American Journal of Industrial Medicine 20:371–379 (1991)

Occupational Asbestos Exposure and Mesothelioma Risk in Los Angeles County: Application of an Occupational Hazard Survey Job-Exposure Matrix

Carla Cicioni, MD, Stephanie J. London, MD, DrPH, David H. Garabrant, MD, MPH, Leslie Bernstein, PhD, Karen Phillips, MD, MPH, and John M. Peters, MD, ScD

We evaluated the newly available National Institute for Occupational Safety and Health (NIOSH) National Occupational Hazard Survey (NOHS) job exposure matrix (JEM) by considering mesothelioma risk from asbestos exposure. We applied this system (NOHS–JEM) to the Los Angeles County Cancer Surveillance Program (CSP) to see how many cancer cases could be assigned asbestos exposure and how asbestos exposure affected mesothelioma risk. Using the same CSP data, our "experts" classified asbestos exposure simply by occupation and industry. Both exposure classifications were divided into low and high; the NOHS–JEM by the number of exposed people per couplet, and ours by judgments of intensity. Odds ratios (OR) for mesothelioma risk for low and high asbestos exposure for the NOHS–JEM were 2.0 (95% C.I. 1.2–3.4) and 2.5 (95% C.I. 1.2–4.8). For ours, corresponding risks were 1.6 (95% C.I. 1.1–2.4) and 6.3 (95% C.I. 2.5–15.1). Our system was able to assign more cases to couplets then the NOHS–JEM (35,895 to 22,369). Three limitations of the NOHS–JEM were that many occupation-industry couplets were not classified at all, many couplets associated with past asbestos exposure (before the 1972–1974 NOHS survey) were not classified as asbestos exposure, and no assessment of intensity was made. These limitations may apply to other exposures and should be carefully considered before the NOHS–JEM is applied to other case-control studies.

Key words: job exposure matrix, inferring occupational exposure, mesothelioma risk, surveillance programs

INTRODUCTION

Reported occupations and industries are often used as surrogates for occupational exposure assessment in surveillance programs and in case-control studies. Both occupation and industry classifications lack sensitivity and specificity in defining exposures, resulting in misclassification of exposure status. Combining information across occupation and industry provides greater accuracy as to exposure status. To provide more detailed exposure information based on these classifications, job ex-

Division of Occupational and Environmental Medicine, Department of Preventive Medicine, University of Southern California School of Medicine, Los Angeles, CA.
Address reprint requests to Dr. John M. Peters, Department of Preventive Medicine, University of Southern California School of Medicine, 1420 San Pablo Street, B-306, Los Angeles, CA 90033–9987.
Accepted for publication November 27, 1990.

posure matrices (JEM), defined as "a cross-classification of job titles with a list of agents to which persons carrying out the job are exposed" [Acheson, 1982], have been developed.

One approach is to assign exposures based on the experience of occupational health professionals and available literature. Several efforts have been made to test the efficiency of this approach [Hoar et al., 1980; Macaluso et al., 1982; Coggon et al., 1984; Pannett et al., 1985; Linet et al., 1987; Steineck et al., 1989; Heederick et al., 1989]. Siemiatycki et al. [1987] extended this approach to include detailed evaluation of exposure by professional industrial hygienists.

Another potential resource is represented by the National Occupational Hazard Survey (NOHS) carried out between 1972 and 1974 in the United States by the National Institute for Occupational Safety and Health [Sieber et al., 1991], which collected information at the work site on chemical and physical agents in a wide range of occupations and industries. It was anticipated that the resulting data from this survey would be used for occupational surveillance activities and for application to epidemiologic studies. One potential drawback of this approach is that this JEM is founded on exposure conditions in 1972–1974, and these may differ from periods before or after this time interval.

Since malignant mesothelioma is a rare tumor strongly associated with asbestos exposure [Hulks et al., 1989; Zwi et al., 1989], we decided to compare the NIOSH NOHS approach with a simple "expert" approach for assessing the association between asbestos exposure and mesothelioma occurrence in Los Angeles County, based on data collected by the Los Angeles County/University of Southern California Cancer Surveillance Program (CSP). Mesothelioma was chosen because it occurs in sufficient numbers for analysis and because we know of no single tumor besides angiosarcoma of the liver with a higher attributable risk from a specific occupational exposure.

MATERIALS AND METHODS

The CSP is a population-based cancer registry that identifies nearly all newly diagnosed cancer cases occurring among the residents of Los Angeles County (Hisserich et al., 1975). Only patients with basal and squamous cell carcinomas of the skin are not included in the registry data base. Since 1972, well over 95% of the patients diagnosed with incident cancer of all other sites and histologies who are residents of Los Angeles County have been identified. A detailed description of the methodology, organization, and administration of the CSP has been published elsewhere [Mack, 1977]. As of May 1987, the CSP became part of the statewide California Tumor Registry.

Cancer patients are identified from hospital, clinic, and pathology records as well as from death certificates. Data items collected for each cancer patient include tumor site, histology, date of birth, age at and date of diagnosis, sex, race, and occupation and industry at the time of diagnosis. Occupation and industry are coded according to the 1970 United States Bureau of the Census classification system [U.S. Bureau of the Census, 1977].

During 1972–1988, 46,644 cancers were diagnosed among men aged 18–64, who had information on occupation and industry available. We excluded cases of lung cancer because of the well-established risk associated with asbestos exposure. Thus,

the analysis included 143 patients diagnosed with mesothelioma and 35,751 with cancer other than lung cancer. Proportions of cases with missing information on occupational and industry do not vary by tumor site.

Asbestos Exposure Categories

The NOHS–JEM is based on a survey of 538,871 workers [National Occupational Hazard Survey, 1978]. The number of surveyed workers and the number who were exposed to asbestos are provided for occupational categories within industry categories. This results in a series of occupation-industry couplets in which asbestos exposure is known to have occurred. This system does not evaluate the intensity of such exposure. For the purposes of this study, the industry codes from NOHS were changed from the original SIC codes to 1970 U.S. census codes for industry so that the data would be compatible with CSP information. The original industry data collected by NIOSH during the NOHS survey were categorized according to the 1972 Standard Industrial Classification system (SIC) and were converted by NIOSH to 1970 BOC industry codes. (The data were supplied to us in this form, with both industry and occupation classified by 1970 BOC codes). Because the original data had been coded to 4-digit SIC codes, the conversion was possible with a high degree of accuracy. An edit of the 16,000 industry and occupation pairs contained in the NOHS data indicated that all but 1% of the pairs could be correctly coded to the 1970 BOC system [Sieber et al., 1991]. Thus, incompatibilities between the 1972 SIC and 1970 BOC coding systems are unlikely to result in appreciable misclassification.

The data from the National Occupational Hazard survey (NOHS) were adapted to the CSP data by the following methods. The NOHS data contained information on industry and on occupation coded to the 1970 Bureau of Census classification system (1970 BOC). For each occupation within each industry, the number of workers employed was listed, and exposures were identified. For each exposure identified in an occupation and industry couplet, the number of workers observed to be exposed to that agent was listed. We calculated a probability of exposure to asbestos for each occupation and industry couplet by taking the ratio of the number of workers observed to have asbestos exposure to the number of workers employed. This probability of exposure was then assigned to each subject in the CSP whose information reflected employment in that occupation and industry couplet. For the analyses presented here, three asbestos exposure probability categories were created: no exposure, $>0-0.1$, and >0.1.

For our job title exposure level, each 1970 U.S. census code for occupation and industry was given an asbestos exposure level by two of us (CC and JMP), based on judgements of likelihood of exposure and exposure intensity. Exposures were graded "none", "low", and "high." The exposure categories were decided blindly and are listed in Appendix A.

Statistical Methods

For the purposes of this study, we obtained estimates of the odds ratio of mesothelioma associated with a particular level of asbestos exposure by comparing the number of patients with mesothelioma in a particular exposure category to the number of other cancer patients (excluding lung because of its known association with asbestos) in that particular category. This case-control design is similar to that of a

TABLE I. Characteristics of NOHS–JEM and CSP

Classification	N	%
NOHS–JEM		
Surveyed workers	539,871	
Occupation-industry couplets	8,491	
Workers/couplet	63.6	
Range of number of workers per couplet	1 to 5,217	
CSP		
Male cancer cases aged 18–64	46,644	100
Mesothelioma	143	0.3
Lung cancer	10,749	23
Other cancer	35,752	77
Subset of cancer cases in NOHS–JEM couplets	29,479	63
Occupation-industry couplets	7,426	100
Couplets in NOHS–JEM	3,310	45

hospital-based case-control study, where controls are patients with diagnoses thought not to be associated with the risk factors under study.

Data were analyzed by standard case-control methods [Breslow and Day, 1980]. Both crude and adjusted (age and race/ethnicity) odds ratios were estimated using the no exposure-level category as the baseline category. For the adjusted analyses, age was categorized as 18–24, 25–34, 35–44, 45–54, and 55–64; racial/ethnic groups were non-Spanish-surnamed whites, Spanish surnamed whites, blacks and others (a category consisting primarily of Asian subgroups). Summary odds ratios were estimated using the Mantel–Haenszel method; 95% confidence limits for the odds ratio were computed using Cornfield's methods.

RESULTS

Application of NOHS–JEM to CSP Data

The 1970 U.S. census codes for industry and occupation delineate 424 occupations and 213 industries, with a maximum possible number of occupation-industry couplets of 90,312. Since many occupations are industry related, the number of actual couplets is much lower. NOHS–JEM provides information on hazard exposure for 8,491 occupation-industry couplets (Table I). The number of workers surveyed in each couplet ranged from 1 to 5,217, and for 3,351 couplets (39.5%), the number was ≤ 10.

Many NOHS occupation-industry couplets did not occur among the Los Angeles County cancer patient population studied. On the other hand, many occupation-industry couplets not included in NOHS gave rise to at least one cancer case in the County. The 46,644 male cancer cases identified by the CSP worked in 7,426 occupation-industry couplets at the time of diagnosis; of these, 4,116 (55%) were not included in the NOHS–JEM. Many of these occupation-industry pairings are rare, so that the number of cancer cases in couplets included in NOHS–JEM was 63% of the total.

Mesothelioma risk based on NOHS–JEM asbestos exposure categories. Of the 8,491 occupation-industry couplets included in NOHS, 544 had an asbestos exposure probability of >0. Based on the NOHS–JEM, asbestos exposure probability

TABLE II. Mesothelioma Risk in Exposure Categories Based on NOHS–JEM Asbestos Exposure Probabilities

Exposure probability	0	>0–0.10	>0.10	Total
Mesotheliomas	68	22	11	101
Cancer controls	18,185	2,887	1,196	22,268
Crude OR[a]	1	2.0	2.5	
95% C.L.		1.2–3.4	1.2–4.8	
Adjusted OR[b]	1	2.0	2.4	
95% C.L.		1.2–3.3	1.2–4.7	

[a]OR, odds ratio.
[b]OR adjusted for age and race/ethnicity.

was missing for 42 mesotheliomas and 13,484 cancer controls. Thirty-three of the 101 mesothelioma cases had jobs with an asbestos exposure probability greater then 0 according to NOHS–JEM (Table II). The crude odds ratio was 2.0 (95% confidence limit (CL) 1.2–3.4) for the lower exposure probability (0–0.10), and 2.5 (95% C.L. 1.2–4.8) for the higher exposure probability (>0.10). The odds ratios were not sensitive to the choice of different cut points partly because the number of cases was small and partly because there were few cases with exposure probability of >0.2 (data not shown). Furthermore, adjusting for age and race/ethnicity did not appreciably alter the odds ratios or the confidence intervals (Table II).

Mesothelioma risk based on job title exposure levels. Based on our classification of exposure, 51 mesotheliomas (36% of all mesothelioma cases) had jobs classified as asbestos exposed (Table III). The crude odds ratio was 1.6 (95% C.L. 1.1–2.4) for the low asbestos exposure category, and 6.3 (95% C.L. 2.5–15.1) for the high exposure category.

Comparison of the two methods. In order to describe the degree to which these two JEM methods agreed in the assignment of an exposure classification to cases included in this study, we estimated the correlation between exposure assignments for cancer cases that could be assigned an exposure by both methods (Table IV). There was a weak correlation between the two methods with Spearman correlation coefficient of 0.28. Of the 4,116 cancers in occupation-industry couplets with an exposure probability above 0 according to NOHS–JEM, 1,851 (45%) were in couplets assigned to the "none" exposure category by us.

Of the 288 cancers in occupation-industry couplets classified as highly exposed by us, 180 (62.5%) were in couplets with an asbestos exposure probability equal to 0, according to NOHS–JEM, and 59 (20.5%) in couplets not included in NOHS–JEM. Most of these, 97% of those in 0 exposure probability and 81% of those in unincluded couplets, were in the shipyard industry.

DISCUSSION

We believed that the application of the NOHS–JEM to a well-known carcinogenic hazard would shed light on its advantages and weaknesses. Our analysis reveals several limitations of the application of the NOHS–JEM for exposure assignment in case-control studies. The first is that the time period during which the exposure data

TABLE III. Mesothelioma Risk in Exposure Categories Based on Occupation and Industry (Our Classification)

Asbestos exposure	None	Low	High	Total
Mesotheliomas	92	45	6	143
Cancer controls	27,281	8,189	282	35,752
Crude OR[a]	1	1.6	6.3	
95% C.L.		1.1–2.4	2.5–15.1	
Adjusted OR[b]	1	1.6	6.4	
95% C.L.		1.1–2.3	2.5–15.2	

[a]OR, odds ratio.
[b]OR adjusted for age and race/ethnicity.

TABLE IV. Number of Cancer Cases (Mesothelioma + Cancer Controls) Classified in the Three Exposure Categories Using the NOHS-JEM and Our Classification for Asbestos Exposure

Our job title assignment	NOHS–JEM exposure probability				
	0	≤0.10	>0.10	Not included	Total
NO	14,125	1,521	330	11,397	27,373
LO	3,948	1,386	830	2,070	8,234
HI	180	2	47	59	288
Total	18,253	2,909	1207	13,526	35,895

were collected (1972–1974) may not represent the appropriate etiologic period for an epidemiologic study. This is probably why shipyard workers were not classified as having asbestos exposure in the NOHS–JEM. Another shortcoming is that many occupation-industry couplets were not sampled so that the effective sample size for an analysis may be substantially reduced (more than one-third of our cases could not be assigned an asbestos exposure category). In addition, NOHS–JEM is based on a national sample, and industry-specific exposures may vary by locale. It is also important to note that the NOHS–JEM provides no estimate of exposure level, but only the percentage of workers exposed, which probably accounts for its inability to isolate a high risk group. There were also very few occupational categories with high probabilities of exposure. These limitations may be more severe for asbestos exposure than some other exposures, but our results suggest that the NOHS–JEM should be employed thoughtfully in epidemiologic studies, preferably in combination with industrial hygiene expertise regarding industry specific exposures in the region of interest during the calendar period of interest.

The JEM that we constructed for this study has several shortcomings: it is based only on men under 65 who are likely to have a listing of occupation and industry; it is based on information as of the time of diagnosis; and it is crude, relying on the ability of two of us to assign asbestos exposure by considering lists of jobs and industries. Despite these weaknesses, our system appears to have some advantages over the NOHS–JEM: we were able to make an exposure assignment for every couplet; we were able to incorporate probability of exposure in the past; and we estimated the intensity of exposure. This resulted in a much clearer exposure–effect relationship between asbestos exposure and mesothelioma risk, at least in our high exposure category. Although one could argue that our knowledge of risks of cancer

in the CSP could bias our assignment of asbestos exposure to the occupations and industries, we believe that our choices were objective and would largely be duplicated by others with a knowledge of asbestos use in industry (see Appendix A).

Our reliance on occupation and industry at time of diagnosis introduces misclassification with either approach. This probably accounts for the small fraction of mesothelioma cases that were included in asbestos exposed categories by both methods (23% for NOHS and 36% for ours). Furthermore, the diagnosis of mesothelioma is variable from pathologist to pathologist and region to region [Wright and Sherwin, 1984; Spirtas et al., 1986]. These weaknesses would tend to bias results produced with both methods toward the null.

With the ubiquitous nature of asbestos in the environment, it is also possible that there were significant exposures in some of the occupation-industry couplets considered as unexposed. It may also be true that for other chemical or physical exposures that are less well understood and characterized, the NOHS–JEM will have a greater ability to identify exposures than does professional opinion because the jobs and industries are actually surveyed, although the experience of Linet et al. [1987] does not support this. For example, professional judgement would probably classify asbestos exposure better than a substance such as methylene chloride.

CONCLUSIONS

This study was conducted to gain experience with a promising and newly available JEM (NOHS). Some weaknesses were noted in this system that we have pointed out. It is our general opinion that JEMs, with a few exceptions, have been used with too little thought and evaluation. Our principal message is that investigators should use all JEMs, including the NOHS–JEM, thoughtfully. JEMs should not be considered the principal means of exposure assessment but as part of the armamentarium available for exposure assignment in epidemiologic studies.

ACKNOWLEDGMENTS

This work was supported by NIOSH research training grant IT15 OH07214, by grant CA17054 from the NIH, by grant CA 01291 from the NCI, and by subcontract 050E-8709 with the California Public Health Foundation, which is supported by the California Department of Health Services as part of its statewide cancer reporting program, mandated by Health and Safety Code Section 210 and 211.3. The ideas and opinions expressed herein are those of the authors, and no endorsement of the State of California, Department of Health Services, or the California Public Health Foundation is intended or should be inferred.

REFERENCES

Acheson ED (1982): What are job exposure matrices? Job Exposure Matrices, Conference Report Southampton.

Breslow NE, Day NE (1980): "Statistical Methods for Cancer Research, Vol. I: The Analysis of Case Control Studies." Scientific Publication No. 32. Lyon: International Agency for Research on Cancer.

1970 Census of Population (1971): "Alphabetical Index of Industries and Occupations." Washington, DC: U.S. Bureau of the Census, Government Printing Office.

Coggon D, Pannet B, Acheson ED (1984): Use of job exposure matrix in an occupational analysis of lung and bladder cancers on the basis of death certificates. JNCI 72:61–65.

Heederik D, Pouwels H, Kromhout H, Kromhout D (1989): Chronic non-specific lung disease and occupational exposures estimated by means of a job exposure matrix: The Zutphen study. Int J Epidemiol 18:382–389.

Hisserich JC, Martin SP, Henderson BE (1975): An area-wide cancer reporting network. Public Health Rep 90:15–17.

Hoar SK, Morrison AS, Cole P, Silverman DT (1980): An occupation and exposure linkage system for the study of occupational carcinogenesis. J Occup Med 22:722–726.

Hulks G, Thomas JSTJ, Waclawski E (1989): Malignant pleural mesothelioma in western Glasgow. Thorax 44:496–500.

Linet MS, Stewart WF, Van Natta ML, McCaffrey LD, Szklo M (1987): Comparison of methods for determining occupational exposure in a case-control interview study of chronic lymphocytic leukemia. J Occup Med 29:136–141.

Macaluso M, Vineis P, Continenza D, Ferrario F, Pisani P, Andisio R (1982): Job exposure matrices: Experience in Italy. Job Exposure Matrices, Conference Report Southampton.

Mack TM (1977): Cancer surveillance program in Los Angeles County. Natl Cancer Inst Monogr 47:99–101.

National Institute for Occupational Safety and Health (1978): "National Occupational Hazard Survey, 1972–1974." Vols. 1–3. Department of Health and Human Services. Publications 74-127, 77-213, 78-114.

Pannett B, Coggon D, Acheson ED (1985): A job-exposure matrix for use in population-based studies in England and Wales. Br J Ind Med 42:777–783.

Sieber WK, Sundin DS, Frazier TM, Robinson CF (1991): Development, use and availability of a job exposure matrix based on National Occupational Hazard Survey data. Am J Ind Med (in press).

Siemiatycki J, Wacholder S, Richardson L, Dewar R, Gérin M (1987): Discovering carcinogens in the occupational environment: Method of data collection and analysis of a large case-referent monitoring system. Scand J Work Environ Health 13:486–492.

Spirtas R, Beebe GW, Connelly RR, Wright WE, Peters JM, Sherwin RP, Henderson BE, et al. (1986): Recent trends in mesothelioma incidence in the United States. Am J Ind Med 9:397–407.

Steineck G, Plato N, Alfredsson L, Norell SE (1989): Industry-related urothelial carcinogens: Application of a job-exposure matrix to census data. Am J Ind Med 16:209–224.

Wright WE, Sherwin RP (1984): Histological types of malignant mesothelioma and asbestos exposure. Br J Ind Med 41:514–517.

Zwi AB, Reid G, Landau SP, Kielkowski D, Sitas F, Becklake MR (1989): Mesothelioma in South Africa, 1976–84: Incidence and case characteristics. Int J Epidemiol 18:320–329.

APPENDIX

Low Exposure Industries

Code	Description
57	Non-metallic mining and quarrying
67	General building contractors
77	Non-specified construction
127	Cement, concrete, gypsum, and plastic products
138	Miscellaneous non-metallic mineral and stone products
219	Motor vehicle equipment
227	Aircraft and parts
229	Railroad locomotives and equipment
237	Mobile dwellings and campers
309	Floor coverings, except hard surface
318	Miscellaneous textile mill products
327	Miscellaneous fabricated textile products

407 Railroads and railway express service
428 Pipelines, except natural gas
469 Gas and steam supply system
559 Scrap and waste materials
569 Lumber and construction materials—wholesale trade
607 Lumber and building material retail
728 Services to dwellings and other buildings
757 Automobile repair and related services

High Exposure Industries

228 Ship and boat building and repairing

Low Exposure Occupations

190 Painters and sculptors
415 Carpenters
416 Carpenters' apprentices
430 Electricians
431 Electricians' apprentices
436 Excavating, grading, and road machine operators, exc. bulldozer
440 Floor layers, exc. tile setters
455 Locomotive engineers
456 Locomotive firemen
470 Air conditioning, heat, and refrigerator mechanics and repairmen
473 Automobile mechanics
474 Automobile mechanics apprentice
481 Heavy equipment mechanics, including diesel
486 Railroad and car shop mechanics and repairmen
492 Miscellaneous mechanics and repairmen
495 Not specified mechanics and repairmen
510 Painters, construction and maintenance
511 Painters, apprentices
520 Plasters
521 Plasters' apprentices
522 Plumbers and pipe fitters
523 Plumbers' and pipe fitters' apprentices
534 Roofers and slaters
615 Dry wall installers and lathers
623 Garage workers and gas station attendants
680 Welders and flame-cutters
712 Railroad brakemen
713 Railroad switchmen
751 Construction laborers, except carpenters' helpers
961 Firemen, fire protection

High Exposure Occupations

404 Boilermakers
540 Shipfitters
601 Asbestos and insulation workers