

Different Measures of Asbestos Exposure in Estimating Risk of Lung Cancer and Mesothelioma Among Construction Workers

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To analyze occupation, expert-evaluated cumulative exposure, and radiographic abnormalities as indicators of asbestos-related cancer risk we followed 16,696 male construction workers for cancer in 1990–2000. We calculated standardized incidence ratios (SIR) in comparison to the Finnish population and relative risks (RR) in a multivariate analysis in comparison to the internal low-exposure category of each indicator. Overall, the risk was increased for mesothelioma (SIR 2.0, 95% CI = 1.0–3.3), but not for lung cancer (SIR 1.1, 95% CI = 0.9–1.2). Radiographic lung fibrosis indicated a 2-fold and a high value of the exposure index a 3-fold RR of lung cancer, while there was no risk among those with pleural plaques. The risk of lung cancer was the highest in insulators (RR 3.7, 95% CI = 1.4–9.9). Occupation, expert-evaluated cumulative exposure, and lung fibrosis are useful indicators of lung cancer risk among construction workers (J Occup Environ Med. 2002;44:1190–1196)

Exposure to asbestos is known to cause pulmonary fibrosis (asbestosis), pleural plaques and other fibrotic lesions of the pleura, lung cancer, mesothelioma, and possibly some other malignant diseases.¹ Earlier asbestos was widely used as a constituent of various construction materials in Finland, but average exposure levels were not as high at the construction sites as in some specific occupational settings of asbestos production or shipyard industries.^{2,3} Construction workers nevertheless constitute the largest group of exposed workers.⁴ In the United Kingdom, construction and building maintenance is estimated to account for the largest proportion of the current and future mesothelioma burden.^{5,6}

Estimation of the level of risk is needed in the planning of medical follow-up, in providing the exposed workers with information on their individual risk, and in assessing occupational diseases. In addition to the cumulative exposure to asbestos, information on occupation and radiographic changes have been used as indicators of risk.⁷ The exact estimation of past exposure among construction workers is complicated. The numbers of past jobs and of employers are usually high, and the occurrence and type of past exposure to asbestos were very heterogeneous. For example, in Finland, altogether 250 applications and product names containing asbestos have been identified in the construction industry.³ It is difficult for construction workers

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themselves to know and recognize all their past exposures, and even for an experienced industrial hygienist to assess exactly the cumulative exposure of a construction worker. However as compared to self-reported exposure, an expert evaluation seems to give a somewhat better estimate of the risk.⁸

A screening campaign for benign asbestos-induced occupational diseases was carried out in Finland in 1990–1992 as part of the Asbestos Program of the Finnish Institute of Occupational Health.⁹ Various occupational groups in the construction industry constituted the majority of the screened population.¹⁰ The major aims of the screening campaign were to find the asbestos-related occupational diseases and to organize their follow-up.⁹ One of the aims was also to create a database for scientific studies on asbestos-related risks among construction workers in Finland.

This report analyses the significance of occupation, estimated cumulative asbestos exposure, and radiographic abnormalities as indicators of asbestos-related cancer risk among those construction workers who participated in the Finnish asbestos screening campaign in 1990–1992.

Materials and Methods

Subjects

The study population was selected from among the participants of the Finnish asbestos screening campaign in 1990–1992.^{10,11} All those men who participated the screening campaign and indicated that they had been employed mainly in building construction were included. Originally the participants of the screening campaign had been identified from several registers of construction workers: the Finnish Electrical Workers' Union, the Construction Union (plumbers and pipe insulators), the Finnish Metal Workers' Union (construction sheet metal workers), the Central Association of

Construction Engineers, and the LEL Employment Pension Fund register covering other occupational groups in the construction industry.¹⁰ The original selection was composed of all those persons who had worked at least 10 years in the construction industry in 1962–1990, had begun their work before 1980, and were aged less than 70 years at the time of the campaign. A preliminary questionnaire on job history and willingness to participate was sent to all the above groups. After exclusion of those who did not respond, did not want to participate, or had worked less than 10 years in a risk occupation according to the preliminary questionnaire, altogether 22,583 construction workers were invited to the screening campaign; 17,335 (77%) of them participated.¹⁰ Among this group there were 17,235 (16,696 men and 539 women) who gave their written permission to follow their health status. In this article we report the cancer incidence for those 16,696 men who gave their permission for the follow-up. In this group the mean year of entering work life was 1960. At the time of the screening campaign, the mean duration of employment in construction was 26 years and the mean age of the workers was 53 years.

Occupation and Exposure to Asbestos

The screening survey included a structured questionnaire interview conducted by a trained occupational nurse. The questionnaire covered smoking habits and a complete job title and industrial sector history. The participants were also asked to indicate their main type of work for each year of their work career. The alternatives included some specific types of work with known exposure to asbestos and a category of other work (Table 1). As some of the construction workers had also worked in other trades during their career, specific alternatives were given for shipyard, asbestos product

manufacture, and car repair work (Table 1).

The participants were classified according to their main occupation. In addition, a cumulative exposure index for the work career until the screening visit was calculated by summing up the working years before and after the first regulation concerning asbestos work in Finland weighted by the respective estimated exposure levels (Table 1):

Exposure index = Σ weighting factor
* duration (years)

The weighting factors were estimated according to the results of past industrial hygiene measurements performed in Finland for some specific asbestos work tasks during typical construction activities.^{2,3}

Radiology

A full-size chest-radiograph (postero-anterior and lateral view) was taken of all participants in the screening. The classification system for the screening campaign was an intermediate form between the complete and short ILO classification¹² with some modifications and additions.¹¹ The ILO reference films were used for comparison with every postero-anterior radiograph. The profusion of small lung opacities was classified in accordance with the complete ILO system using a 12-point scale. Right-sided and left-sided pleural abnormalities were recorded separately. In this article we report the cancer risk according to the ILO profusion score of small irregular opacities (less than 1/0, at least 1/0) and the presence of pleural plaques (yes, no).

Smoking

A person was classified as a smoker if he had smoked at least 1 cigarette, cigar, or pipeful of tobacco per day for at least 1 year. Ex-smokers were persons who had stopped smoking at least 6 months before the screening visit. At the time of the interview, 28% of the male construction workers were cur-

TABLE 1

Exposure Weighting Factors According to Type of Work and Period of Time

Type of main activity	Exposure weight- ing factor in 1976 and before	Exposure weight- ing factor in 1977 and after
Construction		
Installation of new pipes	2	1
Demolition of old pipes	5	5
Pipe insulation work	10	2
Other insulation work	2	1
Electrical installation work	1	1
Other construction work in new buildings	1	1
Other construction work in building repair	2	2
Shipyard		
Any installation work after the hull building phase	5	2
Ship repair work	5	5
Asbestos spraying and asbestos insulation work	20	1
Other shipyard work	1	1
Asbestos product industry		
Asbestos product manufacture	5	5
Asbestos mining	10	—
Other work in asbestos production	2	2
Car repair shops		
Brake or clutch repair work	1	1
Other work in car repair	0	0
All other trades	0	0

TABLE 2

The Distribution of Smoking Habits by Age in the Study Population

Age (years)	Population N (%)	Smoking habits		
		Never (%)	Ex-smoker (%)	Smoker (%)
< 45	3868 (100)	35	30	36
45-59	8074 (100)	30	40	30
≥ 60	4756 (100)	25	56	19
All	16698 (100)	29	42	28

rent smokers, 42% ex-smokers and 29% lifetime nonsmokers (Table 2).

Cancer Follow-Up

The follow-up for cancer was done in a computer linkage with the Finnish Cancer Registry, using personal identifier as key. The calculation of person-years started from the date of the screening visit. The calculation of person-years ended at emigration, at death, or on December 31st 2000, whichever was first. There were 149,607 person-years of follow-up.

The numbers of cancer cases and the person-years were counted by five-years age groups and two follow-up intervals (0-4 years, and ≥5 years since the screening visit). The

expected number of cancer cases was calculated by multiplying the number of person-years in each stratum by the corresponding average cancer incidence rate in Finland. The standardized incidence ratio (SIR) was calculated by dividing the observed number of cases by the expected number of cases. The 95% confidence interval (CI) for SIR was calculated from the Poisson distribution. There are no national cancer incidence rates separately for smokers, ex-smokers, and nonsmokers.

Multivariate Analysis of Risk of Lung Cancer

In an internal analysis of the determinants of risk of lung cancer

within the construction worker cohort the stratum-specific incidence rates of lung cancer were calculated by dividing the numbers of cases by the accumulated person-years. The incidence rate ratios, hereafter referred to as relative risks (RR), of lung cancer were estimated using a log-linear model. Age at start of follow-up (continuous variable), smoking status, presence of lung fibrosis, presence of pleural plaques, the asbestos exposure index and occupation were included in the multivariate model. Univariate analyses (adjusted for age and smoking) were also performed for presence of lung fibrosis, presence of pleural plaques, the asbestos exposure index and oc-

TABLE 3

Observed Number of Cases and Standardized Incidence Ratio (SIR) with 95% Confidence Intervals (CI) of Cancer Among Male Finnish Construction Workers

	Population	Lung cancer		Mesothelioma		Total cancer	
		Obs	SIR (95% CI)	Obs	SIR (95% CI)	Obs	SIR (95% CI)
All	16696	249	1.07 (0.94-1.20)	13	1.96 (1.04-3.35)	1320	1.03 (0.98-1.09)
Smoking							
Nonsmoker	4919	7	0.11 (0.04-0.22)	5	2.70 (0.88-6.30)	282	0.80 (0.71-0.90)
Ex-smoker	7073	59	0.49 (0.37-0.62)	8	2.45 (1.06-4.33)	627	0.96 (0.89-1.03)
Smoker	4701	183	3.74 (3.21-4.29)	0	exp 1.51 (0.00-2.44)	411	1.50 (1.36-1.64)
Pleural plaques							
No	10132	99	0.94 (0.85-1.11)	9	2.77 (1.27-5.25)	592	0.99 (0.91-1.07)
Yes	6563	150	1.18 (1.00-1.38)	4	1.19 (0.32-3.05)	728	1.07 (1.00-1.15)
ILO fibrosis score							
< 1/0	16186	217	0.98 (0.85-1.11)	13	2.05 (1.09-3.50)	1247	1.03 (0.97-1.08)
≥ 1/0	510	32	2.74 (1.88-3.87)	0	exp 0.30 (0.00-12.9)	73	1.20 (0.94-1.51)
Exposure index							
< 20	1610	6	0.65 (0.24-1.40)	0	exp 0.30 (0.00-12.3)	54	0.96 (0.72-1.24)
20-39	5736	50	0.80 (0.60-1.05)	3	1.59 (0.33-4.84)	303	0.94 (0.84-1.04)
40-89	8448	170	1.14 (0.98-1.32)	7	1.73 (0.69-3.55)	849	1.06 (0.99-1.13)
≥ 90	902	23	1.78 (1.13-2.67)	3	7.02 (1.61-22.8)	87	1.22 (0.98-1.51)
Occupation							
Construction technicians	1351	8	0.46 (0.20-0.90)	0	exp 0.52 (0.00-7.15)	105	1.08 (0.88-1.29)
Construction carpenters	4503	85	1.00 (0.80-1.23)	2	0.89 (0.11-3.22)	440	0.97 (0.88-1.05)
Bricklayers and tile setters	1256	20	0.83 (0.51-1.28)	2	3.17 (0.38-11.4)	117	0.91 (0.76-1.08)
Reinforcement concreters etc	809	16	1.03 (0.59-1.86)	1	2.40 (0.06-13.4)	94	1.14 (0.82-1.39)
Insulators	334	10	3.03 (1.45-5.56)	3	28.9 (5.97-84.6)	29	1.55 (1.04-2.22)
Plumbers	2106	21	1.24 (0.76-1.88)	1	1.78 (0.04-9.90)	102	1.02 (0.84-1.23)
Electricians	2135	9	0.90 (0.41-1.71)	4	9.78 (2.66-25.0)	66	1.02 (0.79-1.29)
Painters and lacquerers	1267	20	1.13 (0.69-1.74)	0	exp 0.53 (0.00-6.97)	117	1.20 (0.99-1.42)
Other construction workers	2935	60	1.40 (1.07-1.80)	0	exp 1.22 (0.00-3.02)	250	1.07 (0.94-1.21)

Exp = expected number of cancer cases. This parameter is given when no cases were observed.

cupation. Similar analyses were performed for mesothelioma, but due to the low number of cases, not all of the above variables could be included into the models. SAS software was used in the statistical analyses.

Results

A total of 1320 cases of cancer were observed among the male construction workers during the follow-up (Table 3). The risk was significantly increased for mesothelioma (SIR 1.96, 95% CI = 1.04-3.35) but not for lung cancer (SIR 1.07, 95% CI = 0.94-1.20).

The SIR of lung cancer was highest among insulators (SIR 3.03, 95% CI = 1.45-5.56) (Table 3). The SIR of lung cancer was also significantly increased among those with an ILO small opacity score of at least 1/0. Those with pleural plaques had a

slightly, but not significantly increased SIR of lung cancer. The SIR of lung cancer increased as the exposure index increased. About 97% of the lung cancers occurred among current or ex-smokers.

Table 4 reports the relative risks of lung cancer from the univariate and multivariate internal analyses. The risk estimates from the univariate and multivariate analyses are very similar, except for some occupational groups. The RR was 35 (95% CI = 16-74) among smokers as compared to nonsmokers and 4.6 (95% CI = 2.1-10) among ex-smokers as compared to nonsmokers. Those with an ILO fibrosis score of at least 1/0 had a 1.9-fold and those with the highest value of the exposure index a 3.3-fold risk of lung cancer. In comparison to construction technicians, the RRs were increased in all the other construction

occupations, but in the multivariate analysis statistically significantly increased estimates were observed only for insulators, construction carpenters, and other construction workers.

There were only 13 cases of mesothelioma. The SIR of mesothelioma was significantly increased among insulators (SIR 28.9, 95% CI = 5.97-84.6) and electricians (SIR 9.78, 95% CI = 2.66-25.0). There were no cases of mesothelioma among the current smokers (Table 3). Because of the low number of cases of mesothelioma and lack of cases in several strata, the internal analysis of relative risk included only age, occurrence of pleural plaques, and intensity of exposure (two lowest categories combined). Again the results of the univariate and multivariate analysis were very similar, the risk increased with in-

TABLE 4

Age- and smoking-adjusted relative risk of lung cancer (RR) with 95% confidence intervals (CI) in Finnish construction workers according to a univariate and a multivariate log linear model

	Univariate analysis		Multivariate analysis	
	RR	95% CI	RR	95% CI
Pleural plaques				
No	1.0	ref	1.0	ref
Yes	1.3	(1.0–1.7)	1.2	(0.9–1.6)
ILO fibrosis score				
< 1/0	1.0	ref	1.0	ref
≥ 1/0	2.0	(1.4–3.0)	1.9	(1.3–2.7)
Asbestos exposure index				
< 20	1.0	ref	1.0	ref
20–39	1.2	(0.6–2.5)	1.3	(0.6–2.6)
40–89	1.7	(0.8–3.4)	1.8	(0.9–3.8)
≥ 90	2.7	(1.2–6.0)	3.3	(1.3–8.3)
Occupation				
Construction technicians	1.0	ref	1.0	ref
Construction carpenters	2.0	(0.9–4.0)	2.1	1.0–4.4
Bricklayers and tile setters	1.6	(0.7–3.7)	1.6	0.7–3.7
Reinforcement concreters etc	1.9	(0.8–4.3)	2.1	0.8–4.9
Insulators	5.0	(2.0–12.6)	3.7	1.4–9.9
Plumbers	2.4	(1.1–5.3)	1.5	0.6–3.9
Electricians	1.8	(0.7–4.7)	2.2	0.8–5.8
Painters and lacquerers	2.1	(0.9–4.7)	1.9	0.9–4.4
Other construction workers	2.3	(1.1–4.9)	2.7	1.3–5.6

The following variables were included into the multivariate model: age (continuous variable), smoking, occurrence of pleural plaques, ILO fibrosis score, asbestos exposure index, and occupation.

TABLE 5

Age-Adjusted Relative Risk of Mesothelioma (RR) with 95% Confidence Intervals (CI) in Finnish Construction Workers According to a univariate and a multivariate log linear model

	Univariate analysis		Multivariate analysis	
	RR	95% CI	RR	95% CI
Pleural plaques				
No	1.0	ref	1.0	ref
Yes	0.7	(0.3–1.6)	0.6	(0.3–1.4)
Asbestos exposure index				
0–39	1.0	ref	1.0	ref
40–89	1.9	(0.7–5.1)	1.9	(0.7–5.2)
≥ 90	10.1	(3.4–30.1)	10.5	(3.5–31.3)

The following variables were included into the multivariate model: age (continuous variable), occurrence of pleural plaques and asbestos exposure index.

creasing value of the exposure index, but was lower for those with pleural plaques than for those without plaques (Table 5).

Discussion

The risk of total cancer and of lung cancer among the male construction workers overall was similar to that of the general male population, but the risk of mesothelioma was significantly increased. Possible healthy

worker effort in the case of cancer incidence is much smaller than in mortality studies and is restricted to the very first years of follow-up. Although the reference population also includes numerous asbestos-exposed individuals this can only bias the observed risk estimates slightly downward. The prevalence of smokers among the participants of our study (Table 2) was similar to that reported in a random sample of

the general population at the same point of time.¹³ The differences in smoking habits thus have probably not biased the results significantly. We conclude that the risk of lung cancer among construction workers is close to that of the general population.

Of the occupational groups, insulators had clearly the highest risk of lung cancer. Their risk of mesothelioma was also higher than among the

other occupational groups, although the number of cases of mesothelioma in each of the groups was small. These observations are well in line with the industrial hygiene data, ie, exposure to asbestos was heavy during the installation of pipe and boiler insulation and such tasks were frequent among insulators during the past decades. All in all, the occupation-specific SIRs of lung cancer in our study were similar to those in previous job-title-based follow-up studies in the Nordic countries and in Switzerland.¹⁴⁻¹⁷ It must be underlined that for the Finnish part of the Nordic study, there is considerable overlap with the present study and the observed risk estimates are therefore not independent. There have been inter-country differences in the use of different types of asbestos. In Finland, anthophyllite asbestos was widely used, while in other countries chrysotile accounted for a higher proportion of all asbestos used. There is not enough data on use of different types of asbestos in the construction materials to assess potential differences in exposure patterns of construction workers in different countries.

Even if the overall risk of cancer or the risk of lung cancer in construction workers was similar to that in the general population, cases of asbestos-related disease occur frequently among construction workers.^{5,18} It is obvious that some of the workers in these trades were heavily exposed to asbestos. The identification of persons with a heavy exposure is a challenge for those involved in the medical and social follow-up or planning of lung cancer screening trials among these workers. Bronchoalveolar lavage and lung tissue asbestos fiber measurements are often useful in medicolegal cases, but their use is restricted to cases in which bronchoscopy or surgery are based on clinical indications, and such measurements are therefore not feasible in the exposure assessment of large populations of healthy individuals.^{7,19} Of the indicators tested

in our study, the presence of lung fibrosis in chest-rays identified a group with a 1.9-fold risk of lung cancer as compared to those without such changes, while the risk of lung cancer among those with pleural plaques was only slightly increased.

A high value (≥ 90) of the expert-evaluated exposure index revealed a group with a 3.3-fold risk of lung cancer as compared to the group with the lowest value of the index (< 20). We defined the cutoff point for the highest exposure category with the aim of including only about 1,000 cohort members with the highest exposure. That is, only about 6% of the construction workers were classified into this group with the highest exposure. A previous Swedish study among construction workers found that an expert evaluation of job categories was better than self-reported exposure in assessing the exposure and consequent risk of lung cancer.⁸ Both methods were subject to important misclassification and tended to identify better the use of asbestos cement products than the use of asbestos insulation products. In addition to the problems inherent in the identification of asbestos products from among all the construction materials handled during the work career of a typical construction worker, even more problems are encountered when assessing bystander exposure from the asbestos handled by other workers at the same work sites. Such exposure may be very important, especially from asbestos spraying or pipe or boiler insulation work with friable asbestos lagging.²⁰ We used an exposure index which was derived from industrial hygiene measurements (fibers/mL), it must be underlined that the value of the index should not be taken as an absolute value of cumulative exposure in fiber-years (fibers/mL * years). The reported activities are ones that the respondents reported as their main type of work, and the weighting factors describe the exposure level during the most typical exposure situation during that type of work. On the

other hand it was impossible to estimate the absolute duration of the specific asbestos-exposing activity during a typical workday. For example, the most typical exposure situation in the demolition of old pipes is the removal of the old pipe insulation, and the average exposure level during the removal of such insulation material was estimated to be 5 fibers/mL. However, we don't know the typical distribution of the working hours during the demolition of old pipes between the removal of the insulation material and other activities, and the variation between the different demolition work sites.

In our study, the inclusion of the exposure index and occupation in the same multivariate analysis of relative risk of lung cancer reduced the univariate risk estimates most markedly for insulators and plumbers. This indicates indirectly that our exposure index identified best the risk caused by pipe insulation products. Interestingly, the multivariate risk estimates were quite high for all the occupations even if the exposure index was included in the model. That is, either the index did not take properly into account all asbestos exposure (eg, indirect bystander exposure), or there are relevant confounding exposures other than asbestos and smoking in these occupations. Overall the similarity of the results between the univariate and multivariate analyses indicates that there was relatively little correlation between the variables. It seems that the different asbestos exposure indices either capture different aspects of asbestos exposure or that the misclassification is independent among the indices. The practical consequence of these observations would be that combinations of the indices could be used to identify the subgroups with the highest risk of asbestos-related lung cancer.

Because of the small number of observed cases, it is difficult to draw firm conclusions on the distribution of the risk of mesothelioma among construction workers. It is interesting nevertheless that the risk seemed to

be lower among those with pleural plaques and current smokers than among those without plaques and the non- or ex-smokers. These observations would warrant verification in some of the existing large cohorts of asbestos-exposed workers with a relatively long follow-up. Overall the SIR of mesothelioma was only 2-fold among the construction workers as compared to the general male population. Yet, most of the male mesotheliomas in the general population are attributable to occupational exposure to asbestos, and the SIR would have been considerably higher if the comparison would have been made to a truly unexposed population. Such reference rates were not available.

In conclusion our data show that subpopulations with a high risk of lung cancer and mesothelioma can be selected from among the long-term construction workers based on exposure and radiographic information. Of the indicators of asbestos exposure, pleural plaques did not identify a group with an elevated risk of lung cancer, while lung fibrosis score of at least 1/0 identified a 2-fold and a high value of the expert-evaluated exposure index a 3-fold relative risk of lung cancer. The highest risk (RR = 3.7 among insulators), however, was identified by using the exact job title.

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