	**0.189**

Table 2. Measured root-mean squared electric fi ld strengths (E_{RMS}) in the 80 $MHz - 6\ GHz$ frequency band in V/m. [a]'FM' = Frequency Modulated,'TETRA' = Terrestrial Trunked Radio, 'DVB-T' = Digital Video Broadcasting - Terrestrial, 'ISM' = Industrial, Scientifi al, and Medical'LTE' = Long Term Evolution, 'GSM' = Global System for Mobile Communication, 'UMTS' = Universal Mobile Telecommunications System, 'DECT' = Digital Enhanced Cordless Telecommunications, 'WiFi' = Wireless Fidelity. [b]'—' indicates that the frequency band was not present at the measurement site. [c]Th ee identifi d Providers are denoted as Prov. 1, 2, and 3. [d]E_{RMS} values for Wireless Fidelity (WiFi)depend on the used duty-cycle, which depends on the use of the network. [e]Duty cycle of 7%. [f]Duty cycle of 1%.

Location	Maximum E-field (1 s interval) (V/m)	Avg E-field (1 s interval) (V/m)
Aalter	0.430	0.272
Merelbeke	0.233	0.1675
Eeklo	0.652	0.532
Zomergem	0.665	0.346
Drongen	0.397	0.297
Average	0.503	0.344

Table 3. Measured maximum and time-averaged broadband incident electric fi ld strengths ($100\ kHz - 6\ GHz$).

area. WiFi was not measured at three out of five measurement sites. Additionally, at all measurement sites, RF EMFs emitted by a pulsed radar or other wireless technologies used in aeronautical surveillance were observed. Th E_{RMS} value of RF EMFs emitted by a radar cannot be accurately measured without having the specifi ations of the radar. Therefore, we can only measure the peak value over the 6 min measurement interval. These fi lds were the highest in Merelbeke, where at position 1 peak E-fi ld values of 0.017 V/m and 2.2 V/m were measured at 1.09 GHz and 1.3 GHz, respectively, while at position 2 peak E-fi ld values of 0.02 V/m and 2.9 V/m were measured at at 1.09 GHz and 1.3 GHz, respectively.

In order to provide the readers with a complete overview of the exposure to EMF fi lds below 6 GHz at the chosen measurement sites, Table 3 lists measured values in the 100 kHz to 6 GHz range using a broadband fi ld

Fraction $< 3\,GHz$ $(1-p)$ (%)	Fraction $> 3\,GHz$ p(%)	$P_{abs,real}(p)(nW)$					$\frac{P_{abs,real}(p)}{P_{abs,real}(100\,\% < 3\,GHz)}(.)$				
		Drone	Worker 1	Worker 2	Larva	Queen Bee	Drone	Worker 1	Worker 2	Larva	Queen Bee
100	0	0.63	0.010	0.26	0.73	0.71	1	1	1	1	1
90	10	2.5	0.57	1.2	3.0	2.3	3.9	5.7	4.6	4.2	3.3
80	20	4.3	1.0	2.1	5.3	3.9	6.8	10	8.2	7.4	5.6
70	30	6.2	1.5	3.1	7.6	5.6	9.7	15	12	11	7.8
60	40	8.0	2.0	4.0	9.9	7.2	13	20	15	14	10
50	50	9.8	2.4	5.0	12	8.8	16	25	19	17	12
40	60	12	2.9	5.9	15	10	18	29	23	20	15
30	70	14	3.4	6.9	17	12	21	34	26	23	17
20	80	15	3.9	7.8	19	14	24	39	30	26	19
10	90	17	4.3	8.8	22	15	27	43	33	30	21
0	100	19	4.8	9.7	24	17	30	48	37	33	24

Table 4. Absorbed power in the four studied insects for an incident electric fi ld strength of 0.06 V/m, distributed uniformly over frequencies lower and higher than 3 GHz for different relative fractions.

probe. All the average values are higher than what is obtained from the frequency-selective measurements presented in Table 2, as should be the case since a broader band is considered.

Estimation of realistic RF-EMF absorbed power in honey bees. Using the results presented in Table 2, one can rescale the P_{abs} values shown in Fig. 5 in order to obtain a realistic estimate of the absorbed RF-EMF power in honey bees $P_{abs,real}$. The third to eight columns of the top row of Table 4 list $P_{abs,real}$ assuming that all incident $E_{rms} = 0.06\ V/m$ is uniformly distributed over the simulated P_{abs} values lower than 3 GHz. These values range from 0.1 nW for Worker 1 until 0.7 nW for the Larva and Queen Bee. In each subsequent row, 10% of the incident power density is transferred to frequencies higher than 3 GHz. Th s causes an increase in the estimated $P_{abs,real}(p)$. In order to quantify this increase, the five columns to the right show the relative increase in $P_{abs,real}(p)$ as p increases from 0 to 1. A full shift of all RF-EMF power to frequencies higher than 3 GHz - without changing the incident fi ld strength - would result in relative increases in absorbed power between a factors 24–48 for the studied honey bee models. Even a relatively small shift of 10% of the incident power density to higher frequencies will lead to a relative increase in P_{abs} of a factor higher than 3, see Table 4.

Discussion

Th s study investigates RF-EMF absorption in Western Honey Bees as a function of frequency in the 0.6 to 120 GHz range. To this aim, we used five different models of different honey bees: two workers, a drone, a larva, and a queen. These models were obtained using micro-CT imaging and used for FDTD simulations. These were used to evaluate far-fi ld exposure of honey bees. Th s far-fi ld exposure is modeled as a set of plane waves at harmonic frequencies between 0.6 and 120 GHz. The numerical simulations resulted in P_{abs} as a function of frequency for the different studied honey bees. These simulations were combined with real RF-EMF exposure measurements near bee hives in Belgium in order to estimate realistic exposure values for honey bees.

Micro-CT imaging is a technique that has previously been shown to accurately scan insects[35,36]. The models used in this study have resolutions between 0.02 mm and 0.25 mm, which is larger than the resolution of the micro-CT models using in[11]. Since the smallest grid step used in our simulations is 0.05 mm, the ideal resolution of the insect models would be smaller than that. The larger resolution of the scanning is not a problem for the stability of the FDTD algorithm, but more spatial resolution could be obtained with the same simulation settings. It is expected that the micro-CT models used in this study lead to a better estimation of P_{abs} and the spatial distribution of the electric fi lds than approximate models such as ellipsoids or cylinders[37].

The results of our numerical simulations, see Fig. 5, show an increase of P_{abs} with frequency up to 6–12 GHz. Figure 4 illustrates the mechanism behind this increase: as the frequency increases the EMFs are less likely to diffract around the honey bees, that are relatively small in comparison to the wavelengths $<6\,GHz$, and can penetrate further in the models, generating higher internal electric fi lds and consequently higher P_{abs} values. Figure 4 also shows why the whole-body averaged P_{abs} does not increase beyond 12 GHz. As the conductivity increases, see Table 1, the electric fi lds will decay faster within the honey-bee phantoms, which leads to larger relative volumes within the insect with lower fi lds, see Fig. 4, which will also contribute to the whole-body averaged P_{abs}. Th s effect also causes the P_{abs} to have a smaller dependency (variation) on incident angle and polarization, see Fig. 5. We also observe that both the frequency-dependency of the P_{abs}, i.e. the transition point between sharp increase in P_{abs} over frequency and slight decrease over frequency, and the magnitude of the P_{abs}, i.e. the off et of the P_{abs} curve, depend on the honey bee's size. Th s effect was previously observed in[11]. In general, the results presented in this manuscript are in excellent agreement with those presented in[11]. The results in terms of P_{abs} obtained for the honey bees in this study fall right in between those obtained in[11] for the smaller Australian Stingless Bee and the larger Desert Locust, which confi ms again the dependency of P_{abs} on phantom size. The same size-related effect was described for humans in[28,33,38] and comparable frequency trends were observed in humans that have larger full-body sizes at MHz frequencies[28,38]. It should be noted that this manuscript focused on exposure of individual insects in free space. In reality, honey bees might cluster, creating a larger absorption cross section and potentially higher absorption at lower frequencies.

The FDTD simulations presented in this manuscript use dielectric properties that were obtained from the literature survey executed in[11]. Ideally, these dielectric parameters would be obtained for the honey bees studied in this manuscript. However, as shown in[11], most studies on dielectric properties of insects in literature[3,39–41] show similar frequency dependencies of those dielectric parameters. We have executed additional numerical simulations to test for the uncertainty on the dielectric parameters and found deviations up to 210% on P_{abs}, which is signifi ant but still smaller than the variations that exist due to changing angle of incidence and polarization at a fi ed frequency, or changes in frequency. We modeled the insects as homogeneous dielectric objects, while in reality they have heterogeneous dielectric parameters. Even though the FDTD algorithm will always require an averaging of dielectric parameters over the cube size, further developments in honey bee and insect phantoms should be focused on the inclusion of multiple tissues in order to refi e these models.

In-situ RF-EMF measurements were executed using a measurement set up consisting out of a spectrum analyzer connected to an isotropic, triaxial antenna according to the measurement procedure listed in[32]. We measured total incident E_{RMS} between 0.016 V/m and 0.226 V/m in five rural environments with a linear average of 0.06 V/m and a quadratic average of 0.1 V/m. Joseph *et al.*[32] measured a median total E_{RMS} value of 0.09 V/m over several rural locations in Belgium, the Netherlands, and Sweden. Bhatt *et al.*[1] measured an average E_{RMS} value of $0.07 \pm 0.04\ V/m$ in rural environments in Belgium. Both previous studies of rural RF-EMF exposure are close to what we found in this manuscript and certainly within the measurement uncertainty of 3 dB on our measurements.

As our RF-EMF exposure measurements near bee hives demonstrate, see Table 2, most of the current RF-EMF exposure is located at frequencies $\leq 1\ GHz$. Additionally, Fig. 5 demonstrates that the P_{abs} in all studied Honey bee models is lowest at frequencies $\leq 1\ GHz$. Th s implies that in reality, potential shifts in telecommunication frequencies to higher frequencies might induce even larger increases that the ones estimated in Table 4 since in that analysis an average value over all P_{abs} values $\leq 3\ GHz$ is assumed.

Strengths and limitations. This manuscript presents several contributions to the state of the art in the fi ld of RF-EMF exposure assessment of insects. First, to the best of the authors' knowledge, this is the only paper where a numerical RF dosimetry is presented for different developmental stages of honey bees. Second, this is the only study that combined real, *in-situ* exposure measurements with numerical simulations of RF-EMF exposure of insects in order to estimate a realistic exposure of honey bees. In comparison to our previous study[11], we considered a broader frequency range from 0.6 GHz up to 120 GHz, which is more in line with the frequencies used in the current telecommunication networks (3 G and 4 G). Finally, this study presents a unique quantifi ation of real-life exposure of honey bees and estimations of how this might change if future frequency shifts in that exposure might occur. A disadvantage of this study is that we did not executed dielectric and thermal measurements in order to obtain dielectric and thermal properties of the studied honey bees. We obtained dielectric properties from literature and were able to execute electromagnetic simulations. We did not perform thermal simulations in this study. Another disadvantage is that we modeled far-fi ld exposure by a limited number of plane waves, while previous studies have shown that a large set of plane waves is necessary to properly model far-field exposure[26]. We did executed a validation of our exposure set up by comparing it with a set of random plane wave exposures and found good correspondence, certainly close to the mean/median. Finally, we used FDTD simulations that are faced with uncertainties[29] and used models that have a limited spatial resolution. Th s is a disadvantage of any RF-EMF simulation study in comparison to a study that relies on measurements of real insects.

Future research. Our future research will focus on executing exposure measurements of insects in order to validate the RF-EMF P_{abs} values and the dielectric parameters. Additionally, we would like to execute thermal simulations of honey bees and other insects under RF-EMF exposure. Finally, we aim to work on the development of more insect phantoms, with more spatial accuracy and potentially several independently identifi d tissues.

Conclusions

Exposure of Western Honey Bees (*apis mellifera*) to radio-frequency (RF) electromagnetic fi lds was studied using a combination of *in-situ* exposure measurements near bee hives in Belgium and numerical simulations. The simulations use the fin te-difference time-domain technique to determine the electromagnetic fi lds in and around five honey bee models exposed to plane waves at frequencies from 0.6 GHz up to 120 GHz. These simulations lead to a quantifi ation of the whole-body averaged absorbed radio-frequency power (P_{abs}) as a function of frequency. The average P_{abs} increases by factors 16 to 121, depending on the considered phantom, when the frequency is increased from 0.6 GHz to 6 GHz for a fi ed incident electric fi ld strength. A relatively small decrease in P_{abs} is observed for all studied honey bees between 12 and 120 GHz. RF exposure measurements were executed on ten sites near five different locations with bee hives in Belgium. These measurements resulted in an average total incident RF fi ld strength of 0.06 V/m, which was in excellent agreement with literature. Th s value was used to assess P_{abs} for those honey bees at those measurement sites. A realistic P_{abs} is estimated to be between 0.1 and 0.7 nW for the studied honey bee models. Assuming that 10% of the incident power density would shift to frequencies higher than 3 GHz would lead to an increase of this absorption between 390–570%. Such a shift in frequencies is expected in future networks.

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Author contributions

A.T. conducted the numerical simulations, analyzed the results, and drafted the manuscript. L.V. conducted the measurements. M.K.G. conducted the imaging and post processing of the imaging. W.J and L.M. contributed to analyzing the methodology and results. All authors reviewed the manuscript and provided input to the different sections.

Competing interests

The authors declare no competing interests.

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RESEARCH ARTICLE

Radio-frequency exposure of the yellow fever mosquito (*A. aegypti*) from 2 to 240 GHz

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Abstract

Fifth generation networks (5G) will be associated with a partial shift to higher carrier frequencies, including wavelengths of insects. This may lead to higher absorption of radio frequency (RF) electromagnetic fields (EMF) by insects and could cause dielectric heating. The yellow fever mosquito (*Aedes aegypti*), a vector for diseases such as yellow and dengue fever, favors warm climates. Being exposed to higher frequency RF EMFs causing possible dielectric heating, could have an influence on behavior, physiology and morphology, and could be a possible factor for introduction of the species in regions where the yellow fever mosquito normally does not appear. In this study, the influence of far field RF exposure on *A. aegypti* was examined between 2 and 240 GHz. Using Finite Difference Time Domain (FDTD) simulations, the distribution of the electric field in and around the insect and the absorbed RF power were found for six different mosquito models (three male, three female). The 3D models were created from micro-CT scans of real mosquitoes. The dielectric properties used in the simulation were measured from a mixture of homogenized *A. aegypti*. For a given incident RF power, the absorption increases with increasing frequency between 2 and 90 GHz with a maximum between 90 and 240 GHz. The absorption was maximal in the region where the wavelength matches the size of the mosquito. For a same incident field strength, the power absorption by the mosquito is 16 times higher at 60 GHz than at 6 GHz. The higher absorption of RF power by future technologies can result in dielectric heating and potentially influence the biology of this mosquito.

Author summary

Radio Frequency (RF) exposure of the *A. aegypti* mosquito can lead to absorption and dielectric heating. We used Finite Difference Time Domain (FDTD) simulations between 2 and 240 GHz to study the RF power absorbed by the insect and the distribution of the electric field (EF) in and around it. For this, three male and three female mosquito 3D models were constructed from micro-CT scans. We used high resolution models and

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dielectric properties, both retrieved from real insects, to gain realistic outputs. For increasing frequency up to 90 GHz, the absorbed power increases for all models. At 90–120 GHz, the wavelength is comparable to the body size, and the increase in absorbed powers reaches a maximum. Therefore, moving to higher frequencies in 5G, implies higher absorbed power and possibly higher dielectric heating of the insect.

Introduction

With the upcoming fifth generation networks (5G) in wireless telecommunications, the Radio Frequency (RF) electromagnetic fields (EMF) used as carriers will partly shift to higher frequencies. Current telecommunication networks make use of frequencies of 0.1–6 GHz [1], while the carrier frequencies for 5G networks can go up to 300 GHz, entering the millimeter-wave frequency range [2]. For these higher frequencies, the wavelength becomes comparable to the body size of insects. When wavelength and body size become of the same order of magnitude, an increase in efficiency of absorption of RF-EMFs in the body is expected [3]. The absorption of RF-EMF in biological tissues can lead to the dielectric heating of an organism [4]. With the alternating electric field and polarity, the movement of free ions and dipoles causes the heating in dielectric material [5]. This RF heating of insects has been repeatedly investigated as a method to kill insects in low-moisture foods, grain, or wheat storage [6–13]. The difference in dielectric properties, RF absorption and consequential dielectric heating between insect and food, is used to heat the insect up to a lethal temperature for the insect, while the food is not damaged. The frequency and field strength are chosen depending on the type of stored food and the infesting insect.

The insect of interest in this paper is the yellow fever mosquito, *Aedes aegypti*, it is known as a vector for diseases such as yellow fever, dengue fever and zika virus infections [14, 15]. According to the Centers of Disease Control and Prevention in the U.S., yellow fever cases and deaths worldwide are estimated at 200,000 and 30,000 each year [16], respectively. The yellow fever mosquito is a tropical species favouring a hot and humid environment. Temperature affects the life cycle and feeding behaviour of the mosquito and the reproduction of the viruses [14, 15]. RF power absorption and dielectric heating can cause disturbance in for example the behaviour or development of the mosquito. Another interesting consequence of dielectric heating and higher body temperature, may be the spread of the mosquito to areas that are normally unfavorable for them. Be that as it may, the focus in this paper is on the RF power absorption, the dielectric heating or other consequences are not considered.

The absorbed RF power in four different insect species has been examined through numerical simulations by Thielens *et al.* using models created from real insects [17, 18] and it was observed that absorbed power was maximal for wavelengths comparable to the insects' body size. However, the simulations in [17, 18] relied on unverified assumptions regarding the dielectric properties of the studied insects and these arthropods were at least a factor 1.5 larger than the yellow fever mosquito in terms of volume.

The effects of RF-EMF exposure can have an important impact on insects, they have been investigated experimentally on several insects. Influences were reported on e.g. the development and mating of honeybees (reduced hatching of honey bee queens) [19], behaviour of ants (the locomotion) [20], and the morphology of mealworm beetles during development (abnormalities of appendages) [21]. The collective position behaviour of mosquitoes *A. aegypti* was examined under relatively low-power RF-EMFs in the frequency range of 0.01–20 GHz, without any conclusive results about the position of the mosquitoes as a reaction to the

RF-EMF exposure [22]. The absorption of RF-EMFs of mosquitoes has however never been investigated, nor their dielectric properties.

The dielectric parameters, relative permittivity (ϵ_r) and conductivity (σ), have been characterized for other insects before. Coaxial-probe measurements were done on stored-grain insects [23], the Colorado Potato Beetle [24], and insects in dried nuts and fruits [6]. An alternative resonance method has been used as well to investigate dielectric properties of different insects [25].

In this paper, the frequency-dependency of the RF power absorption for *A. aegypti* was investigated by means of numerical simulations at frequencies from 2–240 GHz. This frequency range was chosen to cover both the legacy and 5G telecommunications range and to include wavelengths similar to the mosquito dimensions. To this end, a unique set of high resolution 3D models of yellow fever mosquitoes was developed using micro-computed tomography (CT) scanning. The models were combined with accurate dielectric property measurements in adult yellow fever mosquitoes in order to execute finite-difference time-domain (FDTD) simulations, which resulted in EMF distributions in and around the studied insects. These results provided insights in the power absorption in the mosquitoes' body, but also in the distribution of this power absorption over the body and different body parts. The novel aspects of this study are (i) the simulations on *A. aegypti* in far field EMF exposure between 2–240 GHz, (ii) measurements of dielectric properties in *A. aegypti*, (iii) the creation of 3D models based on micro-CT scanning of real mosquitoes, and (iv) assessment of the RF absorption of the full mosquito body and of the different body parts. Our results provide an important input for studies that investigate the spread and biology of *A. aegypti* on the one hand and regulators and telecommunication operators who are re-evaluating the guidelines regarding RF-EMF exposure in their planned telecommunication networks on the other hand.

Materials and methods

The RF power that is absorbed by yellow fever mosquitoes is studied by means of simulations, i.e. solving Maxwell equations numerically. The simulations require a 3D model and dielectric properties of the yellow fever mosquito as inputs. The 3D models were based on scans of real dried yellow fever mosquitoes and the dielectric properties were measured from a mixture of yellow fever mosquitoes.

Mosquitoes

The yellow fever mosquito specimens were taken from the *Ae. aegypti* Rockefeller colony kept in the insectary facility at the Swiss Tropical and Public Health Institute. The mosquitoes were reared at 26–28°C and 60–80% relative humidity with a 12:12 h day:night light cycle. Larvae were fed with ground TetraMin flakes (Tetra GmbH, Melle, Germany) and adults were provided 10% sucrose solution ad libitum. Females were artificially fed with pig blood received from the local abattoir to keep the stock colony, however the specimens used for the measurements in the current study were unfed.

Scanning and modelling method

In the simulations of RF-EMF exposure of mosquitoes, the models of the insects should be as close to reality as possible. Therefore, real mosquitoes were dried and scanned with a micro-CT scanner to form 3D models. The samples were scanned using the custom-designed HECTOR scanner [26] of the Ghent University Center for X-ray Tomography (UGCT; www.ugct.ugent.be) with a tube voltage of 70 kV and a target power of 10 W. During a full 360°rotation, 2400 projection images were acquired at an exposure time of 1 s each. The samples were positioned on floral foam and positioned close to the X-ray source, resulting in a geometrical magnification of approximately 50. The raw data was reconstructed using Octopus Reconstruction at a reconstructed voxel size of $(4.012)^3$ μm^3. To reduce edge enhancement artefacts and increase the signal-to-noise ratio in the data, the Paganin phase retrieval algorithm was applied [27, 28]. To extract the STL model from the 3D volume, each mosquito datastack was loaded into VGStudio MAX (Volume Graphics, Heidelberg, Germany). Areas where the mosquito touched the floral foam were removed manually. After applying a median filter, the region containing the outer structure of the insect was selected using a growing area function. Although many inside features were not selected with this procedure, leaving large unwanted cavities in the model, this was compensated for by selecting these internal regions separately and merging the volumes. Finally, these regions were converted to a single cohesive STL file per mosquito.

Dielectric properties

In order to determine the internal EMFs inside the insect models developed in the previous section, Maxwell's equations can be solved numerically. For this purpose, the dielectric properties, relative permittivity (ϵ_r) and conductivity (σ) of the insect need to be known and inserted into the equations. The novel dielectric assessment kit for thin layers (DAK-TL) from SPEAG (Schmid & Partner Engineering AG, Switzerland), which is based on the open coaxial probe method, was used to perform dielectric spectroscopy [29]. DAK-TL overcomes the long existing limitation associated with Open-Ended Coaxial Probes (OCP) where sufficiently large samples are needed to avoid reflections at the boundaries. Using full-wave analysis of the open coaxial probe geometry, the complex dielectric properties are calculated from sample thickness and the complex reflection coefficient measured with the vector network analyzer (VNA). The DAK-TL-1.2E probe (5–67 GHz) was used in combination with a ZVA67 VNA (Rohde & Schwarz, Munich, Germany) to perform measurements over the aforementioned frequency range. The measurement resolutions are set to 50 MHz and 250 MHz for the interval 5–6 GHz and 6–67 GHz, respectively. The DAK-TL system was calibrated using the standard 3-point calibration prior to each measurement session: open, short (copper strip), and de-ionized water as the load. A force of 800 N was applied during the short calibration to ensure a good contact between the probe and the copper strip. The validity of calibration was verified by measuring another reference liquid, namely 0.05 M saline solution with known dielectric properties. The measurement uncertainty values (Table 1) that includes possible systematic errors due to design, calibration, thickness measurement uncertainties, and VNA noise were established according to [30].

Table 1. Expanded uncertainties (k = 2) in the measurements of dielectric parameters made with the DAK-TL-1.2E Probe.

Frequency (GHz)	$\Delta\epsilon$ (%)	$\Delta\sigma$ (%)
5	3.4	4.7
6	3.8	5.0
10	3.4	4.3
15	3.1	3.7
20	3.7	4.1
30	3.6	3.7
40	3.9	3.9
50	4.7	5.0
60	5.1	3.9
67	5.1	4.6

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As poikilotherms, the environmental temperature is an important parameter affecting the life of yellow fever mosquitoes. The dielectric characterization was performed at 22˚C, this temperature was chosen because it is a temperature where flight activity, host-seeking, and blood-feeding are not impaired. [31] A metallic Petri dish (inner diameter = 30 mm, height = 4 mm) was used to characterize the homogenised mosquito sample. The different tissues of the mosquito are small in sample size (approximatly < 1 mm^3), dissecting multiple samples is very time consuming and thus it was chosen to work with a carefully prepared homogenized mixture. A reproducible method for preparing an insect-mixture for the measurements was developed. In this procedure, approximately two thousand A. aegypti mosquitoes, including both males and females, were used for dielectric properties measurements. First, the mosquitoes were euthanized prior to measurements using CO2. Afterwards, the samples were homogenized using a small battery-operated mortar in combination with the application of mechanical force. This resulted in a homogeneous semi-solid mosquito-mixture of about 2 ml, for which aliquots were prepared.

To measure the complex permittivity $\hat{\epsilon}$ of each of the two samples, the Petri dish filled with the mixture was slowly moved towards the probe and stopped when the distance between the Petri dish bottom plate to the probe was 1±0.02 mm. This was repeated three times for both samples by removing the slurry from the holder and refilling the Petri dish. The complex permittivity of each sample was determined as the average over these three measurements. The complex permittivities used in the simulations are the averaged values from the two sample characterizations.

The studied frequency region of interest extends outside the measured range of 5 to 67 GHz. Therefore, the dielectric properties are extrapolated down to 2 GHz (within the 4G frequency range) and up to 240 GHz (in the millimeter-wave mobile broadband [2]). The properties were extrapolated by the Debye-model [32] whose coefficients were determined from a least mean square fit to the measured complex permittivity of the mixture, as in [24]:

$$\hat{\epsilon} = \epsilon' - j\epsilon" = \epsilon' - j\frac{\sigma}{\omega\epsilon_0} = \epsilon_\infty + \frac{\epsilon_s - \epsilon_\infty}{1 + j\omega\tau} + \frac{\sigma_s}{j\omega\epsilon_0} \quad (1)$$

with $\hat{\epsilon}$ the complex relative permittivity of the sample, σ the conductivity of the sample, ω the angular frequency, ϵ_s the static permittivity, ϵ_∞ the permittivity at infinity, τ the relaxation time, ϵ_0 the permittivity of free space and σ_s the static conductivity. The measured data is fitted considering firstly one relaxation time and secondly two relaxation times. In the second case, Eq 1 for the real and imaginary part (loss factor) of the relative permittivity reads as:

$$\epsilon' = \epsilon_\infty + \frac{\Delta\epsilon_1}{1 + j\omega\tau_1} + \frac{\Delta\epsilon_2}{1 + j\omega\tau_2} \quad (2)$$

$$\epsilon" = \frac{\sigma}{\omega\epsilon_0} = \frac{\sigma_s}{\omega\epsilon_0} + \frac{\Delta\epsilon_1\omega\tau_1}{1 + (\omega\tau_1)} + \frac{\Delta\epsilon_2\omega\tau_2}{1 + (\omega\tau_2)} \quad (3)$$

where $\Delta\epsilon_i$ is the difference between the static permittivities ϵ_s, i and the permittivity at infinity ϵ_{inf}, with i = 1, 2 corresponding to the two relaxations.

Numerical simulations

The mosquito models and the measured dielectric properties were used in numerical simulations with the commercial software Sim4Life Version 5.2.1 (ZMT Zürich MedTech AG, Zürich, Switzerland), where the FDTD method was used to determine the internal electric field inside and around the mosquito body. This study investigated exposure in the far-field or

Fraunhofer radiation region. In this zone the following conditions hold for the separation distance between insect and RF-EMF source (r): $r \gg 2l^2/\lambda$ with λ the wavelength and l the largest dimension of the RF source and the insect [33]. In this region, any RF-EMF field can be described as a set of incident plane waves [33]. This technique was previously used to determine the RF-EMF absorption in heterogeneous human body models [3] and for other insects [17, 18]. The dielectric heating is proportional to the the total absorbed RF-EMF power (P_{abs}), which in its turn can be found from the internal electric field:

$$P_{abs} = \int \sigma \times |\vec{E}_{int}|^2 \cdot dV \tag{4}$$

with σ the conductivity, $|\vec{E}_{int}|$ the root mean square internal electric field strength and V the volume of the insect. P_{abs} depends on the frequency, as both σ and E_{int} are dependent on the frequency. Therefore, different frequencies were investigated: 2, 6, 12, 24, 60, 90, 120 and 240 GHz. For a flying or resting mosquito, the polarization and angle of incidence of far-field EMFs is unknown a priori. Therefore, twelve incident plane waves were considered to model the far-field exposure, as shown in Fig 1. This was the same configuration as used in [3]: 6 directions along Cartesian axes with 2 orthogonal polarizations per direction. The insects were aligned with the length of the body along one of the axes. In the simulations, all plane waves had a root mean squared electric field strength of 1 V/m. In real situations, this field strength can vary from 1 V/m, since the absorbed RF power scales quadratically with the incident field strength, it can be calculated for an arbitrary field strength given the value at 1 V/m:

$$P_{abs,real} = P_{abs}(1V/m) \cdot \frac{E_{real}^2}{(1/m)^2} \tag{5}$$

with E_{real} and $P_{abs,real}$, the incident electric field strength and absorbed power under realistic exposure conditions.

FDTD is a time-domain method, which has to be terminated after a certain simulation time, which can be quantified in number of periods of the RF-EM waves that is incident on the insect. After a certain number of simulation periods of the incident plane wave, P_{abs} converges

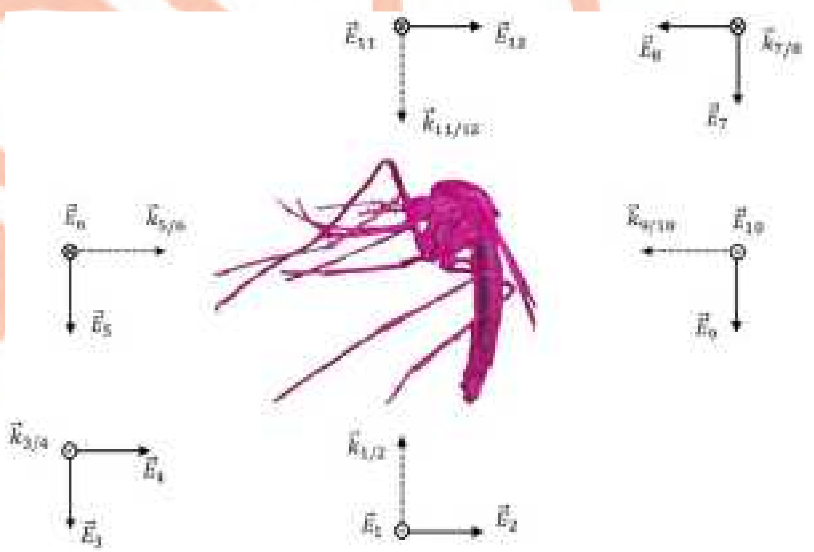

Fig 1. An overview of 12 plane waves in the simulation set up. 6 directions × 2 polarizations. The wave vector is indicated with the dotted arrow and the electric field with a solid arrow.

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to a steady state. The number of periods required to reach the steady state depends on the size of the simulation domain relative to the simulated wavelength. For a smaller wavelength, more periods will be needed to cover the complete domain. The number of periods were 7 and 35 at 2 and 240 GHz, respectively, while for the other frequencies the number of periods was between 10 and 35. The simulation time was always higher than twice the maximum body length of the mosquito, divided by the wavelength.

In the FDTD method, a grid is imposed to the simulation domain discretizing the volume of interest, including the mosquito. The grid step size was defined according to a trade off between a shorter simulation time for large grid step sizes and a better spatial resolution for smaller grid step sizes. Further, the grid step size should be minimum 1/10 of the wavelength. [34]. The smallest wavelength $\lambda/\sqrt{\epsilon_r}$ is 573.5 μm at 240 GHz, while all mosquitoes were discretized in voxels of 25 μm.

The FDTD technique used in this paper also has its limitations. The method is based on the discretization of the differential form of Maxwell's equations [34]. The evolution over time of EMFs is discretized in temporal steps and the simulated space is discretized into voxels. The smaller the voxels and time intervals, the more realistic the simulations are. However, simulations are always an approximation of reality. The simulation domain cannot be infinitely large, and consequently boundary conditions are used to limit the domain. The boundary conditions used in our simulations are Uniaxial Perfectly Matched Layers, which mimic an infinitely extended free space. The simulations further rely on accurate dielectric properties and 3D models.

Results

3D models

Three dimensional numerical models of three female and three male mosquitoes were constructed from micro-CT scans of real mosquitoes. Using the micro-CT technique, internal structures of the insect under investigation could be distinguished, and a high resolution is achieved. However, fine structures such as parts of the wings, scales or other fine structures, were not distinguishable enough from the surrounding air. Hence, they could not be included in the model. Small details on the thorax, abdomen, and head were manually added on slices based on unsegmented features in the raw data. On the abdomen, many fine structures were not captured, especially for the male models, and were impossible to reconstruct completely. During handling, also loss of legs occurred for some samples. Fig 2 shows the top, side and back view of all six mosquitoes as well as a more detailed view of mosquito M1 for the triangulated model and the model after voxelating (voxel length 25 μm).

Table 2 lists an overview of the volumes and dimensions of the mosquito models. The volumes are taken after voxelating with a voxel length of 25μm. The body length of the mosquitoes is measured from the pronotum to the end of the abdomen. The diagonal given in the table, is the diagonal of the bounding box containing the whole insect. This diagonal strongly depends on the presence of legs in the model, therefore the body length is the main representation of the mosquito dimensions in this paper.

Dielectric properties

The insect are approximated as homogeneous models in the simulations, with no differentiation between different tissue and so only one set of dielectric properties are used for the material for every frequency. Fig 3 shows the measured permittivity and conductivity of the mosquito-mixture for frequencies between 5–67 GHz, and extrapolated to 2–300 GHz. The

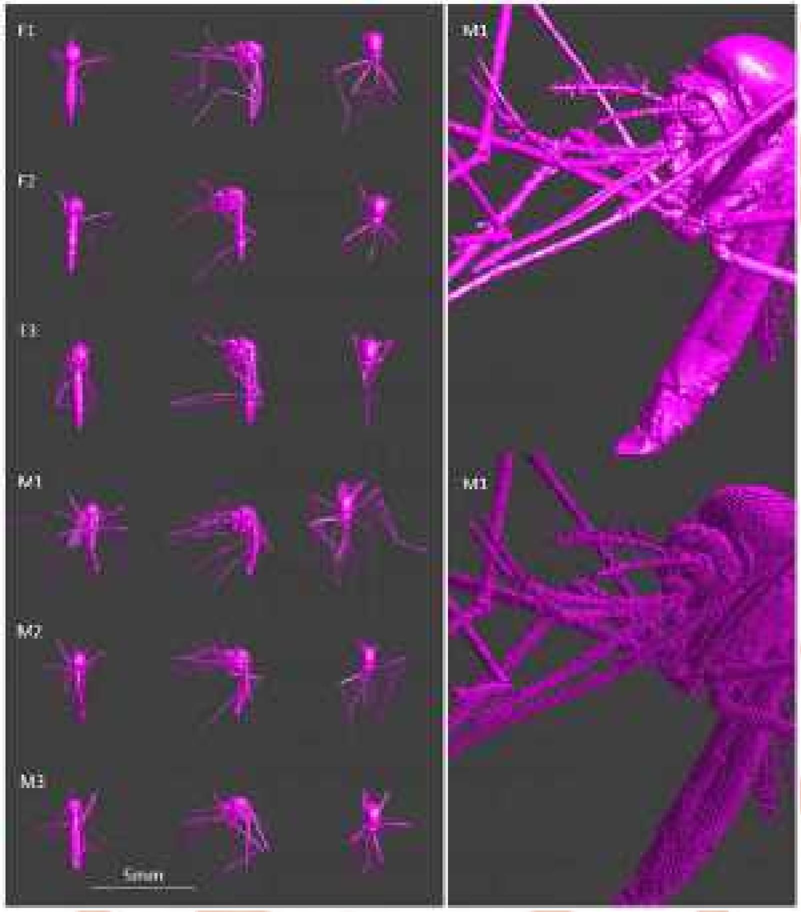

Fig 2. 3D models of mosquitoes. Left: Overview of models used in simulations (F: females, M: males). Left to right: Back, side and top view. Right: Mosquito M1 as triangulated model (top) and voxelated model (bottom) with Voxel size 25 μm.

https://doi.org/10.1371/journal.pcbi.1009460.g002

loss factor (imaginary part of the complex permittivity) was found from the conductivity (Eq 2) and is also given in Fig 3. The extrapolation was done using the Debye relaxation model with two characteristic relaxation times, the resulting parameters for the dielectric curves are given in Table 3. The R^2 for the Debye fit to the measured data is 0.99995 for the real part of the permittivity and 0.999994 for the conductivity with two relaxations, compared to 0.996 and 0.992 respectively for one relaxation time.

Table 2. Volumes and lengths of mosquitoes.

Insect	Volume (mm^3)	Body length (mm)	Diagonal (mm)
F1	1.103	3.985	7.792
F2	1.083	3.774	4.495
F3	1.402	4.287	7.418
M1	0.913	3.586	9.226
M2	0.691	3.417	7.437
M3	0.833	3.629	7.748

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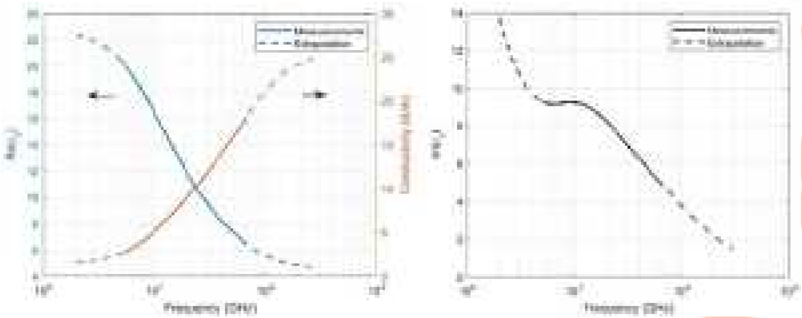

Fig 3. Dielectric parameters. Left: Measured (solid line) real part of the relative permittivity (blue) and conductivity (orange) and the extrapolation (dotted line). Right: Measured (solid line) imaginary part of the relative permittivity and the extrapolation (dotted line).

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The real part of the permittivity decreases with increasing frequency and the conductivity increases with increasing frequency. The loss factor has a local maximum around the frequency corresponding to τ_2, the most prominent relaxation in this frequency range. At lower frequencies a decreasing trend with increasing frequencies is apparent, originating from the static conduction term $\sigma_s/\omega\epsilon_0$.

Simulations

The amount of RF power absorbed by the 3 male and 3 female mosquito bodies in the far field is shown in Fig 4 as a function of frequency. The 3 blue and 3 red lines show the means of P_{abs} for the 12 configurations (Fig 1) in which the the 3 female and 3 male mosquitoes were exposed, respectively. The shaded areas in the graph include all 12 P_{abs} values for all 3 females (blue) and 3 males (red) of the simulations. P_{abs} increases with increasing frequency, up to 90 GHz for all six mosquitoes. At 90 GHz the highest single plane wave absorbed a power of 5.64 nW and was found for the F3 model with plane wave configuration 5 (Fig 1). At this frequency, the wavelength of the incident plane wave becomes comparable to the body length of the mosquitoes. Between 120 GHz and 180 GHz, the averages of P_{abs} for all mosquito reach a maximum, here the wavelength is smaller (2.5 mm and 1.7 mm respectively) than the body length of the insect but still comparable to the insect dimensions. Fig 4B shows P_{abs} for the 12 plane wave configurations for mosquito M1 and (c) shows the average P_{abs} for all mosquitoes at 120 GHz.

From Eq 4, it is clear that the power absorbed by the insect depends on the internal electric field strength. Fig 5 shows the normalized electric field strength (dB) in and around mosquito M1, presented in mid-sagittal cross sections. The normalization was done to the maximum electric field strength of every simulation separately. The maximal and minimal electric field strength found in the 6 GHz simulation in exposure configuration 1, was 3.53 V/m and 1.29×10^{-4} V/m respectively. For 240 GHz, this was 2.72 V/m and 2.29×10^{-2} V/m respectively. It should be noted that the abdomen does not contain a large cavity, it is the dried abdomen that is curved.

Table 3. Parameters for Debye curves, with two (fit 2) and with one (fit 1) relaxation.

	τ_1 (ps)	$\Delta\epsilon_1$	τ_2 (ps)	$\Delta\epsilon_2$	ϵ_∞	σ_s (S/m)
ϵ' fit 2	3.493	4.978	14.68	13.24	4.544	
σ fit 2	2.477	4.213	12.23	12.89		1.297

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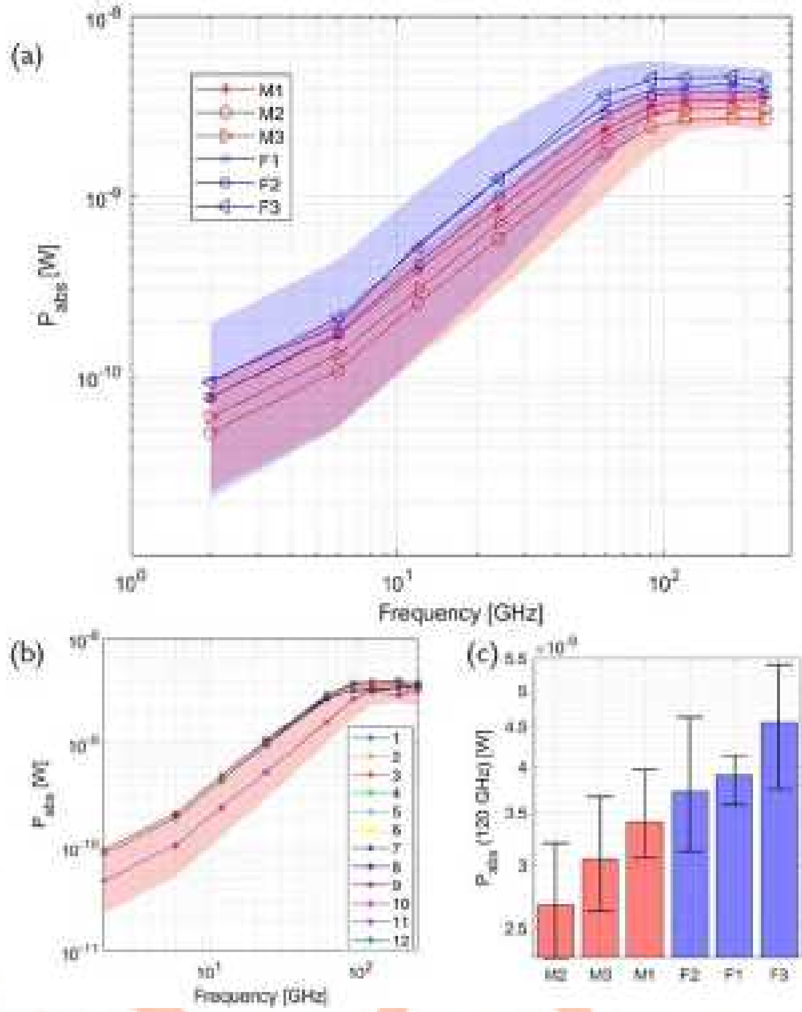

Fig 4. Total absorbed RF power (P_{abs}) by the mosquito as a function of frequency for an incident field strength of 1 V/m. (a) The dots present the means of the 12 plane waves, the blue and red shaded regions represent the range of absorbed power for all 12 plane waves for all female and all male mosquitoes respectively. (b) The absorbed powers for mosquito M1 for the twelve different plane waves as illustrated in Fig 1. The red shaded area represents the range of absorbed power for all 12 plane waves for all male mosquitoes. (c) The bar chart shows the total absorbed power (P_{abs}) at 120 GHz, the whiskers indicate the range for all 12 plane waves.

https://doi.org/10.1371/journal.pcbi.1009460.g004

In studies that investigate absorption of RF-EMF fields, a differentiation between absorption in different body parts is often made. In the case of humans, for example, the international committee on non-ionizing radiation differentiates between RF-EMF exposure of the torso and head on the one hand and the limbs on the other hand [35]. This approach is followed because exposure or heating of different body parts might results in different outcomes. Using the simulations performed in this study, the different parts of the mosquito body can be considered separately as well. The absorbed power in the head, thorax, and abdomen were calculated and averaged over their respective volumes. The volumes selected as the body part varied slightly for simulations at different frequencies due to different grid settings, and thus the volumes varied slightly as well. The volume of the head, thorax, and abdomen were 0.91 ± 0.01 mm^3, 4.30 ± 0.03 mm^3, and 2.91 ± 0.05 mm^3 for M1, respectively. The average P_{abs} for M1 and F1 are given in Fig 6. The head and abdomen have a similar behaviour, while there is more

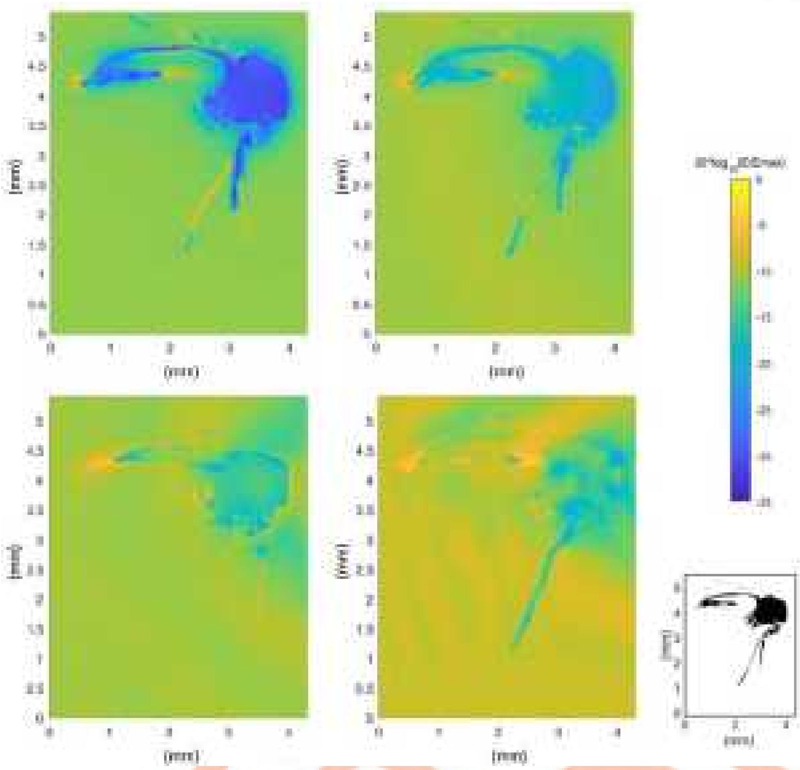

Fig 5. Normalized electric field strength in and around a mosquito. Electric field strength (dB) normalized to the maximal electric field strength of the simulation (E_{max}) in the cross sections of mosquito M1 at 6 GHz (top left), 60 GHz (top right), 120 GHz (bottom left) and 240 GHz (bottom right). Configuration 1 (Fig 1) was used for all simulations. The bottom right panel shows a cross section of the mosquito.

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averaged P_{abs} at higher frequencies for the thorax. For the female mosquito, the thorax and abdomen averaged P_{abs} are slightly higher.

Effect of model variations. The P_{abs} is slightly larger for the three females than for the three males (KS-test, $p<0.05$). This can partly be explained by the larger volume and body size of the females [36] as seen in Fig 2.

In addition to the sex-related differences, the models varied in number of legs still attached to the specimens. Model M1 had 6 legs, while F3 had only two. The influence of the presence of the legs is investigated by removing a hind leg of M1 and by removing all six legs of M1. Simulations were again done at 120 GHz for the 12 different plane waves and compared to the results for the original six-legged M1, which had a mean P_{abs} of 3.40 nW for the 12 plane waves at 120 GHz. When the hind leg of M1 was removed, the volume of the mosquito model was reduced to 97.4%, and the P_{abs} mean decreased to 3.31 nW with a maximal relative deviation of 3.39% for the 12 simulations. For the case where all legs were removed, the model volume was reduced to 86.0% of the original model and the mean of P_{abs} decreased to 2.91 nW, with a maximal relative deviation of 20.92% for the 12 simulations.

Uncertainties of simulation. It becomes clear from Fig 4 that the angle of incidence and polarization of the plane waves, have an impact on the absorbed power. The 12 plane waves seen in Fig 1 are orientated along the main axis of the insects. Real life exposure situations are not limited to those 12 configurations and simulations with 30 random orientations and polarizations were added at 60 GHz for M1. None of these simulations resulted in a P_{abs} outside the

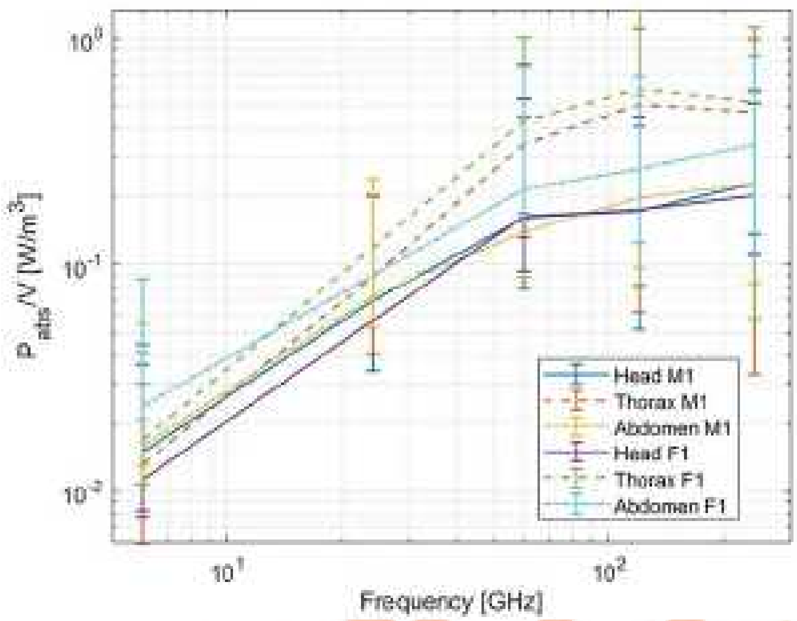

Fig 6. Averaged absorbed power as function of frequency in the head, thorax, and abdomen of a yellow fever mosquito For an incident field strength of 1 V/m. Averaged over the volumes of the body part for mosquitoes M1 and F1.

https://doi.org/10.1371/journal.pcbi.1009460.g006

interval of the 12 plane waves along the main axes. The mean of P_{abs} for the 30 simulations was 2.31 ± 0.36 nW, which is comparable to the mean of P_{abs} for the 12 plane waves 2.37 ± 0.59 nW, for E_{inc} = 1 V/m.

Another element contributing to the uncertainty in the simulations is the grid step size or voxel size. The voxel size of the mosquito models was set to 25 μm, and is larger than the resolution of the mosquito models. To confirm the chosen grid step size is small enough, 12 simulations (six incident angles × 2 polarizations) with a smaller grid step size of 15 μm were performed at 240 GHz. At this frequency, the wavelength is the smallest and the voxel size becomes more important. Compared to the case with 25 μm, P_{abs} for the 15 μm has a maximal relative deviation of 2.61% and has a mean P_{abs} of 3.49 nW (versus 3.51 nW). This smaller voxel size has a smaller impact on P_{abs} than the incident angle and polarization, hence the grid step size of 25 μm can be considered sufficient for these simulations.

The measurement of the dielectric properties was done for two samples of a mosquito-mixture, with a maximal relative deviation between the two samples on the dielectric properties of 4.04% and 5.81% for ϵ' and σ respectively. To establish the influence of the dielectric parameters on the simulation results, four extra sets of 12 simulations were executed for a plane wave of 60 GHz ($\epsilon' \pm 0.0404 \times \epsilon'$, $\sigma \pm 0.0581 \times \sigma$). A maximal relative deviation on P_{abs} was found to be 5.41%, which again is smaller than the influence of incident angle and polarization.

Discussion

3D Models

We used micro-CT scanning to obtain spatially accurate mosquito models that had a sufficient resolution to model exposure at 240 GHz (grid step = 25 μm). The micro-CT approach has the advantage of being non-invasive and providing information of the insect's internal anatomy

[37]. However, dried specimens were used for the micro-CT scans to reconstruct the models in this study and the models were made homogeneous with no distinction between different tissues in the mosquito. Real mosquitoes will have different tissues and the position, size, gradients and edges of these tissues will influence the power absorption. In [17, 18] a similar technique was used for different life stages of the Western Honeybee, an Australian Stingless Bee, a Desert Locust and a Dor Beetle.

Other possible techniques for imaging of insects exist [38, 39], but are not all suitable for reconstruction of 3D models. An example of 3D reconstructions of insects is given in [40], where a camera and different angles and focal depths were used with shape-from-silhouette. In [41], a shape-from-motion approach was used for capturing insects' surface geometries and colours. They were able to capture details such as hairs for different insects and a 3D mosquito model from a *Culex pipiens L.* was retrieved using this method. However the resolution of both techniques was lower than for the 3D mosquito models used in this study. In [42] 3D models of insects constructed by a structured light scanner also showed less details of the surface geometries than for a (Synchrotron Radiation) micro-CT method. To the best of our knowledge, no other 3D model of a yellow fever mosquito exists that has been constructed from data of a real insect. Moreover, our mosquito models are based on micro-CT scannings that have a high resolution in comparison to most existing models.

However, the micro-CT method has its limitations: using this imaging technique, some details such as scales and thin antennae were not distinguishable from air in the 2D cross-sections and are thus not part of the 3D model. Additionally, the scanned insects need to be immobilized or dead. In the case of dried species, small deformations can occur compared to living mosquitoes. Nevertheless, the 3D models based on mosquito specimens are detailed and can be considered a good representation of life mosquitoes. Our models can be used to obtain realistic values of absorbed power and inspection of actual E_{int} distributions in simulations.

Dielectric properties

Dielectric properties of the yellow fever mosquito mixture were obtained using coaxial-probe measurements from 5–67 GHz. Previous studies [6, 23, 24, 43–46] have also investigated dielectric properties of insects in this frequency range, some of these values for ϵ' and ϵ" are given in Fig 7, together with the dielectric properties from this study for comparison.

The dielectric properties are slightly smaller for the yellow fever mosquito than most of the other insects measured in [6, 23, 24, 45, 46] for the same frequency range, but are overall comparable, see Fig 7. The permittivity curves exhibit similar behaviour to each other and to the Debye model, with ϵ' decreasing with increasing frequency. From 6 GHz up to higher frequencies, the ϵ" shows a typical Debye relaxation response, for τ_2 a local maximum is visible in Fig 3 around 9.4 GHz. This same behaviour was also observed in previous studies on insect dielectric properties: a local peak is also found around 9.4 GHz for the red flour beetle and the lesser grain borer in [23], around 15.81 GHz for the Colorado potato beetle in [24] and between 10–15 GHz for the larva of the palm weevil in [44]. At lower frequencies, a decreasing trend with increasing frequencies is apparent for our model (Fig 3) and the measurements presented in [23, 24, 46], originating from the static conduction term.

When two relaxation times are assumed in the Debye fit of the the dielectric properties, the curves ϵ' and ϵ" are well in agreement with the measurements, better than for the case of only one relaxation. The parameters of the Debye model given in Table 3, are similar for both curves, a confirmation that the two relaxation Debye model is suitable. For simulations with frequencies below 5 GHz or above 67 GHz, the dielectric properties are taken from a extrapolation using these parameters.

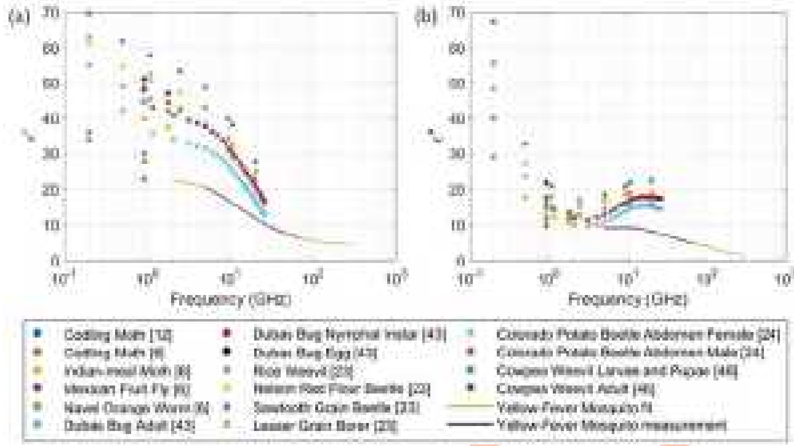

Fig 7. (a) Real and (b) imaginary part of relative permittivity. Given for insects in other studies [6, 12, 23, 24, 43, 45, 46] and for the yellow fever mosquito.

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Numerical simulations

The absorption of RF power by the mosquito is dependent on the electric field in and around the insect, described by Eq 4. At 6 GHz, the wavelength of the incident wave is considerably larger than the insect and will mostly refract and not penetrate the insects' body. At this frequency, it can be seen in Fig 5 that the electric field strength is higher at the boundaries of the insect than inside, making the surface area of the insect an important factor in the power absorption. For increasing frequency up to 120 GHz, EMFs penetrate the insect more efficiently, contributing to an increasing absorption. This is visible in Fig 4. At a frequency of 90 GHz, the increase in absorbed power becomes smaller and the maximum value of P_{abs} is found for mosquito F3 in configuration 5 (Fig 1) with the electric field parallel to the body length of the insect. The incident wave with a frequency of 90 GHz corresponds to a wavelength of 3.33 mm (in free space), comparable to the body length of the insects (Table 2). In this frequency region, whole-body or partial-body resonance [3] occurs causing a higher absorption of the EMFs. The electric field will penetrate more in the insect (Fig 5) at this higher frequency compared to a lower frequency, 6 GHz, inducing more RF absorption inside the insect (Eq 4). On the contrary at 240 GHz, the penetration depth is expected to decrease [18] in comparison to 90 GHz, and spots with lower electric field strength are found in the (middle of the) thorax. Simultaneously, the conductivity increases with increasing frequency as shown in Fig 3. The combination of these two counteracting effects cause the P_{abs} to slightly decrease at 240 GHz in comparison to 90 GHz. At frequencies below 90 GHz, incident electric fields oriented along the same axis induce a P_{abs} in the insect, which are nearly equal to each other. This can be seen in Fig 4B where the P_{abs} under exposure with the electric field along the three main axes show three bundles of four coinciding values at these frequencies below 90 GHz. The relative order of P_{abs} induced by the polarization below 90 GHz is altered for higher frequencies and the polarization responsible for lowest or highest P_{abs} varies.

At 6, 60 and 120 GHz, the mean P_{abs} for an incident field strength of 1 V/m, of all mosquitoes and all 12 plane waves, are 0.165 nW, 2.64 nW and 3.59 nW respectively. For a change of 6 GHz to 60 GHz with the same incident field strength (1 V/m), this translates into a power absorption that is 16 times higher. For a change from 6 GHz to 120 GHz this increase will be even greater, the P_{abs} is 21.8 times higher. In the current networks, frequencies up to 6 GHz are used, with most telecommunication frequencies at $\leq$ 2 GHz [1]. Future networks that emit

EMFs at higher frequencies with a same incident power, will consequently lead to more absorbed power by yellow fever mosquitoes. In reality, the incident electric field strength will vary in time and position. Currently, 5G networks have started being installed and the typical values of the electric field strengths are not yet known for all situations. From measurements at 3.5 GHz in [47] a maximal electric field strength of 4.9 V/m was found at their measurement location, after scaling to a input power of 200 W on the base station. In simulations designed to decrease exposure in a 5G networks presented in [48] at 3.7 GHz, the authors of [48] expected electric field strengths between 0.0068 and 0.0233 V/m in a crowded environment. The values can thus be lower or higher than the 1 V/m that was used in the simulations with the mosquitoes (see Fig 4). Additionally, the exposure in the environment will be limited by (inter)national guidelines and legislation. Many of these are based on the ICNIRP guidelines [35]. The ICNIRP reference level is 61.5 V/m at 2 GHz for the general public when averaged over 30 minutes, which is 61.5 times larger than the electric field strength used in the simulations in this manuscript. For larger frequencies, up to 300 GHz, the guidelines specify a limit on the incident power density, which is 10 W/m2, instead of the incident electric field strength. The absorbed powers in this work can be rescaled to other incident electric field strengths using Eq 5. Further, dielectric heating will be caused by exposure at multiple frequencies simultaneously. Absorbed RF power is a proxy for dielectric heating, which can have an effect on e.g. behaviour, development and dielectric heating of mosquitoes might influence their spread. In order to assess dielectric heating accurately, more precise measurements of A. Aegypti's mass and specific heat capacity would be necessary.

In [17], similar simulations were performed on four insects which resulted in a similar power absorption dependency on frequency. The largest absorption occurred at frequencies with a wavelength comparable to the insect's size. The smallest insect under consideration, the Australian Stingless Bee, experienced less power absorption compared to the larger insects for all frequencies, with a maximal P_{abs} at 60 GHz of $\approx$ 30 nW. The body lengths of the Australian Stingless Bee models are comparable to the length of the mosquitoes, however the peak of maximal absorption is at a lower frequency and P_{abs} is higher than for the mosquitoes. This indicates the necessity of insect-specific simulations and measurements of dielectric properties. Going from 6–60 GHz (the absorption peak), meant for the Australian Stingless a higher P_{abs} by a factor $\approx$ 23. For the mosquitoes, this difference (×16) is smaller, however when looking at 6–120 GHz, i.e. looking at an increase from 6 GHz up to the plateau around the maximum P_{abs}, a similar increase of a factor ×21.8 is seen. For the other insects in [17], the absorption peak is found at even lower frequencies (6, 12 and 24 GHz). In [18], different life stages of the Western Honeybee were subjected to similar simulations, also here a similar power absorption dependency on frequency was observed and absorbed powers were again higher than for the mosquitoes. Going from 6 GHz to higher frequencies in [17, 18], meant going up in absorbed power by the insect, except for the Honey bees that had an absorption peak at 6 GHz.

The power absorption is not proportionally distributed over the body, and thus not only the whole-body absorbed power is considered, the mosquito body is divided in three parts without the legs and the absorbed power is averaged over this body part. Fig 6 shows the averaged head, thorax and abdomen P_{abs} for M1 and F1. This gives insight in the absorption in the different parts of the insect. Abdomen and head have a similar average absorption, and the thorax has a considerably larger averaged absorption at 60 GHz and higher. The thorax has a clearly higher volume-averaged RF absorption than the head or abdomen. We attribute this difference to the shape, the mosquito models have a thorax that can be approximated as a solid sphere, while the abdomen and head have a larger surface/volume ratio than the thorax.

Effect of model. From Fig 4, a larger P_{abs} is found for the three female mosquitoes for all frequencies, than for the three male mosquitoes. When comparing the volume of the mosquitoes in Table 2, it is clear that the female mosquitoes under consideration, have a larger volume and thus can absorb more RF power. When averaging the P_{abs} over the volume of the whole body, the three female mosquitoes still show a higher RF absorption than the three males. The radar cross section does not scale linearly with volume. The female mosquito is not only larger, but differs also slightly in morphology from the male mosquito [36], which also induces a difference in P_{abs}. Further, the models used in the simulations, do not all have the same amount of legs, which influences the absorbed power. Absorbed power in models with less than 6 legs, would have a higher absorbed power in the realistic case of six legs.

Uncertainties of simulations. The FDTD technique makes use of a three dimensional grid and the mosquito models need to be discretized. The voxels used in all simulations were 25 μm. Smaller voxels result in more reliable results, however simulation times will run up. The influence of a smaller voxel size and the influence of the uncertainty on dielectric parameters are smaller than the effect of incidence angle and polarization. It follows that a choice of 25 μm for the voxels is sufficient. The impact of incidence angle and polarization on the P_{abs} is visible from the bar chart in Fig 4, where the whiskers indicate the total range of P_{abs} for the 12 simulations. To verify that these 12 plane waves represent the range of possible absorbed powers, 30 simulations with random orientations and polarizations were considered at 60 GHz. No simulation resulted in a value outside the range of the earlier 12 plane waves.

Strengths and limitations

This paper contributes to the state of the art in different aspects. First of all, six detailed 3D models of the yellow fever mosquito were designed by means of micro-CT scans. The models are, to our knowledge, the first models based on real mosquitoes with a high spatial resolution. Second, the dielectric properties of homogenised yellow fever mosquitoes were measured for the first time, in a 5–67 GHz range. The use of the model obtained from real mosquitoes and the use of dielectric properties of the insect in question, result in more accurate simulations. Advantages of using simulations as opposed to experiments, is the ease in exploring different setups and frequencies. The RF exposure of mosquitoes were numerically simulated, leading to first-time insights on absorbed power by yellow fever mosquitoes at frequencies in 4G and the future 5G mm-waves.

The methods used in this study also come with limitations. The micro-CT scan, despite leading to high resolutions and insight in internal structures of the insects, did not capture the wings and certain thin instances of the mosquitoes. The models were made from dried unfed dead mosquitoes, and no distinction was made between different tissues of the insect. Real mosquitoes will have different tissues and the position, size, gradients and edges of these tissues will influence the power absorption. The dried species can vary slightly from living mosquitoes in form. The dielectric properties below 5 GHz and above 67 GHz, are not measured but acquired by extrapolation. In the simulation environment, the model is discretized in voxels and the simulations are only an approximation of reality. The limitations of the simulations further lie in the uncertainties that accompany the FDTD technique and the use of a limited amount of plane waves representing the far-field. Uncertainties on parameters in simulation settings and random angle of incidence were adopted in extra simulations to explore these limitations. However the absorbed power is a proxy for dielectric heating, values of actual heating are outside the scope of this paper.

Future work

Future work will consist of the study of other life stages of the mosquito exposed to RF-EMF exposure. Another step forward will be investigating heterogeneous models of the insect, with different dielectric properties for different tissues. Experiments concerning RF-EMF absorption, scattering and measurements of heating (by e.g. infrared cameras), can verify current results and give more insight in the matter. Also measurements on living mosquitoes will enable us to study the influence of RF EMFs on the insect. Further, other insects can be used in similar simulations, to have a more complete view of RF-EMF absorption of insects exposed to 4G and 5G telecommunication and size dependency of absorbed power.

Conclusion

By creating six high resolution 3D models and by measuring dielectric properties from real mosquitoes using a coaxial-probe technique, realistic FDTD simulations were possible for far field exposure between 2 and 240 GHz. The absorbed RF power P_{abs} for this insect is lower than for other insects, with a maximum of 5.64 nW for an incident field strength of 1 V/m. Female mosquitoes absorb more power than male mosquitoes, while the body part absorbing most power is the thorax. The distribution of the electric field in and around the mosquito showed a higher field strength in the insect for 120 and 240 GHz than for 6 GHz. The P_{abs} for EMFs with a frequency of 60 GHz was 16 times larger than for 6 GHz, with the latter frequency the upper limit of current telecommunication networks. For 120 GHz, this increase is even larger compared to 6 GHz, with a factor 21.8. Around this frequency, the maximum in RF EMF absorption was observed for all mosquitoes. In the future, the carrier frequency of telecommunication systems will also be higher than 6 GHz. This will be paired with higher absorption of EMF by yellow fever mosquitoes, which can cause dielectric heating and have an impact on behaviour, development and possibly spread of the insect.

Supporting information

S1 File. STL file of a 3D *A. aegypti* male model. A male mosquito mesh 3D model. (STL)

S2 File. STL file of a 3D *A. aegypti* female model. A female mosquito mesh 3D model. (STL)

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Review

Current progress on the effect of mobile phone radiation on sperm quality: An updated systematic review and meta-analysis of human and animal studies

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A B S T R A C T

Potential suppression of fertility due to mobile phone radiation remains a focus of researchers. We conducted meta-analyses on the effects of mobile phone radiation on sperm quality using recent evidence and propose some perspectives on this issue. Using the MEDLINE/PubMed, Embase, WOS, CENTRAL, and ClinicalTrials.gov databases, we retrieved and screened studies published before December 2020 on the effects of mobile phone use/mobile phone RF-EMR on sperm quality. Thirty-nine studies were included. Data quality and general information of the studies were evaluated and recorded. Sperm quality data (density, motility, viability, morphology, and DFI) were compiled for further analyses, and we conducted subgroup, sensitivity, and publication bias analyses. The pooled results of human cross-sectional studies did not support an association of mobile phone use and a decline in sperm quality. Different study areas contributed to the heterogeneity of the studies. In East Europe and West Asia, mobile phone use was correlated with a decline in sperm density and motility. Mobile phone RF-EMR exposure could decrease the motility and viability of mature human sperm *in vitro*. The pooled results of animal studies showed that mobile phone RF-EMR exposure could suppress sperm motility and viability. Furthermore, it reduced sperm density in mice, in rats older than 10 weeks, and in rats restrained during exposure. Differences regarding age, modeling method, exposure device, and exposure time contributed to the heterogeneity of animal studies. Previous studies have extensively investigated and demonstrated the adverse effects of mobile phone radiation on sperm. In the future, new standardized criteria should be applied to evaluate potential effects of mobile phone RF-EMR dosages. Further sperm-related parameters at the functional and molecular levels as well as changes in biological characteristics of germ cells should be evaluated. Moreover, the impact of mobile phone RF-EMR on individual organs should also be examined.

1. Introduction

Mobile phones produce a type of non-ionizing radiation termed radio frequency electromagnetic radiation (RF-EMR; Belpomme et al., 2018). The increasing popularity and use of mobile phones have raised concerns on whether RF-EMR can affect male sperm quality (Jalilian et al., 2019), and the current consensus in the general public is that mobile phone RF-EMR is a major risk factor of decreased sperm quality. However, the results of current research are contradictory, and whether mobile phone RF-EMR exposure decreases male sperm quality remains an unresolved issue in the scientific community. For instance, one study showed that sperm deformation rates in men increased with increasing mobile phone

Abbreviations: RF-EMR, radio frequency electromagnetic radiation; WOS, Web of Science; DFI, DNA fragmentation rate; CENTRAL, Cochrane Central Register of controlled trials.

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0269-7491/

usage time (Agarwal et al., 2008), whereas a different study found no such a correlation (Erogul et al., 2006). Mobile phone radiation was reported to suppress sperm motility and viability (Mailankot et al., 2009; Ghanbari et al., 2013), whereas some different studies suggested that this type of radiation didi not affect sperm density, motility, and viability in rodents (Dasdag et al., 2013; Trosic et al., 2013). In 2014, Liu et al. pooled the results of four cross-sectional studies, four human sperm *in vitro* studies, and four animal studies and attempted to conduct a meta-analysis on the relationships of mobile phone use and sperm quality in terms of the three aforementioned aspects (Liu et al., 2014). The results of this meta-analysis did not suggest that mobile phone usage was associated with changes in human sperm quality; however, direct mobile phone RF-EMR exposure could reduce human sperm motility and viability *in vitro*. Moreover, the results of animal experiments suggested that mobile phone RF-EMR exposure could decrease sperm density and motility (Liu et al., 2014). At approximately the same time, Adams et al. conducted a meta-analysis on human sperm quality, which included 10 studies (five cross-sectional studies and five *in vitro* studies of human sperm) and found that mobile phone RF-EMR exposure could affect human sperm motility and viability (when the results of the two aforementioned study types were pooled; Adams et al., 2014). The additional subgroup analysis conducted by Adams et al. using these limited studies only supported that mobile phone RF-EMR did not decrease sperm density *in vitro* (Adams et al., 2014). These previous studies pooled the findings of earlier studies, formulated some hypotheses, and revealed preliminarily relationships between mobile phone RF-EMR exposure and male subfertility. However, owing to large differences in experimental conditions among the included studies, the meta-analyses by Liu et al. and Adams et al. were highly heterogeneous in terms of results. Moreover, because of the small number of studies available for analysis, further heterogeneity analysis was limited. Thus, both research groups proposed that their preliminary conclusions should be further examined and that their hypotheses should be further tested to elucidate the effects of mobile phone RF-EMR on male fertility. Taken together, additional data analyses are required to test the effects of mobile phone RF-EMR exposure on sperm quality.

In the past six years, the rapid advancement of communication technology and the advent of 5G technology has led to increased cell phone use and subsequent higher exposure rates to associated RF-EMR. Therefore, it is imperative to gain scientific understanding of the effect of mobile phone RF-EMR on male fertility (Choi et al., 2018; Simkó and Mattsson 2019). Whether mobile phone RF-EMR and other RF-EMR types emitted by wearable devices or the "Internet of Things" may exert reproductive toxicity has garnered social attention and has attracted research interest. Many new studies using different experimental conditions have been published, and we conducted a meta-analysis based on these studies to examine the impact of mobile phone RF-EMR on sperm quality and to test some of the hypotheses proposed in previous studies. Our analyses may elucidate the progress in the research on the relationship of mobile phone use and male fertility. Furthermore, we discuss personal views on the topic to provide suggestions for future research.

2. Methods

2.1. Search strategies

This meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, the Meta-analyses of Observational Studies in Epidemiology guidelines, and the guidelines for reporting animal research. We searched the MEDLINE/PubMed, EMBASE, Web of Science (WOS), Cochrane Central Register of Controlled Trials (CENTRAL) and ClinicalTrials.gov. databases for respective studies on this topic.

A mesh was applied to define the subject heading, which was supplemented and simplified to achieve a more accurate literature retrieval. The search strategy in MEDLINE/PubMed was as follows:

("cell phone*"[Title/Abstract] OR "cellular phone*"[Title/Abstract]) OR "cellular telephone*"[Title/Abstract]) OR "mobile phone*"[Title/Abstract]) OR "mobile telephone*"[Title/Abstract]) OR "electromagnetic"[Title/Abstract]) AND (("sperm*"[Title/Abstract] OR "semen"[Title/Abstract]) OR "Seminal"[Title/Abstract]).

We searched for studies conducted before December 2020. The search strategies employed on the EMBASE and WOS databases are shown in Supplement 1. We also screened references in respective articles to identify other potential studies.

2.2. Inclusion and exclusion criteria

The inclusion criteria were as follows: 1. human cross-sectional studies, human sperm studies *in vitro* (i.e., experiments were conducted on ejected semen *in vitro*), and animal experiments on the relationships of mobile phone use/mobile phone EMR and sperm quality/semen quality; 2. associated studies with a control or comparison group; 3. associated studies with semen analysis/sperm quality analysis; 4. a specific absorption rate (SAR) of mobile phone RF-EMR below 2 W/kg for human sperm studies *in vitro* and animal studies.

The exclusion criteria were as follows: 1. studies investigating the relationship of mobile phone base stations, radar EMR, extremely low EMR, wireless fidelity, mobile phone RF-EMR jammers, and joint electromagnetic fields with male sperm quality; 2. studies investigating the effects of mobile phone RF-EMR exposure on pregnancy; 3. animal studies *in vitro* (i.e., studies on biological changes in various germ cell lines such as GC2 and TM4, but lacking data on mature sperm quality); 4. studies containing data values with incorrect decimal points; 5. studies in which the mean or standard deviation could not be calculated based on the accessible data; 6. special article types, including reviews, meta-analyses, comments, statements, and retracted articles.

2.3. Quality assessment

We used the Joanna Briggs Institute Practical Application of Clinical Evidence System (JBI) list to evaluate the included human cross-sectional studies (Laidsaar-Powell et al., 2019). We referred to the method proposed by Liu et al. and evaluated the quality of human sperm *in vitro* studies based on four parameters (Liu et al., 2014): representativeness of subjects, type of the radiation exposure device, comparability of the exposure and the control group, and representativeness of evaluation indices. The scoring system ranged from 0 (low quality) to 4 (high quality). We applied the Collaborative Approach to Meta-Analysis and Review of Animal Data from Experimental Stroke (CAMARADES) list to evaluate animal studies (Tong et al., 2019). Details are provided in Supplement 2.

2.4. Data extraction

Basic information of the included studies was extracted according to different study types. Data on sperm quality data including sperm density, motility, viability, morphology, and DNA fragmentation index (DFI) were pooled. Sperm quality data of rats and mice were pooled separately.

2.5. Statistical analyses

Meta-analyses were performed using RevMan 5.3. Standardized mean differences (SMD) and mean differences (MD) were used to analyze sperm quality. Cochran's Q test was applied to test heterogeneity, after which at $P > 0.1$, a fixed effects model was fitted, and at $P \leq 0.1$, a random effects model was fitted. Heterogeneity is represented by I^2. Subgroup analyses were performed to analyze the origin of heterogeneity using RevMan 5.3. Regarding human cross-sectional studies, we performed a subgroup analysis based on study area, exposure time, and evaluation method. For animal studies, subgroup analyses were conducted with respect to animal age (younger or older than 10 weeks), radiation exposure device (mobile phone or simulator), animal status during modeling (restrained or unrestrained), and modeling time (short-term exposure at < 140 h or long-term exposure at > 140 h).

A one-by-one exclusion method was applied to the sensitivity analysis. For parameters included in more than seven studies, we applied a funnel chart, Egger's test, and Begg's test using Stata 16.0 to evaluate potential publication bias.

Literature retrieval, quality assessment, and data extraction were independently completed by two reviewers. If the opinions were inconsistent, the reviewers consulted with each other or with a third party.

3. Results

3.1. Search results

A flow chart of the screening process is shown in Fig. 1. In total, 1073 studies were retrieved, and after screening, 137 studies remained for full-text reading; of these, 98 studies were excluded, and 39 studies were included, which comprised 5 human cross-sectional studies, 8 human sperm *in vitro* studies, and 26 animal studies (20 studies on rats and 6 studies on mice) for meta-analyses. These 39 studies included results on sperm quality analysis of 2567 men of childbearing age (including 225 semen samples of men of childbearing age for sperm experiments *in vitro*) and 836 epididymal semen samples of animals (583 rats and 253 mice). Full texts of five studies could not be obtained even after contacting the respective authors by e-mail. One study with a data value with an incorrect decimal point mark and one study in which the standard deviation could not be calculated were excluded during screening; despite inquiring with the respective authors by e-mail, no further information was obtained.

3.2. Basic information

The basic information of the included studies is shown in Tables S1, S2, and S3.

3.3. Quality evaluation

As shown in Table 1, the JBI score of the human studies ranged from 9 to 15, and only in one study was the JBI score below 10, whereas in four studies, it was higher than 10. The JBI score for human sperm *in vitro* studies ranged from 8 to 10; in one of these studies, the JBI score was 8, while in seven studies, the JBI score was 9. Regarding animal studies identified through the CAMARADES list, the JBI scores of four studies were below 7, while those of 22

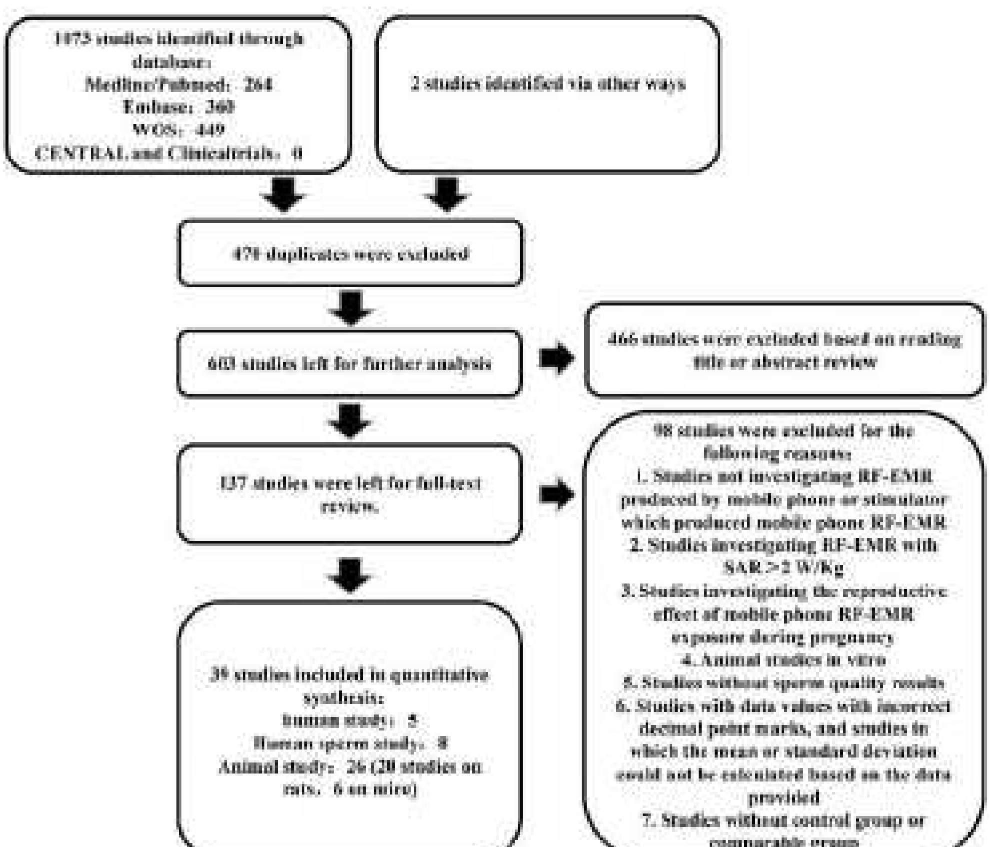

Fig. 1. Flow chart of the screening process.

Table 1
Quality evaluation of included studies.

Human study	Score	Human sperm study	Score	Animal study	Score
Fejes(Fejes et al., 2005)	11	Erogul(Erogul et al., 2006)	9	Dasdag(Dasdag et al., 2003)	10
Agarwal(Agarwal et al., 2008)	11	Agarwal(Agarwal et al., 2009)	9	Yan(Yan et al., 2007)	10
Fejio(Feijo et al., 2011)	9	Ahmad(Ahmad and Baig 2011)	9	Ribeiro(Ribeiro et al., 2007)	12
Rago(Rago et al., 2013)	12	Dkhil(Dkhil et al., 2011)	9	Mailankot(Mailankot et al., 2009)	8
Yildirim(Yildirim et al., 2015)	12	Veerachari(Veerachari and Vasan 2012)	9	Lee(Lee et al., 2010)	8
		Gorpinchenko(Gorpinchenko et al., 2014)	8	Imai(Imai et al., 2011)	6
		Zalata(Zalata et al., 2015)	9	Nisbet(Nisbet et al., 2012)	6
		Nakatani-Enomoto(Nakatani-Enomoto et al., 2016)	9	Ab Zayed(Zayed et al., 2012)	4
				Trosic(Trosic et al., 2013)	8
				Ghanbari(Ghanbari et al., 2013)	10
				Shahin(Shahin et al., 2014)	12
				Tas(Tas et al., 2014)	10
				Liu(Liu et al., 2015)	12
				Gohari(Gohari et al., 2017)	12
				Oyewopo(Oyewopo et al., 2017)	10
				Pandey(Pandey et al., 2017)	10
				Almasiova(Almášiová et al., 2018)	12
				Pandey(Pandey and Giri 2018)	10
				Shahin(Shahin et al., 2018)	10
				Narayanan(Narayanan et al., 2019)	8
				Gautam(Gautam et al., 2019)	6
				Yahyazadeh(Yahyazadeh and Altunkaynak 2019)	10
				Shahin(Shahin et al., 2019)	10
				Yu(Yu et al., 2020)	12
				Vafaei(Vafaei et al., 2020)	10
				Pardhiya(Pardhiya et al., 2020)	10

studies were higher than 7.

3.4. Meta-analysis results

3.4.1. Research status

Currently, relevant human epidemiological studies are still lacking. Studies have been predominantly conducted using animal experiments, some of which used mobile phones, while others used RF simulators to produce mobile phone RF-EMR. Only few studies discussed effects of RF-EMR produced by 4G or 5G devices on reproductive functions, and considerable differences between evaluation methods of the actual RF-EMR dosages in the exposure area were observed. Most studies assessed the effects of RF-EMR on sperm density, motility, viability, and morphology, however, only few investigated the effects of mobile phone RF-EMR exposure on reproduction through advanced sperm function tests, sperm DFI test, and offspring quality tests. Almost all included studies investigated the effects of whole-body RF-EMR exposure on male fertility, and only few investigated the effects of local RF-EMR exposure on certain reproductive organs.

3.5. Meta-analysis results of human cross-sectional studies

3.5.1. Sperm density

As shown in Fig. 2A, five studies were included for sperm density analysis (random model; MD = −1.21 [-15.14, 12.73]; $P = 0.87$; $I^2 = 91\%$; Q test $P < 0.001$). Owing to the large heterogeneity of studies, subgroup analyses were conducted, and the results showed that I^2 decreased to 0% (Q test $P = 0.77$), P was 0.0003 in the East Europe and West Asia group, while in other regions I^2 was 97% (Q test $P < 0.0001$) and P was 0.98.

The sensitivity analysis showed that MD decreased to −7.99 (−19.13, 3.15), I^2 decreased to 79% (Q test $P = 0.003$), and P decreased to 0.16 after removing the Feijo's study. The total effect scale, I^2, Q test P, and the statistical P-value did not significantly change when other studies were removed.

3.5.2. Sperm motility

As shown in Fig. 2B, the sperm motility analysis included five studies (random model; MD = −4.77 [-11.68, 2.15]; $P = 0.18$; $I^2 = 87\%$; Q test $P < 0.0001$). Heterogeneity of the studies was high. The subgroup analysis showed that I^2 decreased to 0% (Q test $P = 0.65$), P was 0.04 in the East Europe and West Asia group whereas in the America group, I^2 was 95% (Q test $P < 0.0001$), P was 0.59. I^2 decreased to 56% (Q test $P = 0.10$), P was 0.56 in the forward motility group, whereas I^2 was 92% (Q test $P = 0.0003$), and P was 0.12 in the total motility group.

The sensitivity analysis showed that removing the study by Agarwal et al. reduced MD to −2.25 (−6.55, 2.04), and I^2 to 35% (Q test $P = 0.20$), $P = 0.30$; the analysis results did not significantly change after removing other studies.

3.5.3. Sperm viability

As is shown in Fig. 3A, the sperm viability analysis included two studies (random model; MD = −4.91 [-23.53, 13.72]; $P = 0.61$; $I^2 = 95\%$; Q test $P < 0.0001$).

3.5.4. Sperm morphology

As shown in Fig. 3B, the analysis of sperm morphology included four studies (random model; MD = −0.32 [-1.01, 0.37], $P = 0.36$, and $I^2 = 91\%$; Q test $P < 0.00001$). The subgroup analysis showed that in the East Europe and West Asia group, I^2 was 0% (Q test $P = 0.87$), and $P = 0.25$, while in the America group, I^2 was 97% (Q test $P < 0.00001$), and $P = 0.46$.

The sensitivity analysis suggested that removing the study by Agarwal et al. decreased the MD to −0.05 (−0.17, 0.07), I^2 to 0% (Q test $P = 0.44$), and P to 0.41. Removing other studies did not significantly change the analysis results.

3.6. Meta-analysis results of human sperm studies

3.6.1. Total sperm motility, viability, and density

As shown in Fig. 4, the total sperm motility analysis included seven studies (fixed model; MD = −3.56 [-5.11, −2.00]; $P < 0.00001$; $I^2 = 0\%$; Q test $P = 0.69$). The sperm viability analysis

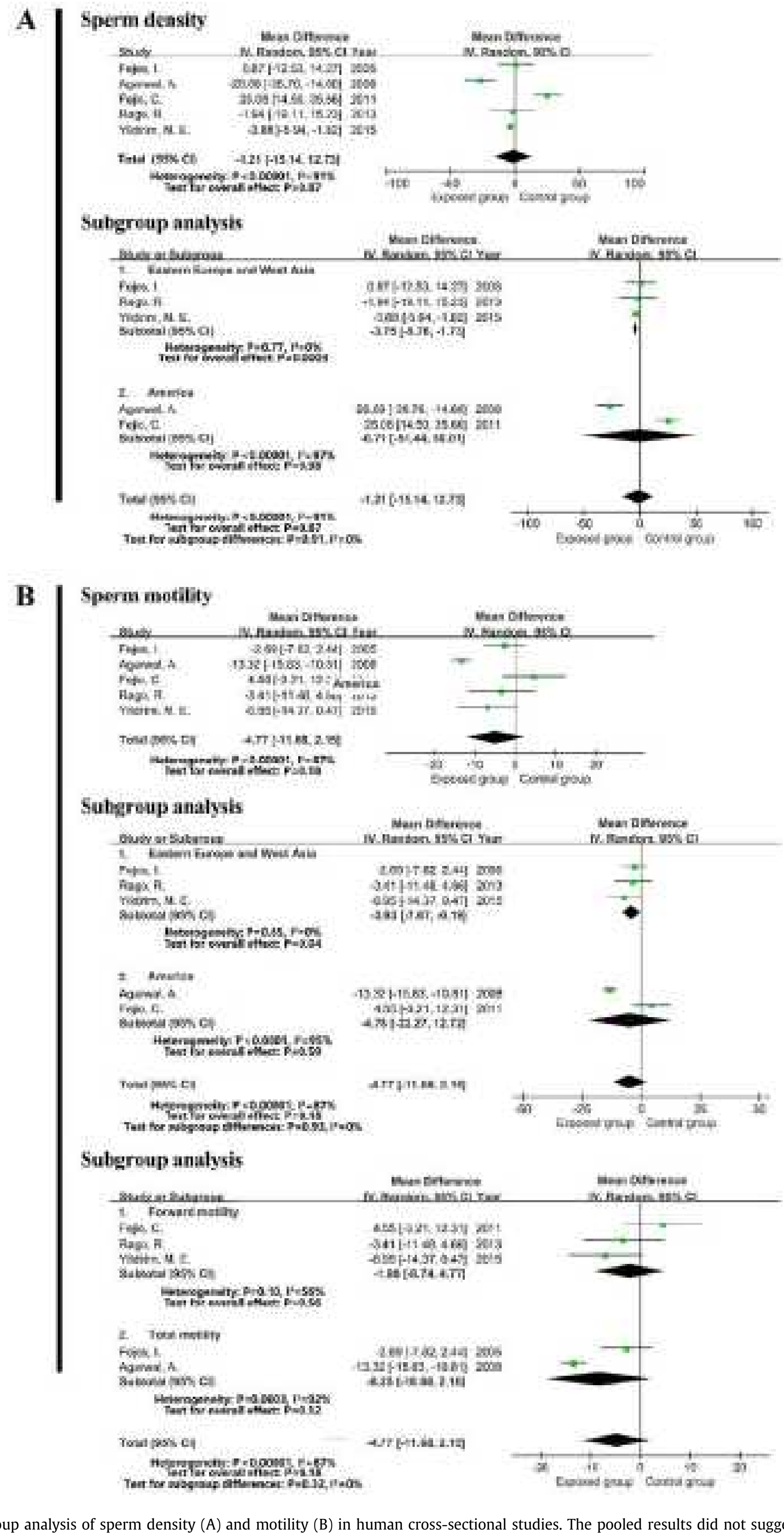

Fig. 2. Forest plot and subgroup analysis of sperm density (A) and motility (B) in human cross-sectional studies. The pooled results did not suggest that mobile phone use was associated with a decline in sperm density in humans. Study area contributed to study heterogeneity in the analyses of sperm density and motility. The evaluation method contributed to study heterogeneity regarding sperm motility analysis. Mobile phone use in East Europe and West Asia was associated with decreased sperm density and motility.

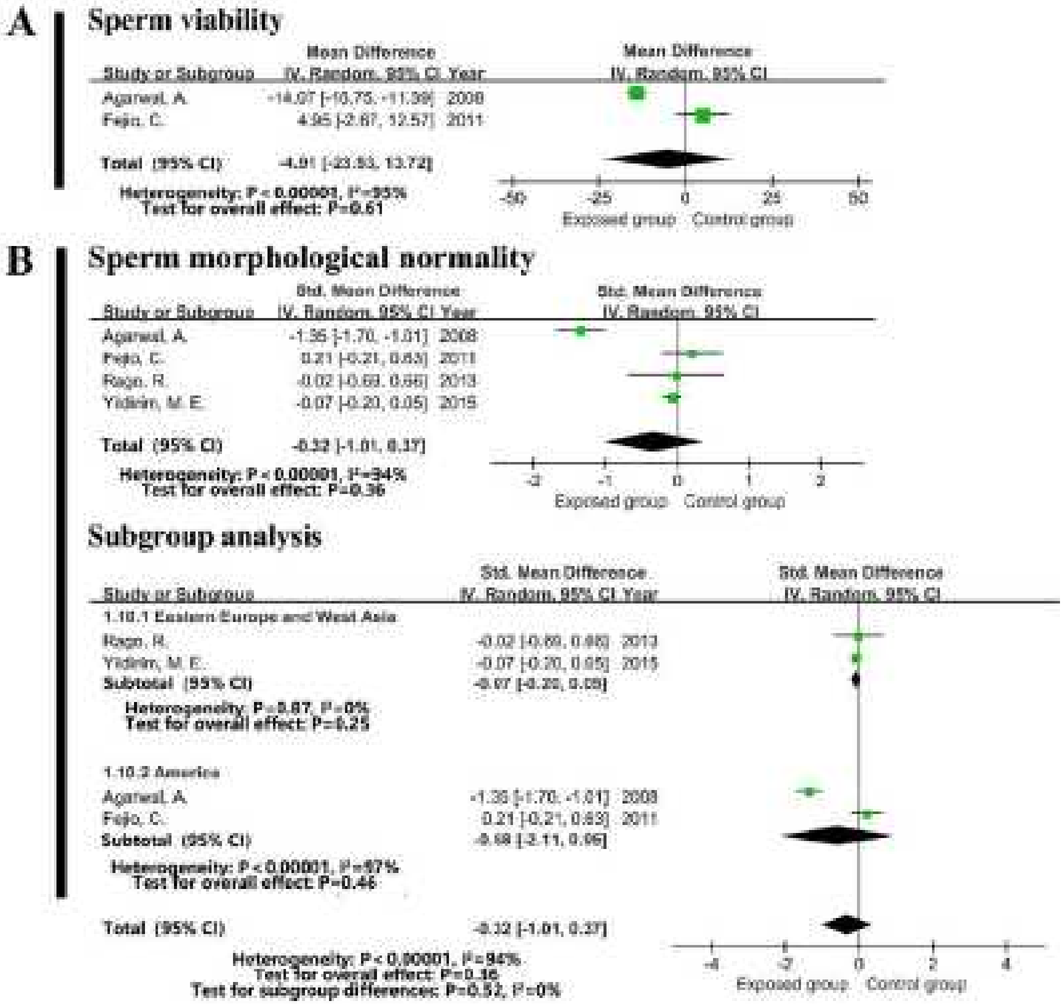

Fig. 3. Forest plot and subgroup analysis of sperm viability (A) and morphology (B) in human cross-sectional studies. The pooled results did not indicate that mobile phone use was associated with decreased sperm viability and morphology in humans. The study area contributed to the study heterogeneity of sperm morphology.

included four studies (random model; MD = −3.51 [-4.32, −2.70]; $P < 0.00001$; $I^2 = 0\%$; Q test $P = 0.74$). Three studies (random model) were included in the density analysis, (MD = −1.07 [-8.34, 6.20]; $P = 0.77$; $I^2 = 0\%$; Q test $P = 0.99$). The sensitivity analysis of total sperm motility, viability, and density showed that excluding any of the studies did not significantly affect the observed total effect scale, I^2, Q test P, and the statistical P-value.

3.6.2. Sperm DFI

As is shown in Fig. 4D, the sperm DFI analysis included two studies (random model; MD = 1.30 [-0.57, 3.18]; $P = 0.17$; $I^2 = 94\%$; Q test $P < 0.0001$).

3.7. Meta-analysis results of animal studies

3.7.1. Sperm density in rats

As is shown in Figs. 5A and 17 studies (random model) were included in the analysis of epididymal sperm density (SMD = −0.32 [-0.64, 0.00]; $P = 0.05$; $I^2 = 58\%$; Q test $P = 0.001$). The subgroup analyses are shown in Table 2. Study heterogeneity ($I^2 = 56\%$; Q test $P = 0.003$) was significantly reduced in the restrained group ($I^2 = 28\%$; Q test $P = 0.22$) and in the simulator group ($I^2 = 40\%$; Q test $P = 0.11$). In addition, subgrouping by animal age did not significantly affect study heterogeneity; however, in animals older than 10 weeks, the P-value of pooled results changed to 0.03, indicating statistical significance.

The sensitivity analysis suggested that removing any study did not change the total effect scale, I^2, Q test P, or the statistical P-value, suggesting robustness of the results. As shown in Figure S1A, the funnel plot, Begg's test (Pr = 0.06), and Egger's test ($P = 0.33$) did not suggest significant publication bias in these studies.

3.7.2. Sperm motility in rats

As shown in Figs. 5B and 11 studies (random model) were included in the analysis of sperm motility (SMD = −0.83 [-1.41, −0.24]; $P = 0.005$; $I^2 = 80\%$; Q test $P < 0.00001$). As shown in Table 2, the subgroup analyses showed that study heterogeneity (80%; Q test $P < 0.00001$) may be reduced in the restrained group (0%; Q test $P = 0.82$), in rats older than 10 weeks (28%; Q test $P = 0.22$), and in the mobile phone group (56%; Q test $P = 0.08$).

The sensitivity analysis showed that after removing the study by Ozlem et al. SMD was reduced to −1.00 (−1.49, −0.52) and I^2 was reduced to 66% (Q test $P = 0.002$; $P < 0.0001$), whereas the analysis results were not significantly changed after removing other studies. As shown in Figure S1B, the funnel plot, Begg's test (Pr = 0.06), and Egger's test (P = 0.111) did not suggest significant publication bias in the included studies.

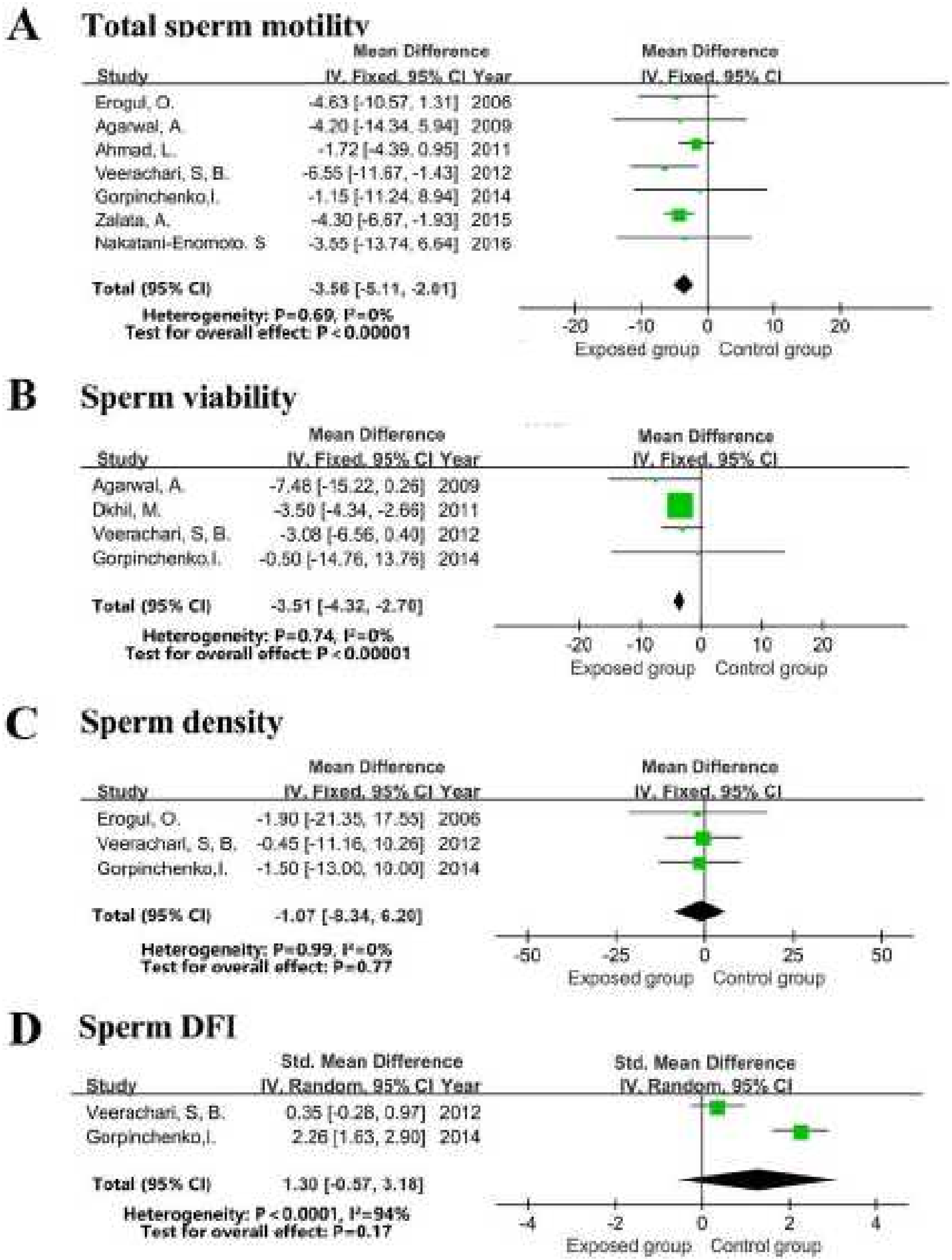

Fig. 4. Forest plot of sperm motility (A), viability (B), density (C), and DFI (D) in human studies *in vitro*. The pooled results supported the claim that mobile phone RF-EMR exposure reduces total sperm motility and viability of human sperm *in vitro*.

3.7.3. Sperm viability in rats

As shown in Fig. 5C, four studies (fixed model) were included in the analysis of epididymal sperm viability (MD = −8.20 [-10.33, 6.07]; $P < 0.00001$; $I^2 = 0\%$; *Q* test $P = 0.57$). The sensitivity analysis showed that excluding any study did not significantly change the observed total effect scale, I^2, *Q* test *P*, or the statistical *P*-value.

3.7.4. Sperm morphology in rats

As is shown in Fig. 5D, seven studies (random model) were included (SMD = −0.37 [-1.12, 0.37]; $P = 0.33$; $I^2 = 79\%$; *Q* test $P < 0.00001$). The subgroup analysis (Table 2) showed that I^2 decreased to 0% (*Q* test $P = 0.59$), and the *P*-value changed to 0.01 in the mobile phone group. Sensitivity analysis showed that after removing the studies by Nisbet et al. or Yahyazadeh and Altunkaynak, the SMD was reduced to −0.59 (−1.25, 0.08) and −0.13 (−0.70, 0.44), respectively, I^2 was reduced to 67% (Q test $P = 0.01$) and 68% (Q test $P = 0.008$), respectively, and P was 0.08 and 0.65, respectively. Removing other studies did not significantly change the pooled results. The funnel plots, Begg's test (Pr = 0.54), and Egger's test ($P = 0.48$) did not suggest significant publication bias in the included studies (Figure S1C).

3.7.5. Sperm density in mice

As shown in Fig. 5E, epididymal sperm density analysis included six studies (random model; SMD = −2.62 [-3.79, −1.44], $P < 0.00001$; $I^2 = 83\%$; Q test $P = 0.0001$). A subgroup analysis showed that there was no significant change in the analysis results after grouping by modeling device, exposure time, or age. The sensitivity analysis showed that removing any study did not significantly change the observed total effect scale, I^2, Q test P, and the statistical P-value, suggesting robustness of the results.

4. Discussion

In the past six years, studies on the effects of mobile phone radiation on sperm quality were mostly conducted using animal experiments rather than human surveys. Consistent with the results of a meta-analysis from 2014 (Liu et al., 2014), the pooled results of cross-sectional studies in our study did not suggest that mobile phone use is associated with a decline in human sperm quality. Current evidence from human sperm *in vitro* studies support the claim that mobile phone RF-EMR exposure can suppress sperm mobility and viability. The meta-analysis by Liu et al. suggested that mobile phone RF-EMR exposure can decrease sperm density and motility in rats (Liu et al., 2014). Our pooled results indicate that mobile phone RF-EMR exposure can reduce sperm motility in rats but that it does not significantly decrease sperm density ($P = 0.05$); moreover, our pooled results also suggest that mobile phone RF-EMR reduces sperm viability in rats, which has not been shown previously. Despite considerable heterogeneity among included human and animal studies, the large number of studies enabled us to conduct subgroup analyses to further analyze these heterogeneities caused by different experimental conditions.

4.1. Human cross-sectional studies

For the first time, our results suggest that differences in study areas may cause heterogeneity when investigating sperm quality, while the evaluation method contributed to heterogeneity of sperm motility results. Analysis of sperm density, motility, and morphology indicated that the respective studies in East Europe and West Asia were less heterogeneous. The fact that study area may be a source of heterogeneity may be due to differences in ethnicities, habits, and research methods; moreover, statistical fluke may not be ruled out, which should be considered in future studies.

There are three particularly important aspects of the present study. First, theoretically, if mobile phone use is associated with reduced sperm quality, such correlations should become stronger with increasing exposure time. Unfortunately, our present subgroup analysis failed to show that duration of phone use affected the pooled results or study heterogeneity, which may be attributed to the recall bias in the epidemiological survey on mobile phone use, which causes inaccuracy of survey results (Halgamuge et al., 2020). Second, the sensitivity analysis suggested that the study by Feijo et al. significantly affected the pooled results, which may be due to the authors' unique research method regarding mobile phone use as they recorded only speaking time (Feijo et al., 2011),

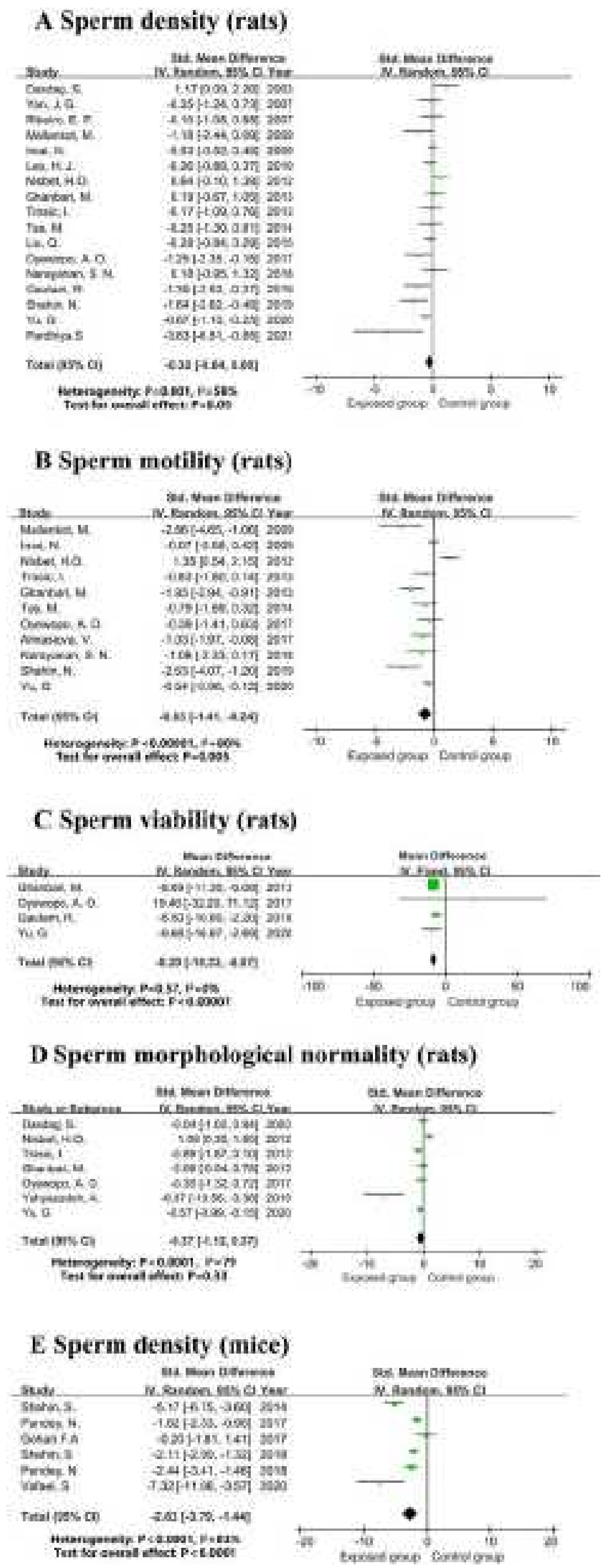

Fig. 5. Forest plot of sperm density (A), motility (B), viability (C), and morphology (D) in rat studies, and sperm density (E) in mouse studies. The pooled results suggested that mobile phone RF-EMR exposure reduced sperm motility and viability in rats, and sperm density in mice.

Table 2
Subgroup analysis of sperm density, motility and morphological normality of rats.

	Condition	Subgroup	n	MD/SMD	I2 (P)	Model	*P*
Sperm density	Modeling method						
		Before analysis	16	−0.26[-0.59,0.06]	56%(0.003)	Random	0.11
		Activity-free	10	−0.16[-0.61,0.29]	62% (0.005)		0.49
		Activity-restricted	6	−0.45[-0.84,-0.07]	28%(0.22)		0.02
	Age						
		Before analysis	16	−0.36[-0.69,-0.02]	59% (0.001)	Random	0.04
		> 10 weeks	9	−0.45[-0.87,-0.04]	52% (0.04)		0.03
		< 10 weeks	7	−0.25[-0.82,0.31]	65%(0.009)		0.38
	Exposure device						
		Before analysis	17	−0.32[-0.64,0.00]	58% (0.001)	Random	0.05
		Mobile phone	9	−0.54[-1.11,0.03]	64% (0.005)		0.06
		Simulator	8	−0.14[-0.48,0.20]	40% (0.11)		0.43
Sperm motility	Modeling method						
		Before analysis	11	−0.83 [-1.41, −0.24]	80% (< 0. 00001)	Random	0.005
		Activity-free	8	−0.95 [-1.85, −0.06]	85% (< 0. 00001)		0.04
		Activity-restricted	3	−0.61 [-0.97, −0.25]	0% (0.82)		0.001
	Age						
		Before analysis	10	−0.70[-1.29, −0.12]	78% (< 0.00001)	Random	0.02
		> 10 weeks	6	−0.79 [-1.23, −0.36]	28% (0.22)	Random	0.0003
		< 10 weeks	4	−0.49 [-1.83, 0.85]	89% (< 0. 00001)		0.47
	Exposure time						
		Before analysis	12	−0.97[-1.57, −0.37]	81%	Random	0.002
		> 140 h	5	−0.45 [-1.36, 0.46]	87% (< 0.00001)	Random	0.34
		< 140 h	7	−1.33 [-1.93, −0.73]	46% (0.09)		< 0.0001
	Exposure device						
		Before analysis	11	−0.83[-1.41, −0.24]	80% (< 0.00001)	Fixed	0.005
		Mobile phone	4	−0.91 [-1.66, −0.16]	56% (0.08)	Random	0.02
		Simulator	7	−0.77 [-1.65, 0.11]	85% (< 0.00001)		0.09
Sperm morphology normality	Modeling method						
		Before analysis	7	−0.37[-1.12, 0.37]	79% (< 0. 0001)	Random	0.33
		Activity-free	3	0.27[-0.60, 1.15]	66% (0. 05)		0.54
		Activity-restricted	4	−0.98[-2.06, 0.10]	78% (0. 003)		0.08
	Exposure device						
		Before analysis	7	−0.37[-1.12, 0.37]	79% (< 0. 0001)	Random	0.33
		Mobile phone	3	−0.47[-0.83, −0.10]	0% (0.59)		0.01
		Simulator	4	−0.81[-2.41, 0.79]	88% (< 0.0001)		0.32

whereas other researchers recorded the entire duration of mobile phone use. The duration of mobile phone use is a broad concept that includes speaking time, thus in the future, researchers should take measures to accurately record mobile phone usage to obtain more reliable results. Third, in daily life, men who use their mobile phones for prolonged periods of time are frequently highly pressured and have irregular lifestyles; therefore, they are more prone to smoking, drinking, and other unhealthy habits which may affect sperm quality (Toda et al., 2006; Zhang et al., 2016). Compared with the effects of mobile phone use on reproductive functions, the effects of these confounding factors on sperm quality would be considerably stronger. Without distinguishing these factors, intragroup differences in sperm quality would increase, resulting in high heterogeneity in the analysis results. Therefore, further studies should consider the importance of using appropriate research and statistical methods that can eliminate the influence of confounding factors. In the MARHCS cohort study, Zhang et al. conducted multivariate analyses using health data of 794 men of childbearing age living in Chongqing, China, and after accounting for potential confounding factors such as smoking and drinking, extended speaking time on mobile phones was found to be a risk factor for the decline in sperm concentrations (Zhang et al., 2016). Apart from cross-sectional surveys, new ways of exploring the effects of mobile phone use on male health should also be encouraged. For example, Volkow et al. used positron emission tomography scanning technology to detect brain function changes in humans when talking on mobile phones, and they found that 50 min mobile phone exposure was associated with increased brain glucose metabolism in the region closest to the antenna (Volkow et al., 2011).

4.2. Human sperm in vitro studies

The pooled results of human sperm *in vitro* studies showed that mobile phone RF-EMR can affect mature sperm *in vitro*, leading to a decline in sperm motility and viability. These results suggest that when performing *in vitro* sperm manipulation in reproductive medicine, researchers should be attentive to the harmful effects of EMR including mobile phone RF-EMR. However, present evidence may not directly support that carrying mobile phones in trouser pockets adversely affects sperm quality in men, resulting in a decline in male fertility. The reason is that mature sperm are stored within the human body where they are shielded by several tissues such as the scrotal wall and the epididymal wall, and are protected by semen components. After passing through these tissue walls, the intensity of RF-EMR may have decreased sufficiently to not affect mature sperm.

The total number of studies included in the sperm DFI analysis was small, and heterogeneity of the results was large. For this reason, even though the pooled results suggested that mobile phone radiation did not affect sperm DFI *in vitro*, further studies are required to support this conclusion.

4.3. Animal studies

Over the past six years, the total number of animal studies on the effects of mobile phone RF-EMR on sperm function has significantly increased. Based on the pooled results, mobile phone RF-EMR suppresses sperm motility and viability in rats and decreases sperm density in mice. For the first time, our subgroup analysis suggested decreased heterogeneity of the pooled results of rats which were restrained during radiation exposure, which may be attributed to the fact that restrained rats received more consistent RF-EMR at larger doses than non-restrained rats. Further analyses showed that sperm density of restrained rats decreased significantly, which differed from the conclusions of Liu et al. as their results showed high heterogeneity (Liu et al., 2014).

Rats are sexually mature at 10–12 weeks of age, and environmental pollution can reduce sperm quality in immature or mature rats via different mechanisms (Berndston 1977). Age may also be an important factor affecting the heterogeneity of rat studies, which has been shown in our analysis of sperm density and motility in rats exposed to mobile phone RF-EMR. In addition, the results of the present study indicate that mobile phone RF-EMR causes a significant decrease in sperm density and motility in rats older than 10 weeks, whereas in rats younger than 10 weeks, exposure to mobile phone RF-EMR at an immature stage does not exert such significant effects. These results may be explained by the low energy of mobile phone RF-EMR and the strong recovery ability of immature rats.

Previously, Liu et al. hypothesized that exposure time and radiation devices may be important factors affecting between-study heterogeneity (Liu et al., 2014). The results of our study showed that exposure time contributed to heterogeneity when investigating sperm motility in rats; however, heterogeneity was large in the long-term exposure subgroup, which may be attributed to the considerable differences in exposure time between studies in this subgroup (the shortest and longest exposure durations were 168 h and 1095 h, respectively). Our results also supported the claim that radiation device type is another important factor that affected heterogeneity when investigating sperm density, motility, and morphology in rats. However, some inconsistencies were observed in the results of the respective subgroup analyses. Compared with the mobile phone group, the simulator group was less heterogeneous regarding sperm density and was more heterogeneous regarding motility and morphology. Generally, RF-EMR produced by simulators is theoretically more stable than that produced by mobile phones, thus heterogeneity in the simulator group should be lower. These inconsistencies may be explained by the results of our sensitivity analysis, which showed that the simulator group included the study by Ozlem et al. which significantly increased heterogeneity of the sperm motility analyses; in the morphology analysis, the simulator group included studies by Nisbet et al. and Yahyazadeh and Altunkaynak, which exerted substantial effects on the heterogeneity of pooled studies (Nisbet et al., 2012; Yahyazadeh and Altunkaynak, 2019). Unfortunately, our results cannot explain how these studies increased the heterogeneity of the pooled results.

Current animal studies have mostly investigated reproductive effects of systemic exposure. As male reproductive ability is affected by multiple tissues such as the hypothalamus, pituitary gland, and the testes (Ajayi et al., 2020), researchers only preliminarily explored whether mobile phone RF-EMR affects male fertility via experiments with systemic exposure. However, they could not determine the main reproductive organ through which mobile phone RF-EMR exerts these effects. The National Institute of Toxicology also proposed that investigating the effects of mobile phone RF-EMR on certain organs was important for further clarifying the mechanism of mobile phone RF-EMR exposure on human health when exploring the relationship between mobile phone RF-EMR exposure and cancer (NIEHS 2018). This perspective is also applicable regarding reproductive-toxicity research on mobile phone RF-EMR. Moreover, the development of 5G, smart multi-antenna, and beamforming technology may cause electromagnetic field energy to concentrate in local space, resulting in a locally high electromagnetic field pattern in certain organs. Research investigating local exposure to certain reproductive organs is thus becoming increasingly important and necessary. Lastly, it should be noted that some studies included in this meta-analysis were of low quality, and their research information was incomplete, which may have contributed to the high study heterogeneity and prevented in-depth analysis.

4.4. Personal views

In the present study, we did not perform a subgroup analysis of SAR owing to inconsistencies in the calculation of SAR values of reproductive organs in the reviewed studies. For many years, SAR has been recognized as a key index for evaluating environmental safety of mobile phone RF-EMR (Chen and Wang 1994). However, the current safety threshold of SAR can only reflect the thermal effect of RF-EMR and does not account for non-thermal effects (Gaestel 2010). In addition, the calculation of SAR is based on a fixed value of a human body model and does not consider the actual density, permeability, and dielectric constant of specific organs affecting SAR values (Sallomi 2012). Moreover, SAR measurements are not standardized. According to a previous report (Davis 2010), the SAR value of the same product varies substantially between measurements by different manufacturers. Thus, the current SAR threshold may not be sufficiently safe to protect human health. The academic community should identify other appropriate indices that are more suitable for health evaluation, and interdisciplinary cooperations should be established to redefine the safe threshold of mobile phone RF-EMR dosages.

Mobile phone RF-EMR is a low-energy electromagnetic radiation. The effects of this radiation on reproductive functions have been examined using some macro-indices such as sperm density, motility, and testicular morphology; however, normality of such indices does not necessarily preclude adverse effects of mobile phone RF-EMR on reproductive parameters. Further sperm-related functional and molecular indices (especially at the genetic and epigenetic levels) should be investigated because macroscopic occurrence of a disease is frequently the result of cumulative changes in the microenvironment.

Recently, low-dose toxins were suggested to alter the biological characteristics of cells (Fernandez-Antoran et al., 2019). Based on this, it is reasonable to assume that even though short-term or intermittent mobile phone RF-EMR exposure is not strong enough to damage organs, it may affect biological characteristics of germ cells, resulting in alterations of disease-resistance ability of the male reproductive system or, even more concerning, of offspring health. Therefore, further research is needed to explore this issue in depth.

Even though effects of mobile phone RF-EMR exposure on male fertility have been studied extensively, progress in this field is slow, and respective studies are limited regarding research scope and depth. Further studies revealing the reproductive effects of mobile phone RF-EMR are still of great practical importance because even if mobile phone RF-EMR exerts only minor effects on the human body and causes health problems in only a few permille of users, it may still result in a global medical catastrophe (Falcioni et al., 2018). With the development of model communication technology, the presence of mobile phone RF-EMR in our lives will increase (Eeftens et al., 2018; Havas 2017), and ignoring the problems caused by this radiation may lead to a lack of relevant protective measures and further decline in male fertility.

5. Conclusion

The results of our meta-analysis indicated that in East Europe and West Asia, mobile phone use is associated with a decline in human sperm density and motility. Mobile phone RF-EMR can reduce motility and viability of mature human sperm *in vitro*, and it can also reduce sperm motility and viability in male animals and decrease sperm density of sexually mature restrained rats. Some important factors that affect the results of animal experiments are study setup and radiation device as well as age and exposure time. Our study is an extension of previous studies and has scientific value for future studies on effects of mobile phone RF-EMR associated with sperm quality.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2021.116952.

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Article

The Effect of Continuous Low-Intensity Exposure to Electromagnetic Fields from Radio Base Stations to Cancer Mortality in Brazil

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Abstract: Background: this study aims to estimate the rate of death by cancer as a result of Radio Base Station (RBS) radiofrequency exposure, especially for breast, cervix, lung, and esophagus cancers. Methods: we collected information on the number of deaths by cancer, gender, age group, gross domestic product per capita, death year, and the amount of exposure over a lifetime. We investigated all cancer types and some specific types (breast, cervix, lung, and esophagus cancers). Results: in capitals where RBS radiofrequency exposure was higher than 2000/antennas-year, the average mortality rate was 112/100,000 for all cancers. The adjusted analysis showed that, the higher the exposure to RBS radiofrequency, the higher cancer mortality was. The highest adjusted risk was observed for cervix cancer (rate ratio = 2.18). The spatial analysis showed that the highest RBS radiofrequency exposure was observed in a city in southern Brazil that also showed the highest mortality rate for all types of cancer and specifically for lung and breast cancer. Conclusion: the balance of our results indicates that exposure to radiofrequency electromagnetic fields from RBS increases the rate of death for all types of cancer.

Keywords: cancer; mortality; electromagnetic fields; breast neoplasms; lung neoplasms; esophageal neoplasms; uterine cervical neoplasms

1. Background

Mobile phones have become extremely common in modern times. Wireless technology has a large number of Radio Base Stations (RBSs), which transmit information through radiofrequency signals. In 2006, there were already more than 1.4 million RBSs in the world [1]. In the Brazilian capitals, RBSs were implemented in 1992 in Brasília (the capital of Brazil), and in 2017, there were 27,145 RBSs indexed in the capitals [2].

The effect of electromagnetic fields emanating from RBS on health is not very well known. The World Health Organization (WHO) reported, in 2006, that scientific knowledge indicates that RBS radiofrequency exposure is within the international standards and, therefore, does not pose a risk to human health [1]. However, in 2014, the WHO recognized the need to promote research to investigate the effect of the radiofrequency field on human health as a priority in order to fill the knowledge gaps [3]. Several issues relating to new wireless technologies are currently highlighted: the environmental impact of RBS radio frequency exposure, its effects on human health, its thermal effects, and its noise emission [4].

In Brazil, the National Telecommunications Agency (ANATEL) is the entity that regulates the electromagnetic emission of RBSs in accordance with the limits established by Resolution No. 700 of 28 September 2018 (Union Official Diary) [5]. In addition to ANATEL, telecommunication antenna installations are also regulated by municipal laws in order to minimize environmental and human health impacts [4].

Mobile phone-derived electromagnetic fields are classified by the International Agency for Research on Cancer (IARC) as possibly carcinogenic to humans [3,6,7]. The intensity of the RBS radiofrequency fields is higher near the antenna and decreases as the distance from it is greater [1,8]. In big cities, however, RBSs are located very close to populated areas, above or between homes and businesses. The antennas are so close to homes that the multi-story windows of residential buildings, for example, are side by side to these antennas [9].

Despite the scarce knowledge on this subject, there are few resources allocated to investigating the role of exposure to electromagnetic fields from RBSs on human health. In the United States, for example, until 2010, no funding had been reserved by government agencies to study the possible health effects on people living near RBSs [9]. This study aims to estimate the rate of death for cancer according to RBS radiofrequency exposure, especially by breast, cervix, lung, and esophagus cancers, which are among the most common cancers in Brazil for men, women, or both sexes.

2. Methods

This is an ecological study using capitals as the unit of analysis. We collected information on the number of deaths by cancer per gender, age group, Gross Domestic Product (GDP) per capita, death year, and the amount of exposure over a lifetime.

Information on deaths by cancer per gender and age was collected from the Mortality National System (SIM) from the Computer Science Department of the Unified Health System (DATASUS) website [10]. We investigated all cancer types and some specific types: (1) deaths by breast cancer (International Classification of Diseases 10th Revision (ICD10) group—malignant breast neoplasms), (2) deaths by cervix cancer (C54 category of ICD10—malignant neoplasm of the cervix), (3) deaths by lung cancer (C34 category of ICD10—malignant neoplasms of the bronchi and lungs), and (4) deaths by esophageal cancer (C15 category of ICD10—malignant neoplasm of the esophagus). The choice of these specific types of cancer for this study took into account the high frequency of new cases in women or in men. Current statistics from 2020 from the National Cancer Institute show that breast cancer had the highest number of new cases in 2020 for women (about 66,000 cases, corresponding to about 30% of cases). Cervical cancer was the third, with more new cases in 2020 in women. Lung cancer was the fourth with more new cases in 2020 in men and women, and esophageal cancer was the sixth with more new cases in men. With regard to mortality, data from 2018 indicate that the cancers selected for this study are among the top five in number of deaths. These values refer to both genders for lung cancer, to female strata for breast and cervical cancers, and to the male stratum for esophageal cancer [11]. Although brain cancer does not have a high frequency in Brazil and metastatic brain tumors are more frequent than primary brain tumors, as several studies have evaluated their relationship with exposure to electromagnetic fields, we have included the results of the analysis of this type of cancer in Supplementary Tables S1 and S2.

Census population data [12] and GDP were also collected from the DATASUS website [10]. The number of RBSs and the year they were implemented in each capital were collected from Telecommunication Service System [2].

People's exposure times were calculated according to birth and death years. The annual RBS radiofrequency exposure was calculated by summing the number of RBS implementations in each year multiplied by the people's exposure time. The total exposure was calculated from the sum of annual exposures.

A map with charts was built using the mortality rate per square kilometer (km^2) and the median of RBS radiofrequency exposure in the 2010–2017 period.

3. Statistical Analysis

We calculated the median and interquartile range of mortality rate per 100,000 according to the levels of explanatory variables. The Kruskal–Wallis test was used to access the statistical differences between groups.

Multilevel Poisson regression models were used to estimate the risk-adjusted mortality. The response variable was death by cancer, and the fixed effects were the logarithm transformation of RBS radiofrequency exposure, gender, age group, and death year. We also included an offset with the logarithm of population size. The random effects included capital city (intercept), square root transformation of GDP (slope), and capital's area per km^2 (slope). When the response variables were death by breast and cervix cancer, the gender was not included as a fixed effect, as only females were investigated.

The abovementioned logarithmic transformations and the square root transformation were used to normalize the distribution of variables. We used R-Project version 3.6.1 (R Foundation, Vienna, Austria) and ArcGis version 10.5 (Environmental Systems Research Institute, Redlands, CA, USA) to perform the analysis.

4. Results

For all cancers and for the specific types investigated (breast, cervix, lung, and esophagus cancers), the higher the exposure to RBS radiofrequency, the higher the median of mortality rate. In capitals where RBS radiofrequency exposure was higher than 2000/antennas-year, the median of the breast cancer mortality rate was 27.33/100,000, while for all cancers, it was 111.68/100,000 (Table 1).

Table 1. Descriptive analysis of cancer mortality in Brazilian capitals.

	Breast	Cervix	Lung	Esophagus	All Cancers
	Median/10^5 (IQR)	**Median/10^5 (IQR)**	**Median/10^5 (IQR)**	**Median/10^5 (IQR)**	**Median/10^5 (IQR)**
RBS-sign	*	*	*	*	*
≤500	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	7.30 (44.94)
501–1000	1.16 (27.11)	2.74 (26.30)	0.00 (38.97)	0.00 (0.00)	26.32 (382.14)
1001–2000	20.12 (54.53)	7.38 (25.79)	4.47 (63.42)	0.00 (8.74)	71.95 (500.43)
>2000	27.33 (63.06)	9.56 (16.43)	9.58 (76.46)	1.62 (14.21)	111.68 (552.78)
Sex-sign			*	*	*
Female			3.77 (46.88)	0.00 (3.17)	75.31 (360.87)
Male			4.31 (98.82)	0.45 (22.06)	56.49 (540.97)
Age group-sign	*	*	*	*	*
<30	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.75 (4.53)
30–49	9.89 (13.56)	6.75 (7.31)	1.81 (4.39)	0.00 (1.13)	38.59 (44.90)
50–69	43.43 (20.19)	15.02 (14.71)	34.08 (42.50)	6.75 (16.28)	258.79 (240.76)
≥60	91.18 (64.51)	27.35 (37.02)	159.40 (159.63)	20.31 (39.68)	1178.11 (1012.72)
Year-sign	NS	NS	NS	NS	NS
2010–2011	16.95 (52.66)	6.29 (19.36)	4.44 (64.91)	0.00 (8.87)	68.76 (508.70)
2012–2013	15.98 (56.94)	6.42 (19.09)	4.13 (66.30)	0.00 (10.29)	65.09 (501.19)
2014–2015	17.36 (56.05)	8.29 (19.52)	4.13 (65.15)	0.00 (9.54)	65.56 (491.10)
2016–2017	18.01 (52.08)	7.62 (16.66)	3.54 (65.52)	0.00 (8.22)	61.87 (444.41)

RBS = exposure to radio base stations (antennas-year); IQR = interquartile range; sign = statistical significance − significance. * p-value < 0.001 and NS, p-value > 0.05.

Females showed the highest median of mortality rate for all cancers but specifically for lung and esophagus cancers; the highest median of mortality rate was observed in males (4.31/100,000 and 0.45/100,000, respectively) (Table 1).

For all cancers and for the specific types investigated, the higher the age group, the higher the median of mortality rate. Lung and breast cancers showed high medians of mortality rate (159.40/100,000 and 91.18/100,000, respectively) (Table 1).

The median of mortality rate for all types of cancer decreased from 68.76/100,000 to 61.87/100,000 over the period. For breast, cervix, lung, and esophagus cancers, it showed slight variations over the period, around 17/100,000, 7/100,000, 4/100,000, and lower than one per 100,000, respectively (Table 1).

In the adjusted analysis, the results showed that the higher the logarithm of RBS radiofrequency exposure, the higher the cancer mortality rate. The highest adjusted risk was observed for cervix cancer (Rate Ratio (RR) = 2.18) (Table 2).

Table 2. Adjusted risk of cancer mortality in Brazilian capitals.

	Breast		**Cervix**		**Lung**		**Esophagus**		**All Cancers**	
	RR	**Sign**	**RR**	**Sign**	**RR**	**Sign**	**RR**	**Sign**	**RR**	**Sign**
Fixed effects										
Log RBS	1.25	***	2.18	***	1.14	***	1.18	**	1.15	***
Sex										
Female					1.00		1.00		1.00	
Male					1.97	***	4.88	***	1.42	***
Age group										
<30	1.00		1.00		1.00		1.00		1.00	
30–49	37.59	***	13.82	***	20.11	***	73.84	***	6.06	***
50–69	132.29	***	30.74	***	323.80	***	876.50	***	40.73	***
≥60	297.55	***	53.88	***	1250.63	***	2154.44	***	164.61	***
Year										
2010–2011	1.00		1.00		1.00		0.00		1.00	
2012–2013	0.97	NS	0.78	***	0.97	NS	0.96	NS	0.98	*
2014–2015	0.96	NS	0.62	***	0.93	**	0.88	***	0.95	***
2016–2017	0.81	**	0.46	***	0.84	***	0.76	***	0.84	***
Random effects										
	Std Dev				Std Dev		Std Dev		Std Dev	
Capital (intercept)	0.61	***	1.55	***	0.19	***	0.86	***	0.28	***
Sqrt GDP (slope)	0.00	***	0.01	***	0.00	***	0.00	***	0.00	***
Area/Km^2 (slope)	0.00	NS	0.00	NS	0.00	NS	0.00	*	0.00	NS
Deviance	12274		8345		24732		10364		100918	

Sqrt GDP = square root transformation of gross domestic product per capita; RR = rate ratio; Std Dev = standard deviation; Log RBS = logarithm transformation of radio base station radiofrequency exposure (RBS radiofrequency exposure = sum of the number of RBS in each year multiplied by the exposure time); sign = statistical significance − significance. *** p-value < 0.001; ** p-value < 0.01; * p-value < 0.05; and NS, p-value > 0.05.

A multilevel Poisson model was used to estimate the risk of cancer mortality. Except for breast and cervix cancers, which were estimated only for women, every adjusted models included as fixed effects the variables sex, logarithm of RBS, age group, and death year. The variables included as random effects were capital (intercept), GDP (slope), and area/Km^2 (slope). The offset of the population was also included in the models.

Males showed the highest adjusted risk of lung, esophagus, and all types of cancer (Table 2), although the median of mortality rate for all cancers was higher for females in the bivariate analysis (the results are shown in Table 1).

As expected, there was an increasing trend in the adjusted risk of cancer mortality in the older the age group. Compared to people younger than 30 years old, the adjusted risks were 297.55, 53.88, 1250.63, 2154.44, and 164.61 for breast, cervix, lung, esophagus cancer, and all cancers, respectively (Table 2).

For cervix cancer and all types of cancers, there was a decreasing trend in the adjusted risk of cancer mortality for more recent periods. For lung and esophagus cancers, this trend is observed from 2014–2015 period (Table 2).

The inclusion of random effects was significant in every models for the following effects: “capital” (intercept) and “square root of GDP” (slope). However, for the “area of the capital” (slope), it was significant only for esophagus cancer. For all models, the greatest standard deviation of random effects was observed for the “capital” (intercept) (Table 2).

The spatial descriptive analysis showed that the highest median of RBS radiofrequency exposure was observed in Florianópolis (South of Brazil) (44.23 antennas-year/km^2). Florianópolis also has the highest mortality rate per km^2 for all types of cancer and specifically for lung and breast cancer (0.09/100,000, 0.31/100,000, and 0.93/100,000, respectively). Recife (Northeast) and Belo Horizonte (Southeast) showed medians of RBS radiofrequency exposure higher than 20 antennas-year/km^2, and their mortality rates per km^2 for all cancers were 0.29/100,000 and 0.19/100,000, respectively. Vitoria (Southeast), Teresina, Fortaleza, Natal, and Aracaju (both in Northeast) showed medians of RBS radiofrequency exposure higher than 10 antennas-year/km^2, and mortality rate per km^2 for all types of cancer were 0.60/100,000, 0.49/100,000, 0.21/100,000, 0.35/100,000, and 0.38/100,000, respectively (Figure 1).

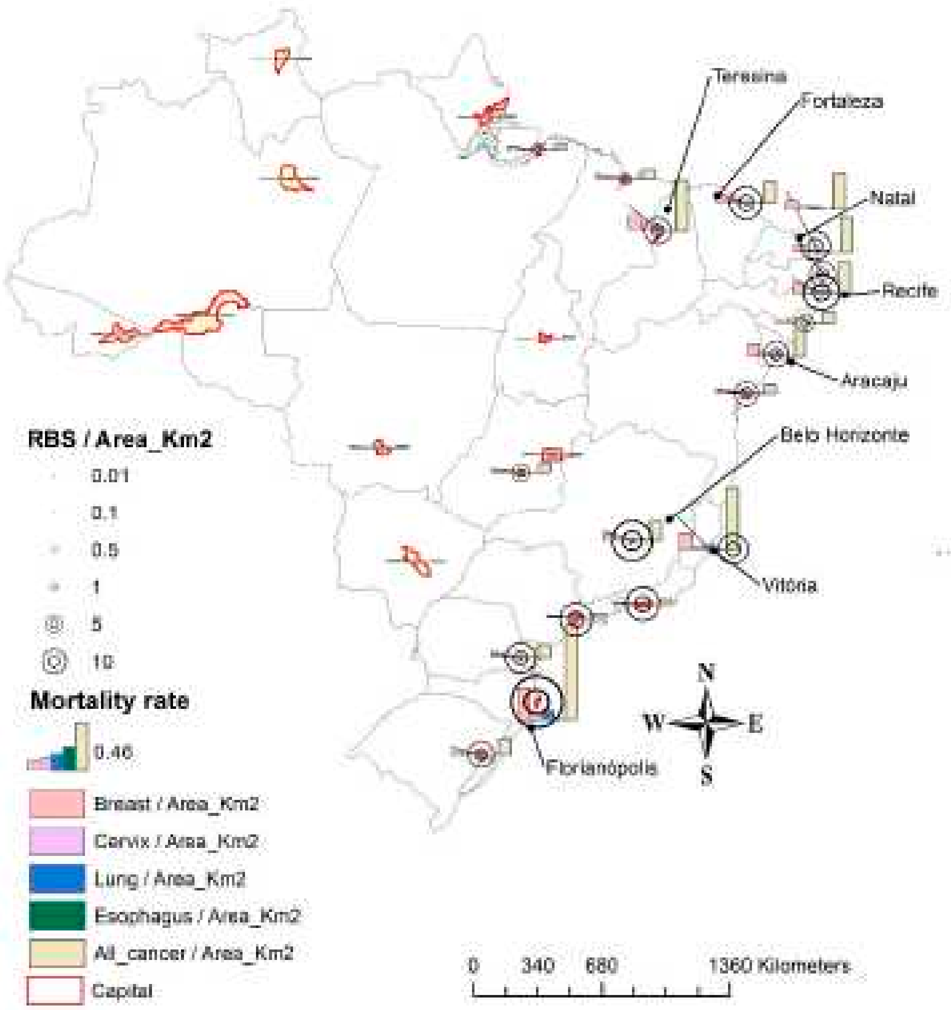

Figure 1. Distribution of the cancer mortality rate in each capital and their experience of exposure to radio base stations radiofrequency, 2010–2017. RBS = median of the number of radio base station radiofrequency exposure (RBS radiofrequency exposure = sum of the number of RBS in each year multiplied by the exposure time). RBS/Area_Km2 = median of the number of RBS per Km^2. We used the median of mortality rate. Breast/Area_K2, Cervix/Area_K2, Lung/Area_K2, or Esophagus/Area_K2 = median mortality rate for a specific cancer type per Km^2.

Figure 1. Distribution of the cancer mortality rate in each capital and their experience of exposure to radio base stations radiofrequency, 2010–2017. RBS = median of the number of radio base station radiofrequency exposure (RBS radiofrequency exposure = sum of the number of RBS in each year multiplied by the exposure time). RBS/Area_Km2 = median of the number of RBS per Km^2. We used the median of mortality rate. Breast/Area_K2, Cervix/Area_K2, Lung/Area_K2, or Esophagus/Area_K2 = median mortality rate for a specific cancer type per Km^2.

5. Discussion

The biological effects of exposure to electromagnetic fields were investigated in some

5. Discussion

The biological effects of exposure to electromagnetic fields were investigated in some studies, mainly experimental studies with mice. The authors point out the following effects: an increase in the calcium efflux in human neuroblastoma cells, impairing cellular functions [13]; changes in the immune system [14]; a decrease in reproductive function [15]; an increase in serum testosterone levels [16]; an increase in permeability of the blood–brain barrier, which protects the brain from toxic substances, bacteria, and viruses [17]; and damage to cell DNA [18–20].

The evidence of radiofrequency radiation carcinogenesis has increased since 2011. Some animal studies suggest that exposure to electromagnetic fields accelerate the development of sarcoma colonies in the lung, mammary tumors, skin tumors, hepatomas, and sarcomas [21,22]. This study detected an increase in the rate of death by cancer in capitals where there is a greater exposure to electromagnetic fields emanating from radio base stations. Studies made in Stockholm (Sweden) indicate that high levels of environmental radiofrequency radiation are quite present in residential and commercial areas [23–25]. In the United Kingdom, at the beginning of 2009, there were 51,300 RBSs and two thirds were installed in existing buildings or other structures [9].

Dode et al., 2011, pointed that electromagnetic fields from telecommunication systems is an important environmental problem nowadays [8]. The authors detected 6724 deaths by neoplasia occurring within an area of 500 m from the RBS and 320 deaths within an area between 500 and 1000 m. The mortality rate within an area of 500 m was 34.76 per 10,000 inhabitants, while within an area of 1.000 m, the rate was 32.78 [8].

Although in the present study, we investigate all cancers, we also investigated breast, cervix, lung, and esophagus cancers separately. In a mortality study performed in Brazil, breast and lung cancers were among the main cancers related to radiofrequency electromagnetic fields from RBS radiofrequency exposure [8].

Breast and cervix cancer have cure rates of around 95% when diagnosed early [26]. Mortality from breast cancer continues to increase in Brazilian capitals, while mortality from cervical cancer remains stable, unlike what occurs in developed countries, in which mortality for these cancers is decreasing. Lung cancer has less chances to be cured when detected in the early stages (56%) [26]. Esophageal cancer is difficult to detect early. In most cases, the signs and symptoms only appear in more advanced stages of the disease [26].

Despite the advance in knowledge about cancer, not all countries seem to benefit from this advance. This is the case of low- and middle-income countries, where a significant portion of the population does not have access to diagnosis and treatment, decreasing their chances of survival.

In the present study, we detected that the higher the exposure to radiofrequency electromagnetic fields from RBSs, the higher cancer mortality is. A study conducted in Israel also found that low-frequency electromagnetic fields contribute to breast cancer development [27–29]. Others studies also referred to the relationship between cancer and radiofrequency electromagnetic fields [30,31], including in animal studies [32].

In addition to exposures to radiofrequency electromagnetic fields, we have to consider other factors that contribute to the increase in cancer incidence and mortality. In Brazil, about 70% of the population depends on public health [33], and there are difficulties accessing cancer diagnosis and treatment in public health services. Opportunistic screening is still adopted, performed only when the patient in the risk group comes to the health service and there is difficulty starting cancer treatment within 60 days, as required by Brazilian law [34]. The consequences of these problems are the worsening of the disease and the high number of preventable deaths.

The main risk factor for lung cancer is tobacco consumption, which is higher for males [35]. Tobacco consumption has been decreasing gradually in Brazil from 1980 to 2013 [36], and this decline may have contributed in some way to reducing lung cancer mortality in men over time [37]. The main risk factors for esophageal cancer are the high intake of hot drinks [38], alcoholic beverages, and tobacco; low ingestion of fruit and vegetable; and exposure to occupational agents like benzene, silica, and asbestos [39]. Family history is one of the most important breast cancer risk factors [40]. However, there are many other risk factors, such as aging, genetic mutations, reproductive history, dense breasts, past history of breast disease, previous treatment with radiotherapy, sedentary lifestyle, overweight or obesity after menopause, alcohol intake, and use of hormones and some oral contraceptives [41]. Cervix cancer risk factors are associated with the risk of Human Papillomavirus (HPV) infection. A high number of pregnancies and no regular preventive colpocytology are pointed out as risk factors to cervix cancer [42].

In the present study, a capital located in the south showed the highest RBS radiofrequency exposure and the highest mortality by cancer (Florianópolis). In fact, other studies have also reported high rates of cancer in this capital [43–47].

Our results showed that, in general, men had a higher mortality rate of esophageal and lung cancer and that this rate increases with age. In fact, the scientific literature corroborates these results [48–52].

In order to keep the cellular sets running, the radiofrequency transmitters installed on the tops, roofs, and façades of buildings and residences emit electrical and magnetic fields 24 h a day. However, it is known by scientific knowledge that the nonthermal magnetic component can penetrate deeper into the body than the electrical one [53].

A person can stand at a fixed distance to an RBS and be exposed to 100% of the maximum permissible exposure or 5% of it depending on the antenna height and the bystander altitude. Therefore, people living in the upper floors of a building located in front of the antennas receive radiofrequency corresponding to 100% of the maximum permissible exposure [54]. Those data were confirmed in the Post-Graduation Project conducted at the Federal University of Minas Gerais (UFMG), Brazil, based on measures made in the capital of the state inside 400 residences located near the RBS from 2015 to 2019, measurements made by “MRE Engenharia—Medição de Radiações Eletromagnéticas” [55].

The measured values of the electrical and magnetic fields have shown more human exposure to electromagnetic radiation in an area within a 500 m radius from the transmitter antennas of cellular telephony [8]. To avoid hazards to human health, the safest solution would be to switch off the RBS in an area within a 500 m radius from residences, workplaces, hospital areas, kindergartens, and buildings.

As a limitation, it is important to note that this study used cancer data from national Brazilian sources, which can provide underestimated rates at different levels according to the region. For example, a study conducted in northern Brazil found a large proportion of deaths classified as unspecified uterine cancer. After the proportional redistribution of these deaths, there was an increase of 46% in the average cervical cancer mortality rates [56]. Another study conducted in a northeastern region of Brazil highlights that, within the older age group, the number of deaths before and after correction showed a significant variation, especially for breast cancer, where variation reached 54% [57].

Still as limitations of the study, we highlight two more points. As this is an ecological study and due to the unavailability of individual dwelling time data, the time that each individual lived close to an RBS could not be accessed. The possible migratory movements could also not be considered for calculation of the amount of exposure to RBS radio frequency throughout life in the resident population. This was calculated only according to birth, death year, and the year in which the RBS was implemented. However, people could have been born in another city and then migrated to the capital where the death was recorded. The other point is the proximity of stations to places of residence that interfere with the level of exposure of individuals. As it is an ecological study in which the unit of analysis is the capital, this study did not take into account the distances between stations and homes.

6. Conclusions

The balance of our results indicates that the exposure to radiofrequency electromagnetic fields from an RBS increases the rate of mortality by all cancers and specifically by breast, cervix, lung, and esophageal cancers. These conclusions are based on the fact that the findings of this study indicate that, the higher the RBS radiofrequency exposure, the higher the cancer mortality rate, especially for cervix cancer (adjust RR = 2.18). The spatial analysis showed that the highest RBS radiofrequency exposure was observed in a city located in the southern region of Brazil, which also showed the highest mortality rate for all types of cancer and specifically for lung and breast cancers.

Environmental pollution caused by nonionizing electromagnetic fields increases continuously. The location of RBSs is still a controversial field with regard to their regulation. There are numerous RBSs installed in residential areas, including on their roofs. Some epidemiological studies indicate an increased risk of cancer close to RBSs. It is important that further epidemiological investigations are conducted to elucidate the role of the environment in radiofrequency signals on carcinogenesis processes.

Supplementary Materials: The following are available online at https://www.mdpi.com/1660-4601/18/3/1229/s1, Table S1: Descriptive analysis of brain cancer mortality in Brazilian capitals, Table S2: Adjusted risk of brain cancer mortality in Brazilian capitals.

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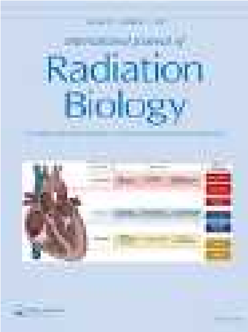

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REVIEW

Threshold of radiofrequency electromagnetic field effect on human brain

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ABSTRACT

Purpose: This review aims to estimate the threshold of radiofrequency electromagnetic field (RF EMF) effects on human brain based on analyses of published research results. To clarify the threshold of the RF EMF effects, two approaches have been applied: (1) the analyses of restrictions in sensitivity for different steps of the physical model of low-level RF EMF mechanism and (2) the analyses of experimental data to clarify the dependence of the RF EMF effect on exposure level based on the results of published original neurophysiological and behavioral human studies for 15 years 2007–2021.

Conclusions: The analyses of the physical model of nonthermal mechanisms of RF EMF effect leads to conclusion that no principal threshold of the effect can be determined. According to the review of experimental data, the rate of detected RF EMF effects is 76.7% in resting EEG studies, 41.7% in sleep EEG and 38.5% in behavioral studies. The changes in EEG probably appear earlier than alterations in behavior become evident. The lowest level of RF EMF at which the effect in EEG was detected is 2.45 V/m (SAR = 0.003 W/kg). There is a preliminary indication that the dependence of the effect on the level of exposure follows rather field strength than SAR alterations. However, no sufficient data are available for clarifying linearity-nonlinearity of the dependence of effect on the level of RF EMF. The finding that only part of people are sensitive to RF EMF exposure can be related to immunity to radiation or hypersensitivity. The changes in EEG caused by RF EMF appeared similar in the majority of analyzed studies and similar to these in depression. The possible causal relationship between RF EMF effect and depression among young people is highly important problem.

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Introduction

The world population has been exposed to man-made coherent electromagnetic radiation, different from the natural radiation emitted by the Sun, over a very long period of time without remarkable effects on health. The people are adapted to the level of radio and TV broadcasting radiofrequency electromagnetic field (RF EMF) about 0.1 V/m. During recent decades, the applications of mobile telecommunication technology have drastically changed the situation. The sources of RF EMF have moved closer to people and the levels of exposure are much higher. The current guidelines recommend health protection limits up to 61 V/m (ICNIRP 2020). Hundreds of studies have detected biological RF EMF effects in humans, animals and cells at the levels of exposure much less than existing health protection limits. According to the Ericsson Mobility Report, the number of mobile subscriptions by technology is over eight billion in 2020 (Ericsson Mobility Report 2020). This number is higher than the world population. The wide applications of RF EMF rise concern about possible consequences on health.

The increased oxidative stress caused by RF EMF exposure has been reported in many animal and cellular studies (Schuermann and Mevissen 2021). The relevant consequences on health (genome stability, immune system, neurodegeneration, reproduction) are likely. The radiofrequency electromagnetic field was classified as possibly carcinogenic to humans (class 2B) by the International Agency for Research on Cancer (IARC 2013).

The RF EMF effects on brain bioelectrical activity, cognition and behavior, not obligatory related to genome instability, have been a topic of interest over the past decades. The neurophysiological effects on humans have been detected in many experimental studies but the results are controversial (Valentini et al. 2007; Marino and Carruba 2009; Kwon and Hämäläinen 2011). The large variations in applied methods, different frequencies, levels of exposure and modulation parameters cause high diversity of the effects and results. The recent cohort study does not provide sufficient confirmation about the correlation between more extensive use of mobile phones and the reported symptoms nor sleep quality (Auvinen et al. 2019; Tettamanti et al. 2020). It is complicated to determine causal relationship between RF EMF biological effects and its health consequences due to diversity of exposure conditions and numerous concomitant other factors.

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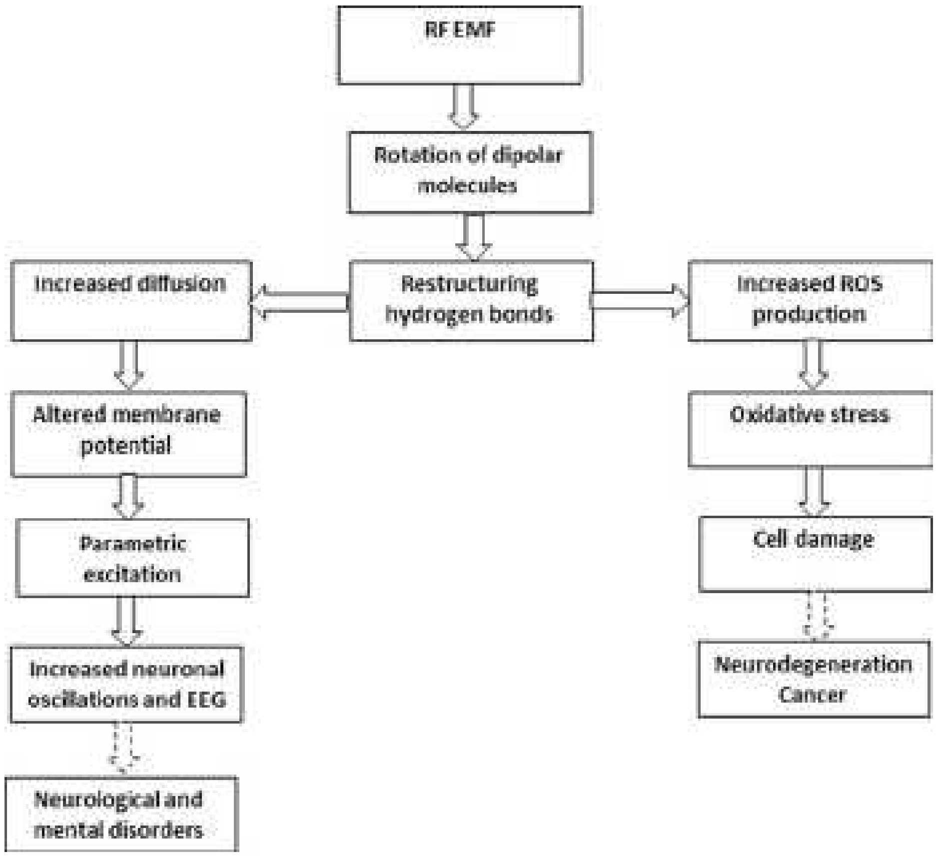

Figure 1. Model of nonthermal mechanisms of low-level RF EMF: left track neurophysiological effect, right track neurodegeneration.

Does the RF EMF has a threshold, lower of which the RF EMF does not have biological effect? This is an important question and crucial to avoid possible consequences on health.

Theoretical estimations for the sensitivity of living cells to electric field provided the threshold values about $10^{-6} - 10^{-7}$ V/m Hz$^{1/2}$ (Weaver and Astumian 1990; Hinrikus et al. 1998). In the case of wide-band telecommunication technology, the threshold rises: at 1 MHz bandwidth, the sensitivity is $10^{-3} - 10^{-4}$ V/m. However, these estimations used a simple single-cell model. Realistic model involving combinations of different cells, molecules and partly nonlinear physiological processes is highly complex. To the best of our knowledge, the calculations using complex model have been not performed.

To clarify the threshold of RF EMF effects, two approaches are applied in the current review: (1) the analyses of restrictions in sensitivity for different steps of the physical model of low-level RF EMF mechanism and (2) the analyses of experimental data to clarify the dependence of the effect on exposure level.

Analyses of different steps of the physical model of low-level RF EMF mechanism

The RF EMF is a physical stressor. Electric forces keep together atoms and molecules. The coherent RF EMF, due to regular synchronous electrical forces, causes stronger cumulative impact in a medium compared to random thermal processes (Hinrikus et al. 2018). Therefore, a nonthermal physical model based on electrical phenomena (Hinrikus et al. 2018) has been selected as a base for estimations. Figure 1 presents the logical structure of the mechanisms of the model. The low-level RF EMF approach, without heating, is appropriate in considering threshold of the effect.

Origin of the effect

The RF EMF causes displacement of free and bound charges in a dielectric medium and dielectric polarization of the medium. Displacement of electrons or ions inside a molecule leads to electronic or molecular, rotation of dipolar molecules to orientational polarization (King and Smith 1981). The intermolecular and even intramolecular electrical fields are much stronger than the applied RF EMF. Therefore, the imbalances in the spatial distribution of charges created by a RF EMF are very small. The synchronization of the displacements in a very large number of molecules leads to the measureable dielectric permittivity of materials (Zahn 2003).

Whereas the intramolecular electric forces are weaker than intermolecular forces, the orientational polarization dominates. Traditionally, the rotation of dipolar molecules caused by high-level RF EMF is considered as the origin of RF EMF thermal effect. However, the measureable electric permittivity exists also in low-level RF EMF and, consequently, the rotation of dipolar molecules takes place in low-level RF EMF at constant temperature. The synchronous cumulative impact of coherent RF electric field makes possible the low-level field-induced effect despite the energy of RF EMF is lower thermal energy causing random displacements (Hinrikus et al. 2018).

The polarization in dielectrics and water as well as dielectric parameters of tissues have been investigated in many studies (Hasted 1973; Pethig 1979; Mudgett 1985; Foster and Schwan 1995; Gabriel, Gabriel, et al. 1996; Gabriel, Lau, et al. 1996). The relaxation time of orientational polarization decreases with temperature due to increasing number of collisions disturbing the rotation. Therefore, the orientational polarization of tissues decreases with temperature (Pethig 1979).

Orientational polarization depends on the frequency and decreases with frequency due to inertia of molecules. Experimental data indicate that the dielectric constant has the frequency independent value of 1.8 at frequencies close to 100 GHz where the dielectric constant is determined only by the molecular polarization (Hasted 1973).

No theoretical nor experimental data about the threshold of polarization are available. In a linear medium, dielectric constant most probably is constant and does not depend on the level of EMF. The linearity of the response of living tissues to electromagnetic forces can be presumed at low level of EMF. Therefore, the rotation of dipolar molecules has no a determined threshold.

The synchronous rotation of dipolar molecules presumes unavoidable restructuring and weakening of hydrogen bonds between these molecules (Hinrikus et al. 2018). Hydrogen bonds are responsible for the properties of water and for holding together the DNA double helix. Hydrogen bonds are being constantly broken and reformed in liquid water because of random thermal motion of molecules despite the bonding energy is higher kT (Petrucci et al. 2007). The induced by low-level microwave radiation alterations in the properties of water demonstrate restructuring of hydrogen bonds by RF EMF (Fesenko and Gluvstein 1995). Consequently, kT does not determine the threshold of the phenomenon. There are no data about the threshold of restructuring the intramolecular bonds.

Neurophysiological effect

The left tract in Figure 1 presents the model of neurophysiological RF EMF effect that presumes no oxidative stress nor cellular damage.

Hydrogen bonds are responsible for many of the properties of water including viscosity. Weakening of hydrogen bonds decreases viscosity and increases diffusion. The caused by RF EMF increase in diffusion at constant temperature has been demonstrated by experiments in water and supported by the results of in vitro study (Hinrikus et al. 2015; Aly et al. 2008). Diffusion plays crucial role in many physiological processes including neuronal membrane potential and transfer of neurotransmitters in synapses. There are no factors nor data determining the threshold of the effect on diffusion.

Alterations in diffusion cause change in resting neuronal potential and misbalance of membrane currents (Malmivuo and Plonsey 1995; Hinrikus et al. 2017). No factors causing the threshold of membrane potential change have been reported (Malmivuo and Plonsey 1995).

The modulation of RF EMF at low frequencies close to the brain physiological frequencies is important and determines the intensity of the effect (Sanders et al. 1985; Hinrikus, Bachmann, Lass, Tomson, et al. 2008; Hinrikus, Bachmann, Lass, Karai, et al. 2008; Juutilainen et al. 2011). Low-level pulse-modulated RF EMF causes periodic alterations in neuronal electric parameters.

Periodic alterations of neuronal parameters can lead to parametric excitation of neuronal oscillations at predetermined electroencephalographic (EEG) frequencies (Hinrikus, Bachmann, Karai, et al. 2011). The process of excitation of parametric oscillation in a system has a threshold determined by the damping factor and losses in the system (Tso and Caughey 1965; Butikov 2004). However, biochemical energy compensates the losses in neuronal oscillations in brain. Therefore, the lower limit of parametric excitation is not defined. Disturbances in brain bioelectrical activity probably lead to alterations in cognition and behavior.

The brain's defense mechanisms can easily compensate the mild alterations caused by RF EMF (Bachmann, Tomson, et al. 2007). The fast compensation has been demonstrated in the experiments with RF EMF one minute ON-OFF pulse modulation: the effect has appeared statistically significant during first 30 s of ON-pulse but not significant during second 30 s (Hinrikus, Bachmann, Lass, Tomson, et al. 2008). However, in the case of continuous long-term exposure in RF EMF environment, the effect becomes permanent and consequences on health are possible.

Neurodegeneration

The right tract in Figure 1 presents the possible biological model of RF EMF effect that presumes oxidative stress and cellular damage.

The experimental results have demonstrated low-level RF EMF induced increase in the level of reactive oxygen species (ROS) (Xing et al. 2016; Marjanovic Cermak et al. 2018). The RF magnetic fields have been shown to affect the concentrations of ROS via the radical pair mechanism (Usselman et al. 2014; Castello et al. 2014; Barnes and Greenebaum 2015). The low-level RF EMF caused oxidative stress has been reported in many animal and cellular studies (Schuermann and Mevissen 2021). Oxidative stress can lead to cell damage. Further consequences in health including genome instability, neurodegeneration, immune system, male and female reproduction system are possible (Schuermann and Mevissen 2021).

Whereas body's defense mechanisms can repair the temporal changes in ROS formation process in brain cells, the health effect does not necessarily become evident. However, the probability that the defense mechanism can repair the changes caused by permanent exposure by RF EMF is much smaller.

The analyses of both models indicated no data about the factors determining the threshold of low-level RF EMF effect. The radiological protection system in low-level ionizing radiation still bases also on 'linear, no threshold' model, which assumes that there is no dose so small that it has no effect (McLean 2017).

Analyses of experimental data

Search of studies

The current review analyses the results of published original RF EMF human studies for 15 years 2007–2021. The EMF portal database was used for searching of publications. The filters: radio frequency, mobile communication, experimental studies and keywords: EEG, cognition, behavior were used for selection. Further individual evaluation excluded animal and in vitro studies. The quality of all studies was evaluated and the studies with drawbacks in used methods (insufficient data about exposure, limited numbers of subjects, incorrect statistics) were excluded. Finally, 76 relevant studies were included for the analyses.

RF EMF effects

Table 1 summarizes the RF EMF effects reported in the selected publications. The results are presented according to the formulations used by the authors. Unfortunately, the majority of studies do not report quantitative information about the effect – the numerical values of the analyzed parameters (e.g. values of changes in the powers of EEG rhythms or other parameters).

The effects are divided into four categories: changes in resting electroencephalography (EEG), in sleep EEG and sleep quality, in event-related potentials (ERP) plus cognition-behavior and others (changes in cortex oxygenation and brain glucose metabolism). Figure 2 presents the distribution of studies according to these categories. The resting EEG constitutes the largest part 47% of the total studies. The resting eyes closed EEG is most thoroughly investigated. The part of studies in sleep EEG and sleep quality constitutes 15%. The part of event-related potentials (ERP) connected to cognition and behavior effects constitutes 34% of total findings and the part of others only 4%.

Figure 3 presents the rate of studies, which revealed RF EMF effect in different categories. The relative part of

Table 1. Distribution of studies according to the reported RF EMF effects in different categories.

Resting EEG	
Increased theta	Bardasano et al. 2007
Increased alpha	Bardasano et al. 2007; Regel, Tinguely, et al. 2007; Vecchio et al. 2007; Krause et al. 2007; Hinrikus, Bachmann, Lass, Tomson, et al. 2008; Hinrikus et al. 2009; Hinrikus et al. 2011; Croft et al. 2008; Croft et al. 2010; Suhhova et al. 2013; Roggeveen, van Os, Viechtbauer, et al. 2015; Ghosn et al. 2015; Hinrikus et al. 2017; Loughran et al. 2019
Decreased alpha	Yang et al. 2017; Vecsei et al. 2018
Increased beta	Bachmann, Tomson, et al. 2007; Hinrikus, Bachmann, Lass, Karai, et al. 2008; Hinrikus et al. 2011; Suhhova et al. 2013; Roggeveen, van Os, Lousberg, et al. 2015; Hinrikus et al. 2017
Decreased beta	Yang, et al. 2017
Increased gamma	Hinrikus et al. 2009; Roggeveen, van Os, Lousberg, et al. 2015; Curcio et al. 2015
Increased complexity	Bachmann, Tomson, et al. 2007 (LDLVP); Vecchio et al. 2010 (coherence); Hinrikus, Bachmann, Karai, et al. 2011 (HFD)
No effect	Kleinlogel et al. 2008a; Loughran et al. 2013; Zentai et al. 2015; Eggert et al. 2015; Trunk et al. 2015, 2013; Nakatani-Enomoto et al. 2020
Sleep EEG and sleep quality	
Increased spindles 11-12 Hz	Schmid, Murbach et al. 2012; Lowden et al. 2019
Increased delta and theta	Lustenberger et al. 2015
Increased slow-wave activity 0.75-4.5 Hz, redused motor task	Lustenberger et al. 2013
Increased delta, theta, alpha	Schmid, Loughran et al. 2012
No effect	Regel, Gottselig et al. 2007; Fritzer et al. 2007; Leitgeb et al. 2008; Nakatani-Enomoto et al. 2013; Danker-Hopfe et al. 2011, 2010, 2020
Event related potential (ERP), cognition and behavior	
Improved memory and motor tasks	Meo et al. 2019
Visual ERP, increased P1 amplitude and N1 latency	Dalecki et al. 2018
Reduced reaction time	Verrender et al. 2016
Decrease correct answers	Sauter et al. 2015
Pain threshold increase	Vecsei 2013
Increased N100	Leung et al. 2011
Acoustic ERP, amplitude decrease, adaptation increase	de Tommaso et al. 2009
Response time change	Luria et al. 2009
Reducing psychological arousal	Augner et al. 2009
Attention increase	Wiholm et al. 2009
No effect	Regel, Tinguely et al. 2007; Haarala et al. 2007; Krause et al. 2007; Cinel et al. 2008; Stefanics et al. 2008; Kleinlogel et al. 2008b; Curcio et al. 2008; Hillert et al. 2008; Eltiti et al. 2009; Kwon et al. 2009; Riddervold et al. 2010; Kwon et al. 2010; Sauter et al. 2011; Loughran et al. 2013; Vecsei et al. 2018; Hosseini et al. 2019
Others	
Cortex oxygenation	Curcio et al. 2009
Brain glucose metabolism	Kwon et al. 2011; Volkow et al. 2011

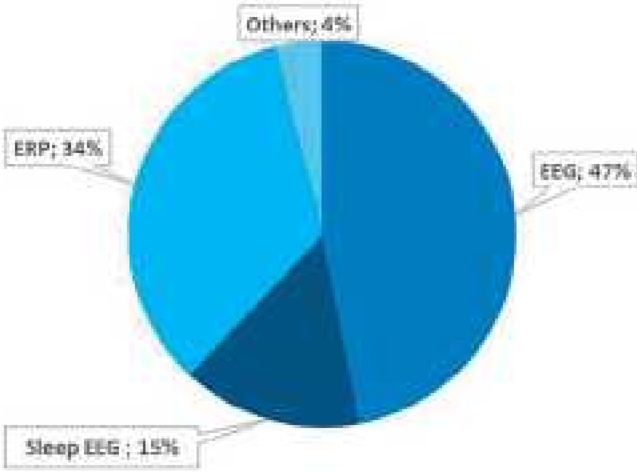

Figure 2. Relative distribution of studies according different categories of the RF EMF effects.

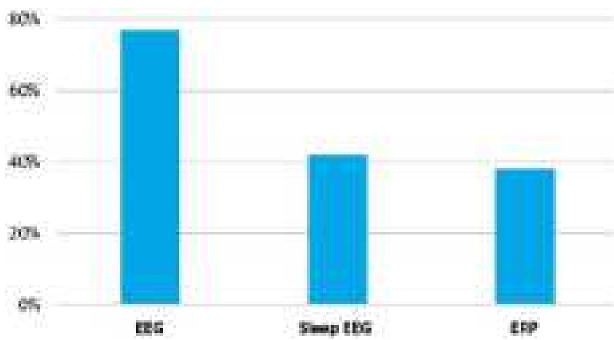

Figure 3. The rate of studies revealing RF EMF effects according different categories.

studies reporting the effect in the resting EEG category is about twofold higher than in the other sleep EEG or ERP categories. All three studies in the category others reported RF EMF effects. However, three studies are too few to make a conclusion about the rate of RF EMF effects.

Resting EEG

The rate of positive findings in resting EEG category (in total 30 studies) is 76.7%. The increased alpha power was most frequently reported (14 studies). Somewhat less studies reported increased beta power (6 studies). Decrease in alpha power was revealed only in two studies and beta power in one study. Increase in gamma power was detected in three and theta power in one study. Increased complexity was evident in three studies. Such distribution of the reported effects is obviously caused by the properties of the resting eyes closed EEG where alpha power (band 8–12 Hz) peak is much higher other bands. Therefore, the alterations in alpha power are detectable more easily.

Only few studies have applied advanced EEG analyses to detect alterations in more complicated nonlinear processes in the brain (Hinrikus, Bachmann, Karai, et al. 2011; Bachmann, Tomson, et al. 2007). The results of these studies demonstrated that RF EMF affected complexity of the brain bioelectrical activity. The RF EMF increased scores of both applied measures, Higuchi's fractal dimension (HFD) and Length distribution of low variability periods (LDLVP).

The results demonstrate that RF EMF causes excitation of brain and related increase in resting EEG alpha and beta bands powers. Exposure to radiation leads also to the higher complexity of brain bioelectrical activity.

Sleep EEG and sleep quality

The rate of positive findings in sleep EEG and sleep quality group is 41.7%. All five studies that reported the effect, declared increase in sleep EEG rhythms or spindles. The increase was evident in slow wave (delta and theta) and in alpha band. No disturbances in sleep quality were reported.

These results suggest that the radiation causes changes in neuronal activity earlier than the subjective feelings become evident.

Event-related potentials (ERP), behavior and cognition

The rate of positive findings in ERP, behavior and cognition group is 38.5%. The reported findings are diverse. Two studies reported changes in ERP. Improved behavior (memory, attention, reaction time) was demonstrated in four studies and reduced behavior (psychological arousal, correct answers, pain threshold) were shown also in four studies.

Exposure to low-level RF EMF, stimulating brain, can cause some improvement of behavior. On the other side, negative impact on behavior and arousal is evident.

Others

Positron emission tomography (PET) study reported significantly correlated with the estimated RF EMF amplitudes changes in brain glucose metabolism and its increase in the region closest to the antenna (Volkow et al. 2011). Another PET study indicated reduced cerebral metabolic rate of glucose in in the area close to the antenna (Kwon et al. 2011). The exposure did not affect task performance (reaction time, error rate). One study, using functional near-infrared spectroscopy, reported a slight influence of the RF EMF on frontal cortex oxygenation (Curcio et al. 2009).

These results support the suggestion that short-term changes in brain physiology are not obligatory related to human performance.

Dependence on exposure level

To study the dependence on exposure level, the selected for analyses studies are divided into groups according to exposure level (Table 2). While studies at SAR > 2 W/kg are considered as a single group, the numbers of studies per group are following: 7 studies in the group of SAR > 2; 22 studies in the group of SAR = 2–1.5 W/kg; 19 studies in the group of SAR = 1.5–1 W/kg; 10 studies in the group of SAR = 1–0.5 W/kg; 15 studies in the group of SAR =0.5–0.1 W/kg; and three studies in the group of SAR < 0.1 W/kg.

Table 2. Studies grouped according to the level of exposure.

SAR W/kg	Effect	No effect
10.98		Sauter et al. 2011
7.82		Sauter et al. 2011
6	Sauter et al. 2015	Eggert et al. 2015
5		Regel, Gottselig, et al. 2007
3.75		Trunk et al. 2013
2.18	Lv, Su et al. 2014; Lv, Chen et al. 2014	
2-1.5	Croft et al. 2010; Leung et al. 2011; Lowden et al. 2011; Schmid et al. 2012; Vecsei et al. 2013; Sauter et al. 2015; Lustenberger et al. 2015; Verrender et al. 2016; Yang et al. 2017; Vecsei et al. 2018; Dalecki et al. 2018; Loughran et al. 2019; Lowden et al. 2019	Stefanics et al. 2008; Croft et al. 2010; Riddervold et al. 2010; Danker-Hopfe et al. 2011; Nakatani-Enomoto et al. 2013, 2020; Trunk et al. 2015; Eggert et al. 2015
1.5-1	Regel, Tinguely et al. 2007; Hung et al. 2007; Krause et al. 2007; Luria et al. 2009; Wiholm et al. 2009; Lustenberger et al. 2015; Verrender et al. 2016; Yang et al. 2017; Dalecki et al. 2018; Loughran et al. 2019	Fritzer et al. 2007; Haarala et al. 2007; Krause et al. 2007; Kleinlogel et al. 2008a, 2008b; Hillert et al. 2008; Kwon et al. 2009, 2010, 2011; Loughran et al. 2013
1-0.5	Bardasano et al. 2007; Curcio et al. 2008; Croft et al. 2008; de Tommaso et al. 2009; Curcio et al. 2009; Croft et al. 2010; Vecchio et al. 2010; Leung et al. 2011; Ghosn et al. 2015; Curcio et al. 2015	
0.5-0.1	Bachmann, Tomson, et al. 2007; Bachmann et al. 2018: Hung et al. 2007; Hinrikus Bachmann, Lass, Tomson, et al. 2008; Hinrikus, Bachmann, Lass, Karai, et al. 2008; Hinrikus et al. 2009; Suhhova et al. 2009; Hinrikus et al. 2011; Hinrikus, Bachmann, Lass et al. 2011; Lustenberger et al. 2013; Suhhova et al. 2013; Hinrikus et al. 2017	Regel, Gottselig, et al. 2007; Eltiti et al. 2009
<0.1	Suhhova et al. 2013	Zentai et al. 2015; Bueno-Lopez et al. 2021

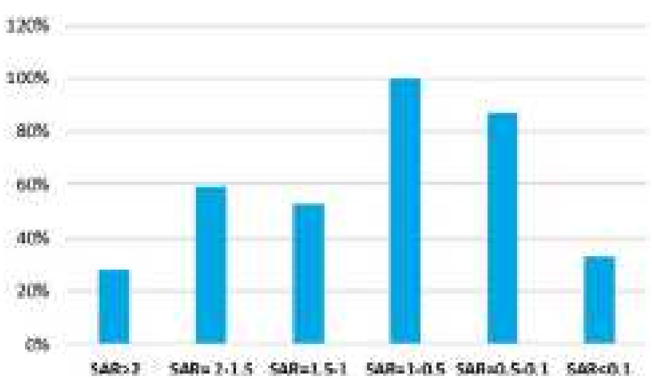

Figure 4. The rate of detected RF EMF effects in the groups of different SAR (W/kg) levels.

Figure 4 presents the rate of detected RF EMF effects in the groups. No any regular trend on the dependence of the effect on SAR level occurs. Unfortunately, only very few studies reported quantitative data about the intensity of the detected effects. The differences in the results can be caused rather by diversity of applied methods and used types of radiation. The fact that all studies at SAR = 1-0.5 W/kg indicated the effect can be considered as a chance. The group includes studies from different groups and various kind of the effects, no any reason exists for systematic advantage. The high rate of the detection 87% in the group SAR =0.5-0.1 W/kg can be explained by fact, that the majority of studies belong to one team. The team (Bachmann, Hinrikus, et al. 2007) has modified the modulation method used in Dicke radiometer (Tiuri 1964) to increase the sensitivity for the detection of changes in EEG. Therefore, small hidden in the variability of EEG changes can be detected and alteration not only in alpha but also in beta and gamma bands become evident.

The other reason for uncertainty of the results of analyses is that the majority of studies have been performed within quite narrow diapason of SAR levels between 2 and 0.1. Only few studies used higher and lower exposure levels.

According to the origin of low-level RF EMF effect mechanism (Figure 1), the effect is related to electric field strength causing rotation of dipolar molecules, not absorbed power. Therefore, electric field strength is more appropriate parameter for determining the experimental condition. Unfortunately, only very few authors have indicated field strength used in their experiments.

The dependence of the effect on exposure level can be evaluated better comparing data at two or more levels of exposure within the same study. Several studies performed experiments at two different SAR values. However, some of these studies reported no effect (Kleinlogel et al. 2008a, 2008b; Sauter et al. 2011; Danker-Hopfe et al. 2011; Eggert et al. 2015). Some others did not provide quantitative data for the results (Leung et al. 2011; Loughran et al. 2013; Sauter et al. 2015; Verrender et al. 2016; Dalecki et al. 2018).

Only one study reported quantitative data about changes at two different levels of exposure (Suhhova et al. 2013). At the higher SAR = 0.303 W/kg ($E = 24.5$ V/m) level, increases in the EEG beta2 (157%), beta1 (61%) and alpha (68%) frequency bands were detected. At the lower SAR = 0.003 W/kg ($E = 2.45$ V/m) level, increase only in the beta2 (39%) frequency band was evident. The decrease in the intensity of the effect at lower level about four times is much less than expected according to the decrease of SAR (100 times). The relative decrease of the effect is rather close to the change in field strength (10 times).

The performed analyses are not helpful in clarifying regularity of the dependence of the effect on the level of radiofrequency radiation. Obviously factors other than the level of exposure plays important role in the low-level RF EMF effects. An important factor is modulation frequency that is expected being close to the EEG frequencies (Hinrikus, Bachmann, Lass, Tomson, et al. 2008; Hinrikus et al. 2011). According to studies analyzed in the current review, the lowest electric field strength at which the effect was detected is 2.45 V/m (SAR = 0.003 W/kg) (Suhhova et al. 2013).

Possible consequences on health

The transformation of the biological effects of radiation into health consequences is a chaotic process (disrupted-line arrows in Figure 1). A very weak initial alteration on neuronal or molecular level can lead to unpredictable consequences on health – or not cause any remarkable health effect. Therefore, the threshold of RF EMF consequences on health cannot be determined.

Main attention in evaluation of the RF EMF health effects has been directed to risk of tumors (Carlberg et al. 2013; Miller et al. 2019; Choi et al. 2020). Due to long latent period, diverse exposure conditions and biological parameters, the causal relationship is difficult to reveal. The recent meta-analyses of case-control studies found that cellular phone use with cumulative call time more than 1000 h statistically significantly increased the risk of tumors (Choi et al. 2020).

Less attention in evaluation of the RF EMF health effects has been directed to neurological diseases and mental disorders. There is a possibility that the RF EMF neurophysiological effect can cause neurological and mental disorders not obligatory related to oxidative stress and genetic instability. The cohort study on cellular telephones and central nervous system diseases risks observed the excesses of migraine and vertigo and a possible association with dementia and Parkinson (Schuz et al. 2009). The recent cohort study concludes that people using mobile phones most extensively reported weekly headaches slightly more frequently than other users (Auvinen et al. 2019).

The analyses in the current review show that alteration in EEG are similar in the high majority of the studies: increase in EEG alpha, beta and gamma band levels as well as higher complexity of the signal (Table 1). Similar changes in EEG are characteristic in major depression disorder (Knott et al. 2001; Fingelkurts and Fingelkurts 2015). Based on these EEG parameters, the quantitative measures for the detection of symptoms of depression have been discussed (Ahmadlou et al. 2012; Hosseinifard et al. 2013).

The causality between the RF EMF and depression is not clear. The results of the study based on a special questionnaire indicated association between higher mobile phone use and symptoms of depression (Thomee et al. 2011). However, it is complicated to differentiate between the direct effect of RF EMF and psychological factors related to the high use of mobile phones leading sometimes even to addiction (Gutiérrez et al. 2016; Lapierre et al. 2019).

Depression has become a common mental disorder during last decades with the highest prevalence among individuals aged 18-25 (13.1%) (NIH 2021). The levels of RF EMF have increased and the use of mobile telecommunication technology has become more intense with prevalence in young people during the same period. Is this a coincidence or causality?

The results of some studies demonstrate that at the same level of RF EMF exposure and identical conditions, only a part of people are affected (Hinrikus, Bachmann, Lass, Karai, et al. 2008; Bachmann, Tomson, et al. 2007). The rate of sensitive people varies from 13% to 31% depending on modulation frequency (Hinrikus, Bachmann, Lass, Tomson, et al. 2008). It is not clear are some people ‘immune’ to the RF EMF permanently or occasionally. The connection between ‘immunity’ and hypersensitivity is important for interpretation of RF EMF health effects.

The results of some studies indicate that RF EMF-related changes in neuronal system (EEG signal) are much more frequent than in subjective behavior (Vecsei et al. 2018). The exposure-induced effects have been seen in objective indicators (EEG, glucose metabolism) but not in cognitive performance (Schmid, Murbach, et al. 2012; Kwon et al. 2011). Therefore, people would not mention existing health symptoms of the RF EMF effect. The situation that objective physiological symptoms appear earlier than the subjective feeling and symptoms is quite usual in the case of many diseases.

Conclusions

The analyses of the model of the non-thermal mechanism of RF EMF effect shows that the steps of the model contain no principal threshold for the effect. Therefore, the only way to estimate the possible threshold is analyses of experimental data. The review of experimental data of human RF EMF neurophysiological effects results in following main conclusions that indicated the directions of future research:

1. The lowest field strength that has caused the effect in EEG, according to the reviewed studies, is 2.45 V/m (SAR = 0.003 W/kg), close to the radio and TV broadcasting RF EMF field strength about 0.1 V/m. The future large-scale human, animal and in vitro studies are required to clarify the level and to increase the reliability of the experimentally determined threshold of RF EMF effect.
2. There is a preliminary indication that the intensity of the effect follows rather the field strength than SAR alteration. However, no sufficient data are available for clarifying regularity and linearity-nonlinearity of the relationship. The studies with systematic variations in exposure level (electric and magnetic field strengths, power density) would help to advance the field. The

research from cellular to humans is needed in this direction.
3. Very limited data are available about the repair and adaptive phenomena important in the interpretation of the RF EMF effects on health. Special studies are required to clarify the mechanisms and possibilities of the repair processes.
4. The finding that only part of people are sensitive to RF EMF exposure can be related to immunity to radiation or hypersensitivity. The variability of sensitivity between people and long-term stability of the status required large-scale long-term experimental studies.
5. The indication that the changes in EEG caused by RF EMF appeared similar to these in depression need a special attention. The fast increase of depression with the highest prevalence among young individuals and more intense use of mobile telecommunication technology with prevalence in young people during the same period needs attention. The possible causal relationship between RF EMF effect and depression among young people is the problem of high importance. The methodology and large-scale investigations in this direction are required.

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