Occupational Risks for Pleural Mesothelioma in Sweden, 1961-79 [1]

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ABSTRACT—From national population-based registries linking cancer incidence from 1961 to 1979 with 1960 census data on industry and occupation for all employed individuals in Sweden, a systematic assessment was made of pleural mesothelioma occurrence according to occupational and industrial classifications. There were 318 cases of pleural mesothelioma recorded during the 19-year follow-up period among males employed in 1960, with significant variation by industrial and occupational categorizations. The observed number of pleural mesotheliomas for men employed in the sugar refining, cellulose, wood and pulp, shipbuilding, and railroad equipment manufacturing industries was more than three times the number expected. Occupations with at least twofold excess of mesotheliomas included the craftsman categories of plumbers, mechanics and repairmen, electricians, painters, tire makers, and stationary equipment operators. Our findings are consistent with available data relating mesothelioma to occupational asbestos exposure in other countries, although unexpected associations were found that deserve further epidemiologic study.—JNCI 1985; 74:61-66.

Malignant pleural mesothelioma is a rare and highly fatal tumor arising from the mesothelial surface lining the pleural cavities. The pleura is the most common site of origin for mesotheliomas in most countries, including Sweden, where 90% of all mesotheliomas among males and 60% among females were from the pleura during the period 1961-79. Throughout the world this neoplasm has been strongly associated with occupational exposure to asbestos (*1*). The rarity of mesothelioma, however, has made evaluation of occupational associations difficult, except in large heavily exposed groups (*2*). The CER in Sweden (*3, 4*), which links cancer incidence data with employment data, provides a unique opportunity to assess systematically the occurrence of pleural mesothelioma by industry and occupation for an entire country. In this paper we utilize this linked data resource to develop new etiologic hypotheses and provide further information regarding previously reported occupational findings.

METHODS

The CER links the cancer incidence data (1961-79) of the National Swedish Cancer Registry with occupational information obtained in the 1960 national census. The CER now contains about 605,000 cancer cases (*5*). Every Swedish citizen has a personal identification number, making linkage between data sources easy. A national law requires cancer cases to be reported to the Registry (*6*). Nonreporting for cancers of the trachea, bronchus, lung, and pleura is estimated to be less than 3% (*7*). For the period under study (1961-79), 99% of all pleural cancers (ICD 7th Revision, 162.2; ICD 8th Revision, 163.0) and 100% of all cancers recorded as malignant pleural mesotheliomas were microscopically verified. Only verified malignant pleural mesotheliomas are used for this analysis.

An SIR was used to estimate risks of mesothelioma for various occupational and industrial categories for the 19-year period. The SIR is the ratio of the observed number of cases of pleural mesothelioma in a particular industry or occupation to the expected number of cases. The expected number of cases is generated by application of the birth cohort- and sex-specific rates for 1961-79 from the general population of Sweden to the birth cohort- and sex-specific distributions of the various occupational and industrial groupings. Five-year birth cohorts were used in these calculations. Because of variation in cancer incidence rates by region, the SIR were also adjusted for region, with the use of the 3 metropolitan areas and 24 counties in an indirect standardization (*8*). Statistical significance was tested under the assumption that the observed number of mesotheliomas followed a Poisson distribution (*9*). Industrial and occupational classifications from the 1960 census (Folk-och Bostadsrakningen 1960) were used to define industrial and occupational cohorts (*10*). These codes are revised versions of the standards from the International Labour Office and the United Nations (*11, 12*). SIR were calculated for all broad (1-digit code) industrial and occupational groups, for all manufacturing and craftsman-tradesman groups (2-digit code), and for selected specific (3-digit code) industries and occupations. Since at the 3-digit level there are more than 300 industry codes and 300 occupation codes, only those industries and occupations with 3 or more observed cases were included in the analysis at this level. When numbers permitted, the distribution of pleural mesotheliomas was also determined for occupations within specific industries to enable a more detailed evaluation of risk.

ABBREVIATIONS USED: CER=Cancer-Environment Registry; ICD=International Classification of Diseases; ind.=industry code(s); NOC=not otherwise classified; occ.=occupational code(s); SIR=standardized incidence ratio(s).

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RESULTS

There were 318 cases of malignant pleural mesotheliomas during the 19-year follow-up among males employed in 1960. The SIR for the 10 broad industries and occupations in Sweden are presented in table 1. Significantly elevated SIR were found for the manufacturing and construction industries (ind. 3 and 4). For occupation, a significantly increased risk was observed for craftsmen and production-process workers (occ. 7). These broad industrial and occupational categories also had the largest numbers of mesotheliomas. Significantly low SIR were observed for farmers (ind. 0; occ. 4) and sales workers (occ. 3).

The manufacturing industries (ind. 2 and 3), the construction industry (ind. 4), and the production-process workers (occ. 7 and 8) were examined further at the 2- and 3-digit coding levels (tables 2, 3). Employment in the general industries (2-digit code level) of paper and allied products (ind. 26), rubber (ind. 30), transportation equipment (ind. 36), and other construction (ind. 41) was associated with a significantly increased SIR (table 2). Other manufacturing industries also showing elevated risks included textile (ind. 22), furniture (ind. 25), chemical (ind. 31), stone, clay, and glass (ind. 33), and machinery and electronics (ind. 35). An examination of the 3-digit level indicates that increased SIR are seen for both cellulose, wood, and pulp (ind. 261) and paper mill industries (ind. 262) within industry 26; that work in shipbuilding and repair (ind. 360) and manufacturing of railroad equipment (ind. 362) account for the high risk within the transportation equipment category (ind. 36); and that painting (ind. 410) and plumbing (ind. 413) are the specific industries accounting for the excess risk within other construction (ind. 41). Significantly elevated SIR were also observed for other specific industries, including sugar factories and refineries (ind. 206) and other manufacturing of industrial chemicals (ind. 312).

Results for general and specific occupations are presented in table 3. Significantly elevated SIR were seen for the general category of toolmakers, machinists, plumbers, welders, and related jobs (occ. 75) and for painters and paperhangers (occ. 78), whereas nonsignificantly increased SIR were seen for some other general occupational categories. Within the general occupation of toolmakers, machinists, plumbers, welders, and related jobs (occ. 75), all of the specific occupations had elevated SIR, two of them significant: mechanics and repairmen (occ. 752) and plumbers and pipe fitters (occ. 754). Of the 16 mechanics and repairmen (occ. 752) who developed pleural mesotheliomas, 4 were employed in the manufacturing of railroad equipment (ind. 362) for an occupation within industry SIR of 9.5, 2 were employed in sugar factories and refineries (ind. 206) for an SIR of 32.5, and 2 were employed in shipbuilding and repair (ind. 360) for an SIR of 11.5. Other specific occupations associated with significantly elevated risks were electricians and electrical repairmen (occ. 761), painters and paperhangers (occ. 781), cellulose and pulp workers (occ. 834), tire workers and vulcanizers (occ. 851), and operators of stationary engines and related equipment (occ. 871). Twofold and greater (nonsignificant) risks were observed for blacksmiths (occ. 735), sheetmetal workers (occ. 753), bricklayers, plasterers, and cement finishers (occ. 791), and craftsmen and production workers (NOC) (occ. 858). Two of the 3 cases in the last occupation occurred in the cement and light concrete industry (ind. 334), which gives an SIR of 3.4 for the occupation within industry. There was also a more than twofold excess risk among woodworkers (NOC) (occ. 779); 2 of these cases were within the sawmill industry (ind. 240), yielding an SIR of 2.1. A fourfold excess (based on 1 case) was found for the

TABLE 1.—*SIR for pleural mesothelioma by major divisions of industry and occupation among males*

Code	Major industry	Cases	SIR[a]	Code	Major occupation	Cases	SIR[a]
0	Farming, forestry, hunting, and fishing	21	0.4[b]	0	Professional, technical, and related workers	41	1.2
1	Mining and quarrying	0	—	1	Administrative, executive, and managerial workers	12	1.0
2	Manufacturing I	56	1.2	2	Clerical workers	9	0.7
3	Manufacturing II	103	1.5[b]	3	Sales workers	9	0.4[b]
4	Construction	63	1.6[b]	4	Farmers, fishermen, hunters, and related workers	21	0.4[b]
5	Electric, gas, water, and sanitary services	2	0.4	5	Miners, quarrymen, and related workers	2	1.3
6	Trade, finance, insurance, and real estate	20	0.6	6	Transport and communications workers	20	0.9
7	Transportation and communication	20	0.8	7	Craftsmen, production-process workers, and laborers	138	1.6[b]
8	Services	30	0.9	8	Craftsmen, production-process workers, and laborers (NOC)	48	1.0
9	Nonclassifiable establishments	3	3.4	9	Service, sport, and recreation workers	18	1.2

[a] Adjusted for age and region.
[b] $P<0.01$.

TABLE 2.—*SIR for pleural mesothelioma by general (2-digit) and specific (3-digit) manufacturing industries among males*

Code	General industry	Cases	SIR[a]	Code	Specific industry	Cases	SIR[a]
20	Food products	10	1.1	206	Sugar factories and refineries	7	6.3[b]
21	Tobacco and beverages	0	—				
22	Textile	9	1.6	220	Wool	3	2.7
				221	Cotton	3	1.3
23	Apparel (includes shoes and furs)	3	0.5				
24	Lumber and wood products	4	0.5				
25	Furniture and fixtures	4	1.4	250	Furniture manufacturing	3	1.4
26	Paper and allied products	23	2.9[b]	261	Cellulose, wood, and pulp	14	4.7[b]
				262	Paper mills	8	2.4
27	Printing and publishing	3	0.6				
28	Leather	0	—				
30	Rubber	6	3.0[c]	300	Rubber manufacturing	5	2.8
31	Chemical	9	2.2	312	Other manufacturing of industrial chemicals	6	3.7[c]
32	Coal and petroleum refining	0	—				
33	Stone, clay, and glass	8	1.3	334	Manufacturing of cement and light concrete	3	2.0
34	Fabricated metal products	11	0.8	345	Iron and steel manufacturing	6	1.1
35	Machinery and electronics	29	1.4	350	Machine manufacturing	19	1.2
				352	Other electrical industry	10	2.0
36	Transportation equipment	40	2.3[b]	360	Shipbuilding and repair	25	3.0[b]
				362	Manufacturing of railroad equipment	11	7.2[b]
37	Miscellaneous manufacturing	0	—				
39	Manufacturing (NOC)	0	—				
40	House building construction	27	1.3	400	House building	27	1.3
41	Other construction	36	1.9[b]	410	Painting	13	2.9[b]
				413	Plumbing	12	4.2[b]
				414	Electrical installation	3	1.6
				415	Road and power plant construction	6	0.8

[a] Adjusted for age and region.
[b] $P<.01$.
[c] $P<.05$.

specific occupation of insulators (occ. 794), an uncommon occupation (1,677 men) in Sweden.

Specific occupations not included in table 3 but with significantly elevated SIR were chemical engineers (occ. 004; 6 cases; SIR=3.2), railroad engineers and firemen (occ. 631; 4 cases; SIR=5.0), and transportation workers (NOC) (occ. 639; 3 cases; SIR=16.4).

The small numbers of cases often precluded examination of risks associated with occupations within industries. For the sugar refining, cellulose, wood and pulp, paper, shipbuilding, and railroad equipment manufacturing industries, however, elevated SIR were found for multiple occupations, although the SIR tended to be highest for mechanics and repairmen.

Although only 41 cases of malignant pleural mesothelioma were observed among women employed in 1960, there were some notable results at the 3-digit industry and occupation levels. A significantly increased SIR was observed for the apparel industry (ind. 233; 6 cases; SIR=3.1). Five of these cases occurred among seamstresses (occ. 716), with an SIR of 3.4 for this occupation within the apparel industry. The occupations of nurses and midwives (occ. 040 and 043; 6 cases; SIR=3.3) had significantly more cases of mesothelioma than expected.

DISCUSSION

This survey of malignant pleural mesothelioma incidence in Sweden and its relationship to occupation and industry revealed findings generally consistent with those reported from other countries (*13*). The highest incidence ratios at the broadest industry and occupation levels were for manufacturing and construction trades, where the potential for exposure to asbestos is greatest. Within this wide category, industries involving the manufacture of ships, railroad cars, paper, pulp, and sugar and occupations involving plumbing, metal, machine and electrical work, and painting showed the largest elevations in the SIR. The four industries account for 20% of the pleural mesotheliomas but only 4% of the work force.

The threefold excess of mesothelioma among shipyard workers adds Sweden to the long list of countries in Europe and North America where this association has been seen (*14, 15*). Of all pleural mesotheliomas among

persons employed in 1960, 8% occurred in the shipbuilding industry, which accounts for about 1% of the total work force.

The almost sevenfold excess among railroad car construction workers confirms an excess recently reported in the United States and other countries (*16*) and seems due to asbestos exposure in the fitting and repair of car engines. Similarly, the association with plumbing and pipe fitting is consistent with previous reports (*17, 18*) of mesothelioma following asbestos exposure in these occupations.

The findings for the paper and pulp industry are new, and the number of tumors found among the workers in this industry was surprisingly high. Mesotheliomas have not been reported among pulp workers in the United States, where the industry is a major one; nor have lung cancer risks been found to be elevated (*19*). The excess in Sweden seems related to differences in the mechanical and chemical processes for converting wood to pulp and the consequent heavier use of asbestos as an insulation material in the machines employed in Sweden. Although more pronounced among workers in the cellulose wood and pulp industry, the increased risk also extends to paper production, where chemical and dust exposure to wood products is considered to be lower but where asbestos has been used in processing equipment. The association with the sugar refinery workers appears most likely to be due to asbestos exposure that occurred during

TABLE 3.—*SIR for pleural mesothelioma by general (2-digit) and specific (3-digit) craftsman-tradesman occupation among males*

Code	General occupation	Cases	SIR[a]	Code	Specific occupation	Cases	SIR[a]
70	Spinners, weavers, knitters, and related jobs	2	0.7				
71	Tailors, cutters, furriers, and related jobs	1	0.4				
72	Shoe and leather workers	0	—				
73	Metal making and treating workers	7	1.3	735	Blacksmiths	5	3.2
74	Precision instrument makers	1	0.7				
75	Toolmakers, machinists, plumbers, welders, and related jobs	59	2.0[b]	750	Toolmakers and machinists	11	1.4
				751	Assemblers and machine erectors	3	1.5
				752	Mechanics and repairmen	16	2.4[b]
				753	Sheetmetal workers	4	2.0
				754	Plumbers and pipe fitters	13	4.8[b]
				755	Welders and flame cutters	4	1.6
				756	Structural metal workers	4	1.8
				758	Other mechanical and metal workers	4	1.4
76	Electricians and electronic workers	12	1.8	761	Electricians and electrical repairmen	10	2.3[c]
77	Woodworkers	25	1.4	771	Carpenters and joiners	12	1.4
				772	Cabinet workers	8	1.4
				779	Woodworkers (NOC)	3	2.5
78	Painters and paperhangers	12	2.0[c]	781	Painters and paperhangers	12	2.3[c]
79	Bricklayers and construction workers (NOC)	19	1.4	791	Bricklayers, plasterers, and cement finishers	6	2.1
				793	Construction workers (NOC)	10	1.1
				794	Insulators	1	4.3
80	Graphical workers	1	0.3				
81	Potters, kilnmen, and glass workers	1	0.6				
82	Food industry workers	1	0.2				
83	Chemical and cellulose workers	8	1.6	834	Cellulose and pulp workers	5	4.0[c]
84	Tobacco workers	0	—				
85	Craftsmen and production-process workers	7	1.8	851	Tire workers and vulcanizers	4	4.4[c]
				858	Craftsmen and production workers (NOC)	3	2.5
86	Laborer (NOC)	9	0.9				
87	Stationary engine and equipment operators	9	1.4	871	Operators of stationary engines and related equipment	7	3.9[b]
88	Packers, handlers, and longshoremen	12	1.0	882	Longshoremen and freight handlers	3	1.3
				883	Stockroom workers	9	1.0

[a] Adjusted for age and region.
[b] $P<.01$.
[c] $P<.05$.

the annual dismantling of the machinery used in sugar production (*20, 21*).

We found a small elevation in risk for males in the textile industry, consistent with reports of mesothelioma among asbestos textile makers (*22*), but the excess was limited to several high-risk occupations such as mechanics and repairmen and operators of stationary equipment, and it was not found among the occupation "textile workers."

Other findings that can be considered as new leads for occupationally induced pleural mesothelioma include elevated SIR among rubber workers, machinists, metal workers, electricians, and painters, although elevated relative risks for mesotheliomas have been reported for the rubber products industry, electricians, and painters in a recent case-control study in which data from the Connecticut Tumor Registry were used (*17*). In the rubber industry in Sweden large amounts of talc, which may have contained asbestos (*23, 24*), have been used.

The results of this analysis linking census and cancer incidence data have served to quantify risks of mesothelioma and identify specific industries and occupations in Sweden where further study may be warranted. The identification of specific industries and occupations for further study was the main rationale for the study, since the CER seems most useful as a tool for generating hypotheses about the occupational causes of cancer. Certain limitations of the CER, however, generally preclude making definitive inferences about the role of occupation in cancer etiology. Most notable are the lack of information on risk factors such as smoking, diet, and other environmental exposures that may affect cancer incidence (although for mesothelioma there are no established risk factors other than asbestos exposure) and the lack of an occupational history. Since occupational change is not very common in Sweden, the occupational categorization reported in the 1960 census is likely to represent an individual's usual adult job classification.

No linked registry is better than the quality of its underlying registries. In the linkage, only 1% of the cancer cases could not be traced in the census (*7*). False matching of cancer cases to census information has been estimated to be less than 0.5% (*25*). There may, of course, be errors in the census classification, but an independent validation of industrial and occupational data by a reinterview of a random sample of the 1960 census revealed close agreement (≈95%) at the broad 1-digit level of coding, with somewhat less agreement for more specific (3-digit) codes (*26*). The problem of multiple comparisons must be recognized in a review of such a large number of occupational categories. The findings in this paper, however, are remarkably consistent with previous studies, suggesting underlying validity to our approach.

The awareness of employees and their physicians regarding asbestos hazards may differ and, consequently, diagnostic procedures may differ by occupation. The diagnosis of pleural mesothelioma is often difficult, and both overreporting and underreporting have been suspected (*27*). Such a problem seems less likely to have occurred for the occupational cohorts in Sweden, since the registration of cancer is thought to be essentially complete and since microscopic verification was obtained for all cancers in the study. It cannot be denied, however, that diagnostic criteria may vary among Swedish pathologists. In addition, some diagnoses may have been influenced by a knowledge of exposure to asbestos, a recently observed phenomenon that could result in differential reporting (*28*).

Finally, the statistical techniques used may have influenced the differential risks by industry and occupation. Because of lack of information on loss to follow-up, either from departure from Sweden or from death, the expected values for the SIR calculations were not based on person-years, but rather they were based on the assumption that the proportions of individuals within each sex-region-birth cohort subgroup for each industry and occupation remained constant over the 19-year follow-up. Thus, if total mortality was elevated (or depressed) for a particular industry or occupation, the expected number of mesotheliomas, which does not take into account loss due to mortality, would be too high (or low) and the corresponding SIR would be too low (or high). Such variations, however, will in most instances affect the SIR by less than a small percent and thus will not alter the interpretation of the data presented (*29*).

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