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ABSTRACT

Background: Chrysotile from the mine in Balangero, Italy is considered to be free of tremolite. In a cohort study of miners and millers only two pleural cancers were reported, a finding considered to indicate that chrysotile has a low potency for inducing mesothelioma. However, follow-up ended in 1987 and white-collar workers and the employees of subcontractors were not studied.

Methods: To complete the case ascertainment, the study searched the Registry of Malignant Mesotheliomas of Piedmont for records of cases of pleural mesothelioma among the following: mine employees; employees of subcontractors or of other firms transporting or refining Balangero asbestos, asbestos ore or mine tailings; individuals exposed to air pollution from the mine or living with mine employees; and individuals exposed to mine tailings from Balangero.

Results: The study identified four new cases of pleural mesothelioma among blue-collar workers in the mine, in addition to the two reported in the cohort study. Thus, six mesotheliomas occurred, compared to the 1.5 expected ($p<0.01$). The study also identified three mesothelioma cases among white-collar employees at the mine, five in workers in the mine hired by subcontracting firms, and three among workers processing Balangero chrysotile outside the mine. Finally, 10 additional cases due to non-occupational exposure or exposure to re-used mine tailings were identified.

Conclusions: The cluster of 14 mesothelioma cases among workers who were active in the mine and 13 among other people exposed to Balangero chrysotile provides further evidence that tremolite-free chrysotile is carcinogenic.

The carcinogenicity of chrysotile is established, although the issue of its potency relative to amphiboles for inducing mesothelioma remains unresolved, with estimates ranging from 1:3 to 1:500.[1 2] A related controversy is whether contamination with tremolite fibre, rather than chrysotile, could be entirely responsible for causing mesothelioma.[3] Chrysotile from the Balangero mine (Piedmont, northern Italy) is tremolite-free and contains trace amounts of balangeroite, a non-asbestos fibrous mineral similar in shape to amphiboles.[4 5]

A study on workers at the Balangero mine reported only two deaths from pleural cancer up to 1987.[4 6] This study has been regarded as contributing to the evidence that chrysotile has relatively low carcinogenic potency.[2] Published reports did not, however, include clerical workers or employees of subcontractors, and four cases of malignant mesothelioma, one in a worker engaged at the mining site by a subcontractor, have been described after 1987.[7–9]

In Piedmont a Registry of Malignant Mesotheliomas (RMM) has been maintained since 1990.[10] We report on a survey of data in the RMM, conducted to identify cases aetiologically related to the mine, including cases among non-occupationally exposed individuals.

METHODS

The plant

The Balangero mine, active from 1917 to 1985, was an open-pit operation, flanked by a mill for opening, separating and mixing fibres of different length. Amiantifera, the company that owned the mine, officially ceased its activities in 1990. Asbestos and the mine tailings, which are crushed serpentine rocks left over after fibre extraction and which still contain up to 1% chrysotile fibres by weight, were removed by trains and lorries. A cohort of miners and millers employed for at least 1 month by Amiantifera and active in 1946 or hired thereafter was established by Rubino *et al* and studied further by Piolatto *et al*.[4 6] The cohort did not include white-collar workers or employees of subcontractors. Fibre measurement during mining activities did not begin until 1969, so Rubino and coworkers experimentally reproduced working conditions for the period 1946–1975. They used these simulated conditions to estimate average fibre concentrations for different jobs and calendar periods, as well as individual cumulative exposures.[6] Occupational exposure was in the range of 100–400 f/mly for about 30% of workers, and >400 for another 30%.[4 6] Fall-out from the mine affected the surrounding towns but, apart from anecdotal descriptions of episodes of very high air pollution in the literature, few measurements are available of asbestos fibre concentrations in the general environment.[8 11 12] Mine tailings from Balangero were used in several areas of Piedmont as ballast for road and railroad construction and for courtyard paving.

Identification of cases

Many asbestos industries were located in Piedmont, a region with 4.5 million inhabitants.[13] Since 1990, the RMM has recorded newly diagnosed cases of malignant mesothelioma among residents; cases occurring in 1980–1989 were registered retrospectively.[10] Structured interviews with subjects with malignant mesothelioma and with respondents were conducted to obtain information on life-long occupational and non-occupational exposure to asbestos. Initially interviews were conducted only with persons enrolled

in surveys and case–control studies.[14 15] Over the years, the RMM has increased its efforts to obtain exposure data, which are now available for approximately 50% of all mesotheliomas diagnosed between 1990 and 2001. Through the network of regional registries connected to the National Registry of Mesotheliomas, the RMM can identify individuals exposed in Piedmont who were living in other Italian regions at the time of diagnosis.[16]

Industrial hygienists performed qualitative and quantitative assessment of asbestos exposure for all interviewed subjects with malignant mesothelioma. They based their assessments on descriptions of the relevant exposure circumstances and on available knowledge of the industrial and non-industrial settings involved. Records have been kept of all settings where exposures occurred. From the RMM records we extracted cases occurring in the following groups: employees of Amiantifera or of its subcontractors at the Balangero mine; employees of other firms transporting or refining asbestos, asbestos ore or tailings from the Balangero mine; individuals either exposed to the fall-out of dust from the mine (environmental exposure) or living with an employee of the mine (household exposure); and individuals reporting exposure to mine tailings from Balangero. Cases occurring in all but the last two groups belong to well-defined occupational populations, although we could not explicitly list these populations as we lack their employment rolls. Cases occurring in the last two groups belong to the general population. People living in the four towns closest to the mine (Balangero, Corio, Coassolo, Lanzo) were considered to have environmental exposure. Sharing a home with an employee of the mine who brought home his working clothes was classified as household exposure. Exposure to mine tailings was assumed for individuals who reported in the interview that they handled such materials or lived close to places where they had been dumped or used for paving. We did not include cases among workers at industries manufacturing asbestos-based products using Balangero asbestos, because most of these workers were also exposed to asbestos from other sources.

Calculation of the expected number of cases in the cohort of miners and millers

Because we did not have access to the files of the mortality cohort study on Balangero miners and millers, we did not know the age distribution of the 631 members alive at the last follow-up in 1987.[4] We estimated the 1988–2006 person-years of observation by applying the following conservative assumptions: no mortality up to 31 December 2006, and all cohort members at least 60 years of age in 1987. We then computed the expected number of cases on the basis of the average incidence of malignant pleural mesothelioma (10.4/100 000 per year) for the period 1990–2001 among men aged 60 or older in the appropriate province (Turin). Reference rates were obtained from the RMM. The corresponding calculation could not be carried out for non-manual workers or for workers not employed by Amiantifera because their numbers were unknown.

RESULTS

Cases associated with exposure to chrysotile

Information on exposures was collected and assessed for 1432 of the 2992 malignant mesothelioma cases registered in Piedmont residents in the period 1980–2007. By reviewing exposure assessment records, we identified 25 cases possibly related to exposure to chrysotile from the Balangero mine, bringing to 27 the overall number of cases considered in the present report.

In the accompanying tables, the exposure patterns of these cases are summarised in brief descriptions of all occupations and circumstances considered to have entailed exposure. Unexposed jobs and life events were not reported. The sentence "no other asbestos exposure at work" recorded for a case meant that the individual held other jobs apart from those mentioned explicitly, and that the rater performing the exposure assessment considered them unexposed.

Of the nine cases of malignant mesothelioma in employees of Amiantifera (table 1A), the first two are those reported by Rubino *et al*[6] and Piolatto *et al*.[4] Case 3, first diagnosed in 1985, was not included in these studies, perhaps because he became a manager in the latter part of his career. Four cases occurred among manual workers after follow-up was closed (cases 4–7), one case in a white-collar worker (case 8), and one in a manual worker who later became a technical staff member (case 9).

Five cases occurred in employees of firms subcontracted by Amiantifera, who reported having worked at the same site, being engaged in the same production processes and using the same machinery as employees of Amiantifera (table 1B).

Three cases were never employed at the Balangero mining site but had worked with asbestos, asbestos ore and mine tailings from the mine (table 2). Cases 15 and 17 had worked at a mill outside the mining site that was not owned by Amiantifera, where low-grade ore yielding short fibres was treated and asbestos was separated, mixed and packaged. Case 16 repeatedly handled materials from the Balangero mine: he worked on extracting nickel from "sterile" Balangero serpentinite and on a project for "wet" extraction of asbestos fibres.

Five cases occurred in the population living in the neighbourhood of the mining area (table 3). Case 18 also reported household exposure. Finally, five cases occurred among persons exposed to mine tailings from Balangero at work or at home (table 4). Three were women who lived for a long time in areas where the surroundings were paved with tailings from Balangero.

Expected number of mesotheliomas in the cohort of miners and millers

The expected number of cases cannot be computed with precision without knowing the age distribution of the cohort of miners and millers. Piolatto *et al* reported that 0.3 deaths from pleural cancer were expected between 1946 and 1987.[4] Since the incidence of pleural mesothelioma is very close to that of pleural cancer, we assume that 0.3 cases would be expected during the same period. Based on our calculations, a further 1.2 cases are expected in 1988–2006, giving a total of 1.5 cases expected between 1946 and 2006. Six cases were recorded (cases 1, 2 and 4–7) in blue-collar employees of Amiantifera, corresponding to a standardised incidence ratio (SIR) of 4.00, with a 95% confidence interval (95% CI) of 1.47 to 8.71. We excluded the following cases from the number of malignant mesotheliomas observed in the cohort: case 8 because he was a clerk, and cases 3 and 9 because, although they had been manual workers, they became clerks and staff members and may not have been included in the cohort study since this was restricted to miners and millers.[4 6]

DISCUSSION

Information on exposure is available for 50% of all cases in the RMM, so additional cases due to the exposures of interest may exist among those whose personal histories are unknown. Despite this limitation, our survey allowed the identification of a cluster of malignant mesotheliomas in persons who were

Table 1 Cases of malignant mesothelioma among workers at the Balangero mining site

Case	Sex	Age	Year	Site	Diagnosis	Source of case	Routes of exposure
A. Cases of malignant mesothelioma among workers employed by Amiantifera at the Balangero mining site							
1	M	51	1975	Pleural	Cytol	Piolatto *et al*[4]	Blue-collar worker at Amiantifera (1940–1973). No further data currently available.
2	M	62	1977	Pleural	Histol	Piolatto *et al*[4]	Blue-collar worker at Amiantifera (1942–1967). No further data currently available.
3	M	64	1985	Pleural	Histol	RMM	Blue-collar worker at Amiantifera (1954–1985): miner in the first years of employment, later technical staff and lastly manager.
4	M	68	1989	Pleural	Cytol, ICC	RMM	Blue-collar worker at Amiantifera (1936–1941 and 1942–1944): miners' aid, and later rock driller, then miller and fibre mixer. No other asbestos exposure at work.
5	M	73	1992	Pleural	Histol, IHC	RMM	Blue-collar worker at Amiantifera (1942–1969) as miners' aid and later miller. No other asbestos exposure at work.
6	M	77	1994	Pleural	Clinical	RMM	Blue-collar worker at Amiantifera (1938–1965). No further data currently available.
7*	M	67	2002	Pleural	Cytol, ICC	RMM	Blue-collar worker at Amiantifera as plant electrician (1964–1965). Electrician in a steel mill (1953–1955), in railway coach construction (1955–1958), in an iron foundry (1959–1963 and 1966–1971), and in a motor vehicle assembly plant (1971–1989).
8	M	76	2005	Pleural	Clinical	RMM	White-collar worker, then manager at Amiantifera (1956–1985). No other asbestos exposure at work.
9	M	78	2006	Pleural	Histol, IHC	RMM	Blue-collar worker at Amiantifera (1959–1967), asbestos bagger. White-collar worker at Amiantifera (1967–1987). No other asbestos exposure at work. Lived close to the mining area (1959–1987).
B. Cases of malignant mesothelioma among workers employed by subcontractors at the Balangero mining site							
10	M	36	1989	Pleural	Histol	RMM	Bricklayer and roofer, engaged in building an asbestos mill at the mining site (1968–1972). Lift mechanic (1967–1968). No other asbestos exposure at work. Lived inside the mining site (1968–1972).
11*	M	59	1992	Pleural	Histol, IHC	RMM	Blue-collar worker for a subcontractor, working at the mining site as a miners' aid (1949). Bricklayer (1949–1957), worker in a nylon production facility (1957–1959), worker in the curing department of a tyre production plant (1963–1977), marble cutter (1979–1989).
12	M	68	2003	Pleural	Histol, IHC	Riboldi *et al*[9]	Blue-collar worker for a subcontractor, working at the mining site as a lorry driver, carrying asbestos ore from the mine to the mill and tailings from the mill to the dumping site (1955). No other asbestos exposure at work.
13	M	74	2003	Pleural	Histol, IHC	RMM	Blue-collar worker for a subcontractor transporting asbestos from the Amiantifera mine to different industries (1967–1989). Furnace worker in a steel mill (1966–1967).
14	M	72	2006	Pleural	Cytol, ICC	RMM	Blue-collar worker for a subcontractor as a lorry driver, carrying asbestos from the Amiantifera mine (1958–1973). No other asbestos exposure at work. Lived close to the mining area (1933–2006).

*Possible exposure to other types of asbestos.
Cytol, cytological confirmation; Histol, histological confirmation; IHC/ICC: immune staining pattern suggestive of a mesothelial neoplasm, based on histological or cytological material, respectively; RMM, Registry of Malignant Mesotheliomas.

Table 2 Cases of malignant mesothelioma in workers never employed at the Balangero mining site but occupationally exposed to chrysotile from the mine

Case	Sex	Age	Year	Site	Diagnosis	Source of case	Routes of exposure
15*	F	53	1990	Pleural	Histol, IHC	RMM	White-collar worker at a mill outside the mining site treating Balangero ore working in an office in the yard of the factory (1957–1990). The mill also treated tremolite-contaminated talc from local mines. Lived close to the mining area (1937–1990).
16*	M	56	1996	Pleural	Histol, IHC	RMM	Researcher and teacher at the Turin Institute of Technology (1964–1969). Analysed ore from the Balangero mine and built/managed pilot plants for ore exploitation (1964–1966, 1968–1969 and 1987). Engineering consultant (1969–1997). Sampled air in brake/clutch lining production plants (1978–1983).
17*	M	68	2001	Peritoneal	Histol, IHC	RMM	Asbestos hand bagger (1950–1961) at a mill outside the mining site treating Balangero ore. The mill (but not the worker) also treated tremolite-contaminated talc from local mines. Lived close to the mining area (1933–1972).

*Possible exposure to other types of asbestos.
Histol, histological confirmation; IHC, immune staining pattern suggestive of a mesothelial neoplasm, based on histological material; RMM, Registry of Malignant Mesotheliomas.

Table 3 Cases of malignant mesothelioma due to household or environmental exposure

Case	Sex	Age	Year	Site	Diagnosis	Source of case	Routes of exposure
18	F	55	1981	Pleural	Histol	RMM	No definite/likely occupational exposure. Husband asbestos packer at the mining site, work clothes cleaned and washed at home (1948–1973). Lived close to the mining area (1926–1981).
19	M	78	2003	Pleural	Histol, IHC	RMM	No definite/likely occupational exposure. Lived close to the mining area (1925–1926 and 1983–2003).
20	F	79	2003	Pleural	Histol, IHC	RMM	No definite/likely occupational exposure. Lived close to the mining area (1935–2003).
21	F	69	2003	Pleural	Histol, IHC	RMM	No definite/likely occupational exposure. Lived close to the mining area (1943–1980).
22	F	75	2007	Peritoneal	Histol, IHC	RMM	Farmer 1944–2002, leaves collected in the surroundings of the mining area used for cattle litter. Lived close to the mining area (1936–2007).

Histol, histological confirmation; IHC, immune staining pattern suggestive of a mesothelial neoplasm, based on histological material; RMM, Registry of Malignant Mesotheliomas.

exposed to chrysotile from Balangero but not, or only to a limited extent, to other types of asbestos.

The expected number of mesothelioma cases in the cohort of Balangero miners and millers may have been overestimated in our calculations, first because we had to make some conservative assumptions to compute the number of person-years accrued during 1988–2006, and secondly because we used the population of Turin province as a reference. We had to approximate the calculation of person-years as we had no access to the individual records of the cohort members alive in 1987, when Piolatto and coworkers ended their follow-up study.[4] The population of Turin province may bias the mesothelioma SIR estimate towards the null, because it includes substantial numbers of former workers in asbestos industries.[13] Nevertheless, it is preferable to the alternatives: national incidence rates are unavailable for the calendar period considered, and estimates based on regional rates would be even more biased due to the overwhelming influence of the atypical epidemiological situation of Casale Monferrato.[14 15] Thus, an SIR of 4.00 (95% CI 1.47 to 8.71), based on six observed cases, can be tentatively estimated for manual workers hired by the firm running the mine. In the most recent update of the mortality study, the standardised mortality ratio (SMR) for pleural cancer was reported to be 6.67 (95% CI 0.8 to 24.1), based on two observed deaths.[4] Both deaths could be confirmed as due to pleural mesothelioma, and they correspond to cases 1 and 2 in the present report. Current and earlier risk estimates are in agreement if their confidence intervals are taken into account. Opportunities for occupational exposure to asbestos of Amiantifera employees outside the mine could be identified only for case 7, a man who worked as an electrician in other plants where asbestos use was possible.

No data were available to estimate expected cases of malignant mesothelioma among non-manual workers or employees of subcontracting firms. However, the detection of three and five cases in these groups, respectively, can hardly be attributed to chance. In particular, regarding the occurrence of malignant mesothelioma in non-manual employees (cases 3, 8 and 9), it is important to note that cases 3 and 9 were manual workers in their first years of employment. Regarding case 8, there are strong suggestions that substantial levels of airborne asbestos fibres were present in all the areas of the mining site. One of us observed a case of fatal asbestosis in a woman (diagnosed in 1989, died in 1993 at age 63) who never worked at the mine but lived in a house inside the Amiantifera premises, close to the fibre separation plant (R Calisti, unpublished data). The administrative offices were located in the same area.

Thus, our present findings indicate that Balangero chrysotile miners and millers experienced increased risk of malignant mesothelioma. In addition, the results suggest that, in workplaces entailing exposure to asbestos in which some activities are carried out by subcontracting firms, any assessment of the burden of disease caused by asbestos should include workers hired by the subcontracted firms, for which nominal rosters for use in conventional cohort studies are rarely collected.

We identified three new cases among workers employed by subcontractors or consultants to Amiantifera who had never worked at the mining site but who used or were in close contact

Table 4 Cases of malignant mesothelioma among persons exposed to mine tailings used outside the mine

Case	Sex	Age	Year	Site	Diagnosis	Source of case	Routes of exposure
23	F	52	1995	Pleural	Histol, IHC	RMM	Corn mill owner. Possibly used asbestos-contaminated bags discarded from the Balangero mine (1961–1995). Lived in a town where Balangero tailings were widely used as road ballast (1943–1995).
24*	F	47	1996	Pleural	Histol	RMM	Employed by Italian railways (1970–1991), where Balangero mine tailings were used as ballast up to the mid-1970s. No other asbestos exposure at work. Lived (1948–1996) close to railway tracks where Balangero mine tailings had been used as ballast.
25*	F	74	1998	Pleural	Histol	RMM	No definite/likely occupational exposure. Lived in a house with Balangero tailings as gravel substitute in the garden (1980–1998). Possible fall-out from an asbestos textile workshop 600 m from home (1978–1990).
26	F	39	2000	Pleural	Histol, IHC	RMM	No definite/likely occupational exposure. Lived in a district where Balangero tailings were used as road ballast (1982–2000).
27*	M	74	2001	Pleural	Histol, IHC	RMM	Employed by Italian railways as a track maintenance worker (1951–1986) where Balangero mine tailings were used as ballast. No other asbestos exposure at work.

*Possible exposure to other types of asbestos.
Histol, histological confirmation; IHC, immune staining pattern suggestive of a mesothelial neoplasm, based on histological material; RMM, Registry of Malignant Mesotheliomas.

Main messages

- Potency for mesothelioma induction was estimated to be two to three orders of magnitude lower for chrysotile than for amphiboles, based on findings from Quebec miners and millers and because of the absence or very small number of cases in other cohorts, including Balangero miners and millers.
- The study identified 14 cases of malignant mesothelioma in workers active in the mine and 13 in other persons exposed to Balangero chrysotile, a situation less reassuring and more complex than previously reported.

Policy implications

- Further investigations are needed to better estimate the carcinogenic potency of chrysotile.
- It may prove difficult to complete enumeration of at-risk individuals and in-case ascertainment, at least in certain settings, so these difficulties will have to be fully addressed in future research.

with its ore, its products or its tailings (table 2). Their common exposure feature is Balangero chrysotile, although cases 15 and 17 may also have been exposed to fibrous tremolite.

Cases 18–22 suggest exposure to Balangero chrysotile in the general environment has an aetiological role. Asbestos fibres have recently been found in the lungs of animals raised in the Balangero area, where the mining site was by far the most important source of asbestos fibres. This is still true today, due to incomplete remediation of the mining site.[17]

Cases 23–27 neither worked at the mine nor reported circumstances corresponding to our definitions of environmental or household exposure. However, they were exposed to Balangero mine tailings used as ballast. Possible exposure to tremolite may have played a role in cases 23 and 27: ballast from Balangero was used for the beds of railway lines up to the mid-1970s, although it was later replaced by other serpentinites, some of which were contaminated with tremolite.

The hypothesis has been advanced that chrysotile itself would not induce malignant mesotheliomas and that their occurrence in Quebec miners and millers could be due to contamination by fibrous tremolite.[3 18] The occurrence of mesotheliomas in individuals with exposure to Balangero chrysotile is important because no tremolite has been detected in it.[4] Instead, balangeroite is present, especially in serpentinites at the northern side of the mine, and represents 0.2–1% by weight of extracted fibres. Recognised in 1983 as a new mineral, it is a fibrous magnesium-iron silicate, appearing as bundles of brownish fibres strictly associated with long-fibre chrysotile.[5 19] It is morphologically similar to amphiboles, and it produced nitrite accumulation, lipid peroxidation and nitrous oxide synthase activation in a human lung epithelial cell line, similarly to crocidolite.[19 20] Thus it exhibited a potential for producing oxidative cellular damage in vitro. However, it is unclear what role these factors play in the induction of human mesothelioma. Furthermore, balangeroite has never been tested for carcinogenicity in long-term animal experiments. Therefore, in light of current knowledge, it cannot be considered a carcinogen, nor it can be implied to cause mesotheliomas instead of chrysotile.

In a meta-analysis of occupational cohort studies, chrysotile carcinogenic potency in inducing mesothelioma was estimated to be two to three orders of magnitude less than that of amphiboles.[2] The major contribution to this assessment came from the results of the cohort study on Quebec chrysotile miners and millers.[18] Supporting evidence was provided by the fact that in other cohorts worldwide – including that of Amiantifera workers – no or very few cases were found.[4 21] Our assessment of the burden of mesotheliomas caused by chrysotile from Balangero is based on incomplete data. Nevertheless, the overall picture linking Balangero chrysotile to malignant mesothelioma is less reassuring than previously reported. Our findings also raise concern about risks caused by the continuing presence of mine tailings on railroad tracks, road beds and paving, and perhaps by incomplete remediation of the mining site.

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