

Causes of Death Among Workers in a Bearing Manufacturing Plant

Robert M. Park, ms, David H. Wegman, MD, MS, Michael A. Silverstein, MD, MPH, Neil A. Maizlish, PhD, and Franklin E. Mirer, PhD

Recent studies identify digestive cancer excesses among workers exposed to cutting fluids, abrasive dusts, and oil smoke. Standardized proportional mortality and mortality odds ratio studies were carried out for a ball bearing plant. Cause of death and work histories were obtained for 702 of 768 hourly employees with ten or more years' service who died between 1969 and 1982. Union and company records were used to define exposure measures. The major findings were significant excesses in proportional mortality ratios (PMR) from stomach cancer (PMR = 2.0) and rectal cancer (PMR = 3.1) among white men. After control for age at death, there was a significant association between stomach cancer and precision grinding exposures, consisting primarily of direct contact with water-based cutting fluids (usually emulsified oils) and their aerosols. Some straight oils and synthetic cutting fluids were used as well. The pattern of stomach cancer is consistent with previous findings and suggests an association with the soluble oil cutting fluids.

Key words: abrasives, cutting fluids, forging, grinding, lung cancer, machining fluids, stomach cancer

INTRODUCTION

The manufacture of parts from iron, steel, and other metals frequently requires machining and high-speed precision grinding. The NIOSH National Occupational Hazard Survey estimated that 1,229,000 workers are exposed to cutting fluids; 6,109,000 to some type of mineral oil; 2,137,000 to abrasives; and 1,221,000 to grinding wheel dust [NIOSH, 1977]. Associations between digestive and respiratory cancer risks and work with these materials have been reported [Decouflé, 1978; Dubrow and Wegman, 1984; Jarvholm et al, 1981b; Jarvholm et al, 1982a; Sparks and Wegman, 1980; Vena et al, 1985; Waterhouse, 1972; Wegman and Eisen, 1981].

International Union, United Automobile, Aerospace and Agricultural Implement Workers of America (UAW), Detroit, Michigan (R.M.P., M.A.S., F.E.M.).

Department of Work Environment, University of Lowell, Lowell, Massachusetts (D. H. W.).

California Occupational Health Program, California Department of Health Services, Berkeley, (N. A. M.).

Address reprint requests to Robert Park, UAW Health and Safety Department, 8000 East Jefferson Avenue, Detroit, MI 48214.

Accepted for publication December 1, 1987.

Cutting fluids are directed in a stream or mist to working surfaces for lubrication, cooling, and removal of metal debris [Springborn, 1967]. They belong to three classes: cutting oils (also called insoluble or straight oils) are naphthenic or paraffinic mineral oils with additives such as polar lubricants e.g., lard, chlorine, sulfur, or phosphorus-based materials; soluble oils (also called emulsified oils) contain mineral oil emulsified with agents such as petroleum sulfonates or amine soaps and additives including special lubricants, corrosion inhibitors (e.g., nitrites), stabilizers (e.g., nonionic wetting agents), and biocides (e.g., triazines); synthetic fluids (also called chemical fluids) are typically alkaline water solutions of ethanalamines with corrosion inhibitors, surfactants, nonmineral oil lubricants, and biocides.

Straight cutting oils have been used since the beginning of the industrial era whereas soluble oils and synthetic fluids have been used widely only since the 1940s. There is, however, considerable overlap in usage.

A manufacturer of ball bearings has operated in New Britain, Connecticut since 1911 as an independent supplier to the automotive and aircraft industries. The international union, the United Automobile Workers (UAW), has represented most of the 20,000 hourly employees who ever worked at this location, since the 1930s. The work force varied between 3,000, and 4,000 during 1950–70. The major production processes have been the forging, machining, and grinding of rings and forming, grinding, and honing of balls for bearings. Other activities include heat treatment, abrasive tumbling, cleaning, inspection, plating, assembly, packing, and shipping operations. In 1979, union concern over lung cancer led to a collective bargaining agreement which stipulated that the company provide mortality information for an epidemiologic investigation. This report presents the findings from a mortality analysis of that data.

The primary hypothesis considered in this analysis was that cancers of the stomach, colon, rectum, and pancreas are associated with exposure to specific classes of cutting fluids and abrasives [Decouflé, 1978; Dubrow and Wegman, 1984; Jarvholm et al, 1982a; Jarvholm et al, 1981b; Sparks and Wegman, 1980; Vena et al, 1985; Waterhouse, 1972; Wegman and Eisen 1981]. Secondary hypotheses included the following: 1) lung cancer is associated with cutting fluid exposures on grinding and machining jobs [Decouflé, 1978; Waterhouse, 1972]; and 2) lung cancer is associated with forge and heat treat exposures [Goldsmith et al., 1975].

SUBJECTS AND METHODS

Study Population: Definition and Identification

The study population was defined as all hourly employees with ten or more years' service who died from January 1, 1969 to July 31, 1982. Candidates for the study population were assembled from death benefit ($n = 811$) and pension ($n = 43$) files of the company, and local union files ($n = 43$). The study population criteria were met by 768 deaths. Death certificates and job histories were obtained for 702 or 91%. Information was abstracted from death certificates on the following items: age at death, place of birth, race, and underlying cause of death. Cause of death was coded according to the Eighth Revision of the International Classification of Diseases (ICD-8).

TABLE I. Process and Exposure Measure Component Job Categories

Process-based groups
Machining: all production machining and allied material handling and inspection job categories.
Grinding: all production grinding and allied parts handling and inspection.
Tool and die: tool and die and tool grinding.
Forge and heat treat: forge, cold heading, upsetting; heat treating for rings and balls.
Skilled trades: electricians and maintenance machinists.
Maintenance: other skilled trades and janitors.
Assembly and packing: gauging, assembly, pressing, salvage and packing.
Exposure-based groups ^a
Straight oil cutting fluids, comprehensive: a broad group of job categories sharing potential exposure to straight oils, including machining and grinding with oil or mixed cutting fluid exposures, and supporting material handlers and machining inspection.
Straight oil cutting fluids, restricted: a less broadly defined set of job categories with more definite oil exposure, including most machining and a small number of grinding jobs working in straight oil.
Water-based cutting fluids, comprehensive: almost all grinding jobs, machining jobs with water-based cutting fluids, supporting material handlers in grinding, and both machining and grinding inspection.
Water-based cutting fluids, restricted: machining and grinding working with water-based cutting fluids.
Inorganic fiber, dust or pulmonary irritant: includes shot blasting, plating, polishing, abrasive wheel making, tool grinding, tumbling, and cleaning.

^aExposure groups are not mutually exclusive. The "restricted" groups are subsets of respective "comprehensive" versions. The two "comprehensive" groups overlap. "Restricted" groups do not overlap.

Job Histories

No standard source of individual work history records was available from the company or union records. Workers' job histories were compiled from a 1967 UAW local union seniority list with department, job, and hire date; a 1962 employer-generated "dues checkoff" list with department only; sets of dues cards retained by the local union (but missing some alphabetic segments), with date of hire, last department, and clock number for three different four-year periods (1952–55, 1956–59, and 1964–67); and from employer records of deferred vested employees (those leaving employment after ten years' service but before retirement age). By using these records, department locations for members of the study population were obtained for a maximum of seven points in time.

Job Categories and Exposure Variables

Most departments were characterized by a single major process. Based on discussions with company and local union officials and a plant walk-through, this process information was used to assign each department to one of 36 job categories. Job categories, in turn, were grouped according to common processes or exposures in order to create two types of exposure groups for analysis (Table I).

Straight oil cutting fluids have been used at this location for most machining operations, particularly the multispindle lathes. Water-based cutting fluids, usually soluble oils, have predominated in grinding; however, selected operations (usually race or "form" grinding) have often been done with straight oil. One cutting fluid used at this plant in the 1950s and 1960s was identified by trade name as a product

known to contain organic amines and potassium nitrite. Some soluble oil cutting fluids in use in 1984 contained nitrite additives.

Short-term breathing zone samples for airborne oil mist were taken by an insurance carrier on six occasions between 1972 and 1980, measuring total particulate concentration. Mist levels on jobs done with straight oils ranged from 0.07–2.8 mg/m³. Mist levels on other grinding jobs, probably using soluble oils, ranged from 0.6–7.2 mg/m³.

The work history information was judged insufficient for estimating cumulative exposure. An effort was made, therefore, to identify an appropriate major job category for each decedent. This was judged to be best characterized by the last known job category held prior to 15 years before death (if unknown, the oldest known job category). This was labeled the Summary Job Category. The 15-year lag was chosen to account for anticipated latency between chemical exposure and deaths due to malignancies and other chronic diseases.

For workers with job histories, 89% had a departmental assignment known at two or more points in time, most of which were classified in only one or two job categories. For example, 94% of the 443 workers with department specified at three or more points had two or fewer distinct job categories. In many cases in which an employee worked in two or more job categories, these were similar, e.g., different subcategories of grinding.

Analysis

Standardized proportional mortality. Standardized proportional mortality ratio analyses were carried out using Monson's PMR program [Monson, 1974]. The United States reference rates were current through 1980. Mantel-Haenszel based chi-squared statistics, two-tailed p-values, and confidence intervals were computed. Poisson p-values and confidence intervals were computed when expected numbers of cause-specific deaths were less than five [Bailar and Ederer, 1964].

Case control. In case-control studies, mortality odds ratios and Fisher exact p-values (one-tailed) were computed for single 2 × 2 tables. If 2 × 2 tables occurred with zero observations in one cell, 0.5 was added to each cell prior to calculating an odds ratio. For stratified 2 × 2 tables, Mantel-Haenszel odds ratios were computed [Mantel and Haenszel, 1959]. A posteriori power calculations were done using the method of Fleiss [1981] for unequal numbers of cases and controls.

For each disease outcome, controls were defined to exclude causes of death plausibly associated with the exposures under consideration. Thus, specific gastrointestinal (GI) cancers were compared with controls excluding other GI cancer sites, lung cancer and nonmalignant GI disease; controls for nonmalignant digestive disease excluded GI and lung cancer. These exclusions were based on prior knowledge of exposure-associated health effects.

For each exposure category, a comparison "nonexposed" category was defined to include all job categories except those known to share substantial exposures with the particular process or exposure category. These nonexposed categories were individually defined for each of the process-based and exposure-based groups (Table I).

For the process-based groups, the following job categories were always included as nonexposed (along with selected others for particular process groups): lapping, honing, stamping/punching, laboratory, shipping, final inspection (not

TABLE II. Race and Sex Distribution With Cause of Death and Job History

	Study population	Study population with cause of death and work history	Percent
White men	616	565	92
White women	124	116	94
Total	740	681	92
Nonwhite Men	20	20	100
Nonwhite Women	2	1	50
Total	22	21	95
Unknown	6	0	0
Total	768	702	91

including machining or grinding inspection), mill supply and cleaners (of bearing parts).

For the exposure-based groups the following job categories were always included as nonexposed (along with selected others for particular exposure-based groups): lapping, honing, stamping/punching, laboratory, assembly, packing, shipping, final inspection, electricians, and mill supply.

RESULTS

The study population criteria were satisfied for 768 deaths. Proportional mortality calculations were made for the 755 (98%) for whom cause of death was determined. Case-control analyses were limited to 702 (91%) for whom both cause of death and job history were available. The sex and race distribution of the decedents is shown in Table II.

Standardized Proportional Mortality Ratio Analysis (PMR)

Standardized proportional mortality analysis was carried out for white males and females. Eighty percent of the study subjects were white males, and for these, the details of the PMR analysis are displayed in Table III.

Gastrointestinal cancer. Proportional mortality was elevated for several gastrointestinal cancer sites in white males, the highest being for stomach cancer (PMR = $11/5.5 = 2.0$, $p = 0.02$) and rectal cancer (PMR = $11/3.6 = 3.1$, $p = 0.002$). Among white females, the stomach cancer PMR was elevated but was not statistically significant (PMR = $3/0.98 = 3.1$, $p = 0.15$).

Within the process-based groupings, men in grinding had the highest excess in proportional mortality due to cancer of the stomach (PMR = $7/1.85 = 3.8$, $p = 0.006$). The stomach cancer PMR was greater among grinders with long latency, i.e., 30 or more years from date of hire until death (PMR = $4/0.95 = 4.2$, $p = 0.03$). No more than two rectal cancer cases appeared in any of the process-based groups. Exposure-based groupings were examined for associations with gastrointestinal cancer by case-control analysis.

Lung cancer. Among white men, there was a nonsignificant excess in lung cancer proportional mortality. Since the question of lung cancer excess had led to the

TABLE III. Standardized Proportional Mortality Ratios for Selected Causes of Death for All White Men in Study Population*

Cause of death	OBS	EXP	PMR	95% CI	p
Total deaths	610				
All malignant neoplasms	157	136.49	1.15	1.00, 1.32	.05
Cancer of digestive organs and peritoneum	55	35.65	1.54	1.20, 1.99	<.001
Cancer of esophagus	6	3.25	1.85	0.68, 4.02	
Cancer of stomach	11	5.53	1.99	1.12, 3.54	.02
Cancer of large intestine	15	12.74	1.18	0.71, 1.94	
Cancer of rectum	11	3.58	3.07	1.54, 5.50	.002
All cancer of liver—primary only	3	2.33	1.29	0.27, 3.76	
Cancer of pancreas	8	7.31	1.09	0.55, 2.18	
All cancer of lung—primary and secondary	59	48.00	1.23	0.96, 1.57	.10
Cancer of skin	4	2.13	1.88	0.51, 4.80	
Cancer of prostate	10	10.91	0.92	0.50, 1.69	
Cancer of testis	0	0.32	0.00	0.00, 9.36	
Cancer of bladder	1	4.24	0.24	0.01, 1.31	
Cancer of kidney	3	3.33	0.90	0.19, 2.63	
Cancer of brain and other central nervous system	4	3.25	1.23	0.34, 3.15	
All lymphopietic cancer	7	11.76	0.60	0.29, 1.23	
Lymphosarcoma and reticulosarcoma	1	2.13	0.47	0.01, 2.61	
Leukemia	1	4.40	0.23	0.01, 1.26	
Cancer of other lymphatic tissue	3	3.88	0.77	0.16, 2.26	
Allergic, endocrine, metabolic, nutritional diseases	6	10.69	0.56	0.26, 1.23	
Mental, psychoneurotic, and personality disorders	13	3.33	3.91	2.08, 6.67	<.001
All diseases of nervous system and sense organs	7	4.89	1.43	0.57, 2.95	
Arteriosclerotic heart disease, including CHD	228	230.43	0.99	0.89, 1.10	
All vascular lesions of CNS	60	43.68	1.37	1.08, 1.75	.01
All respiratory diseases	40	43.33	0.92	0.69, 1.24	
All pneumonia	7	14.28	0.49	0.24, 1.00	.06
Emphysema	8	9.64	0.83	0.42, 1.65	
Asthma	1	0.57	1.75	0.04, 9.75	
All diseases of digestive system	24	26.70	0.90	0.61, 1.33	
All gastric and duodenal ulcer	0	2.77	0.00	0.00, 1.08	
Cirrhosis of liver	18	14.18	1.27	0.81, 2.00	
Chronic nephritis	3	1.24	2.42	0.50, 7.07	
All accidents	12	20.92	0.57	0.33, 0.99	.05
Suicide	8	8.27	0.97	0.49, 1.92	

*p values and confidence intervals based on M-H chi-squared for expecteds >5.0; otherwise based on Poisson; p values are 2-tailed and not shown if >0.1.

study and because of prior hypotheses, the distribution of these deaths was examined in subgroupings. No clear pattern emerged. Small excesses were noted among machining or grinding inspectors in the water-based cutting fluid environment (PMR = $6/2.8 = 2.1$), workers in assembly and packing (PMR = $9/5.7 = 1.6$), and the small group in forge and heat treat (PMR = $3/0.64 = 4.7$). Among females, all lung cancer deaths appeared among grinders (PMR = $5/1.86 = 2.7$, $p = 0.08$).

Other Causes of Death. All four cases of skin cancer as the underlying cause of death in white males were melanomas. Three of the four were in machining or grinding, for whom the expected number of any skin cancers was 0.94.

The PMR analysis of nonmalignant respiratory diseases revealed no clear

TABLE IV. Mortality Odds Ratios for the Association of Stomach Cancer and Cutting Fluid Exposures

Exposure group ^a	Case	Control	Total	OR ^b	p ^c	OR ^{b,d}	p ^c
Grinding	7	146	153	5.9	0.06	6.5	0.01
Water-based CF,							
Comprehensive	8	159	167	6.2	0.05	6.9	0.008
age at death							
<60	2	39	41				
60-74	5	88	93	5.4	0.14	6.6	0.02
>74	1	32	33				
Water-based CF,							
Restricted	2	53	55	4.7	0.22	5.2	0.13

^aExposure groups are not mutually exclusive (see text and Table I)

^bCrude odds ratio except for age-stratified analysis which has Mantel-Haenszel odds ratio.

^cFisher Exact p value for crude ORs; Mantel-Haenszel p-value for age-stratified ORs.

^dBased on contrast to an expanded comparison group because of small number of unexposed cases.

patterns; of 40 deaths, 14 were cases of chronic obstructive lung disease and 2 were silicosis. There were no lipid pneumonia or nasal cancer deaths.

“Mental, psychoneurotic and personality disorders” (ICD-8: 290-317) showed excess mortality (PMR = 13/3.3 = 3.9, $p < 0.001$), most of which (12 out of 13) were recorded as chronic alcoholism.

The PMR for stroke was significantly elevated (Table III). Although not significantly elevated in any of the process groups, it was elevated in grinding (PMR = 19/12.8 = 1.5).

Case-Control Analysis

Case-control analysis was used for selected causes of death to examine associations with process- and exposure-based groups.

Stomach Cancer. The crude mortality odds ratios (OR) were elevated for the association of stomach cancer with work in grinding and in water-based cutting fluids (Table IV). For grinding, the odds ratio was 5.9 ($p = 0.06$), and for water-based cutting fluids, comprehensive, the odds ratio was 6.2 ($p = 0.05$). These two exposure groups included many of the same decedents. When exposure was restricted to those grinding jobs where straight oil cutting fluids (together with soluble oils) were likely to be used, the odds ratio was no different (6.5, $p = 0.06$).

The Mantel-Haenszel summary odds ratio for water-based cutting fluids, across age strata, was 5.4 ($p = 0.14$, Table IV). The estimated stomach cancer odds ratios are unstable, because there was only one case in the comparison group. Expanding the comparison group to include all other job categories not exposed to cutting fluids adds a second case and yields an age-adjusted odds ratio of 6.6 ($p = 0.02$) for the water-based cutting fluid exposure. (Table IV)

Cancer of the stomach was found not to be associated with machining in straight oil, with tool and die work, or with the other major process measures; however, the power for these tests using case-control analysis was low.

Lung cancer. There was a nonsignificant association of lung cancer in white males within the forge and heat treat category (OR = 3.6, $p = 0.10$). All three lung

cancers occurred in the subgroup of those dying between 15 and 30 years following hire.

For lung cancer among females in grinding, the odds ratio was elevated (OR = 19.3, $p = 0.008$), because all lung cancer cases occurred in grinders. The absence of any cases in the comparison group makes this an unstable estimate. The level of risk was indistinguishable with the use of the different grinding-related exposure measures.

Nonmalignant disease: The crude odds ratio for association of nonmalignant respiratory disease (ICD-8: 460-519) with grinding was not elevated (OR = 1.1) except in those dying above age 74 (OR = 4.1, $p = 0.04$; three age strata were examined without a prior hypothesis concerning age).

Case-control analysis of the deaths diagnosed as "chronic alcoholism" in relation to grinding produced a nonsignificant odds ratio of 5.3, ($p = 0.09$) and for water-based cutting fluids, comprehensive, an odds ratio of 4.9 ($p = 0.11$). All cases of "chronic alcoholism" were designated as such by the medical examiner and not by a physician in attendance at the time of death.

DISCUSSION

Validity Issues

Work histories were sparse, limiting the ability to evaluate latency and duration effects. Misclassification of exposure categories would tend to reduce the magnitudes of associations observed, and the considerable stability observed in workers' job categories over time provides reasonable assurance that exposure misclassification was unlikely to result in false associations.

Standardized PMR analysis does not estimate absolute rate ratios but rather relative proportions and thus is subject to misinterpretation if there are several major exposure-attributable causes of death or if the reference population is noncomparable. The overall mortality of this population does not appear to have been highly affected by the general exposure experience; causes of death with significantly elevated proportions constituted less than 10% of total deaths. Noncomparability of the reference population would affect both PMR and follow-up or standardized mortality ratio (SMR) studies, and it has been suggested that PMRs are less sensitive than SMRs to health selection effects that result in population noncomparability [Kupper et al., 1978].

The PMRs were calculated with the use of national population reference rates. The excess in stomach cancer might reflect regional differences. Stomach cancer incidence and mortality were higher among white males in the Connecticut Surveillance, Epidemiology, and End Results (SEER) area in the 1970s than other SEER areas combined [National Cancer Institute, 1981]. Among white men, annual age-adjusted stomach cancer mortality as a proportion of all cancer mortality in the 1970s was .051 in Connecticut and .045 in all SEER areas combined. The age-adjusted stomach cancer mortality rate for Hartford County ($18.7/10^5$), where most of the study population lives, was 23% higher than the national rate for the period 1950-69 for white males [Mason and McKay, 1974]. These differences, however, would not explain the findings noted in the case-control analysis, where the comparison groups were also from the local area.

Cancer of Stomach

There was an association of cancer of the stomach with grinding but not with machining or tool and die exposures. The probability of observing no stomach cancer cases in the workers machining in oil, if they had the same risk as in grinding, was .09 (using United States proportional mortality rates), suggesting that stomach cancer risk is not elevated in straight oil exposed workers.

Most of the water-based cutting fluids used in this plant contained mineral oil emulsified in water along with additives not found in straight oils, such as petroleum sulfonates, amine soaps, and nitrite corrosion inhibitors. Because stomach cancer was not associated with straight oil exposures, it is unlikely that the oils present in water-based fluids were directly responsible for the stomach cancer associated with their use. More likely explanations are that the stomach cancer risk in grinding is due to one or more of the additives not found in straight oils, to abrasive aerosols, or to oil or additives in the presence of some co-factor not present in straight oils, such as abrasive debris.

The stomach cancer associations cannot be explained on the basis of confounding by place of birth. Stomach cancer incidence is quite elevated in Central Europe [Staszewski and Haenszel, 1965] and somewhat less for immigrants from Central Europe [Namura, 1982]. Although 14% of the study population had Central European birth, there was no association of water-based cutting fluids exposure with Central European origin.

The finding of elevated stomach cancer and "chronic alcoholism" concentrated in workers in grinding raises the question of whether the stomach cancer might be attributable to heavy alcohol consumption in that group [Gordon and Kannel, 1984]. However, several other causes of death commonly elevated in groups with a high prevalence of alcoholism, including accidents, suicide, and oropharyngeal and esophageal cancer were not concentrated in grinding. There were eight deaths observed from these causes for 11.6 expected (based on proportional mortality rates). In grinders with 30 years employment at the plant, there was one death for 4.7 expected from these causes. Furthermore the "alcoholism" designations were made by medical examiners who did not see the workers prior to death and who may have been inclined to attach a specific label to cases with general findings of chronic, debilitating disease, perhaps with indications of liver damage.

Several previous studies have found a relationship between cutting fluid exposure and cancers of the digestive system. Waterhouse reviewed 228 cases of scrotal cancer in workers exposed to (straight) oil mist and found significant excesses of subsequent primary malignancies of the skin, respiratory system, and upper digestive tract [Waterhouse, 1972]. There was no stomach cancer association with straight oils in this study. Dubrow and Wegman reported associations between stomach, colorectal, pancreas, and respiratory cancers and work as machinists exposed to any type of cutting fluid in Massachusetts, by using age-standardized mortality odds ratios [Dubrow and Wegman, 1984]. Decouflé calculated standardized mortality ratios among workers exposed to both straight and soluble oil cutting fluids on metal machining jobs in an engine plant [Decouflé, 1978]. For those first employed before 1938 and with at least 20 years' latency, there was a significant two-fold excess of cancer of the stomach and large intestine (15 observed, 7.6 expected). In a proportional mortality study of deaths in a similar engine plant, where

soluble and straight oils were also used, Vena found significant excesses of lung and gastrointestinal cancers, particularly of the pancreas, among those with more than 20 years of employment [Vena et al., 1985]. One study of a population exposed to oil mist reported no excess of cancer mortality; however, the study group size and follow-up period were limited [Ely et al., 1970].

Jarvholm studied a Swedish bearing plant, which is described as similar to the plant in this investigation [Jarvholm et al., 1981b]. Among grinders who worked with soluble oil cutting fluids with nitrite additives and mineral oil contaminants, there was a statistically significant two-fold excess in digestive system cancer incidence (15 observed, 7.8 expected) for those with more than five years of service and 20 years' latency. There were six stomach cancers in this group, while 2.6 were expected. Among machining workers exposed to acid-refined mineral oils, there was no excess incidence in lung or digestive cancer. Jarvholm's proposal that grinding with water soluble cutting fluids, containing nitrites, carries the greatest risk [Jarvholm et al., 1981b], is supported by the findings of this study. This conclusion is supported further by another recent study at a third bearing plant [Silverstein et al., 1988].

The eight stomach cancers in the water-based cutting fluid group included two in process inspectors and one in a parts handler, suggesting that the putative carcinogen may be more general than simply a component of cutting fluid mists concentrated at metalworking machines. Antirust oils are ubiquitous in bearing manufacture, with parts often being bathed in them between production steps to retard corrosion. Jarvholm has reported a cluster of cancer cases (several sites) among women wrapping bearing rings covered with an anti rust oil containing N-phenyl-1-naphthylamine [Jarvholm, 1981a]. If carcinogenic anticorrosion oils were widely used, they would likely become entrained in cutting fluid and parts washing systems.

Exposures to synthetic abrasives have received recent epidemiologic attention. Sparks found excess deaths from pancreatic cancer, stomach cancer, stomach ulcers, and alcoholism in a proportional mortality analysis of 931 deaths among jewelry workers [Sparks and Wegman, 1980]. Stomach cancer and ulcers were elevated in the subgroup of polishers, presumed to experience exposure to abrasive dusts. Wegman found excess digestive cancer (stomach, esophagus, large intestine, rectum, and liver) and nonmalignant respiratory disease among workers in a synthetic abrasive product manufacturing plant [Wegman and Eisen, 1981]. Jarvholm and colleagues have reported a similar excess of digestive system cancer and nonmalignant respiratory disease incidence in workers employed in abrasive product manufacture [Jarvholm et al., 1982a] and an excess of stomach cancer among bearing ring polishers [Jarvholm et al., 1982b]. Wang reported excess standardized mortality odds ratios for colorectal and other digestive cancers among workers manufacturing optical lenses and frames possibly exposed to abrasives and cutting fluids [Wang et al., 1983]. A role for abrasive dusts in stomach cancer etiology is also supported by the finding of elevated stomach cancer SMRs in a cohort of British cement workers [McDowall, 1984].

In view of these findings on stomach cancer, it is worth noting the speculation of Correa and coworkers [1975], that erosion of the gastric surface by abrasive foods and surfactants predisposes the gastric mucosa to dysplasia and malignant change by the actions of nitrosamines or other mutagenic and carcinogenic agents. Although these authors were concerned with diet, this mechanism is plausible in precision grinding environments, where aerosolized abrasive particulates are endemic. Water-

based cutting fluid mists contain abrasive debris as well as metallic matter, low vapor pressure additives and, in some cases, residual oils [Burgess, 1978]. Inhaled mists are probably cleared in part from the upper respiratory passages and swallowed.

Cancer of Rectum

The elevated PMR for rectal cancer was a strong finding for white men overall (PMR = 3.1, $p = 0.002$). This finding is similar to reports for synthetic abrasives manufacturing [Wegman and Eisen, 1981; Jarvholm et al., 1982a] and lens grinding and eye glass frame production [Wang et al., 1983]. Most of the clinical literature on cancer of the large intestine refers to "colorectal cancer" and treats colon and rectal cancer as virtually indistinguishable. It might be puzzling, therefore, that rectal but not colon cancer was found to be elevated in this study group. However, the epidemiologic literature indicates that colon and rectal cancer have different risk factors and population distributions. Schottenfeld and Winawer, for example, point out that the ratio of colon to rectal cancer varies considerably from country to country and that colon cancer incidence has been increasing for the past 30 years in Connecticut, while rectal cancer incidence has been stable [Schottenfeld and Fraumeni, 1982]. Possible explanations for the absence of an exposure association in this study include the following: misclassification of some colon cancers as rectal, creating an artificial excess, or exposure misclassification, particularly early exposures, if the disease has a long latency, e.g., 25 or 30 years.

CONCLUSION

A statistically significant increase in the proportion of deaths due to stomach cancer was found in a population of bearing plant workers. The increase was associated with precision grinding done predominantly with water-based cutting fluids (primarily soluble oils). It supports previous findings of excess gastrointestinal cancer among workers in plants where metal machining and grinding are major activities and confirms the previously reported association of stomach cancer with grinding jobs using soluble oils.

ACKNOWLEDGMENTS

This work was supported under NIOSH Contract No. 210-81-5104. The Fafnir Bearing Company provided some of the records used and consultation on past exposures. Indispensable clerical work was provided by Carole Rogers, Margaret Auch, Pamela Poe, and Melanie Bogoevich. Dr. John Peters and Dr. Jung-Der Wang, formerly at Harvard School of Public Health, contributed to the preliminary investigation.

REFERENCES

- Bailar JC, Ederer F (1964): Significance factors for the ratio of a Poisson variable to its expectation. *Biometrics* 20:639-643.
- Burgess WA (1978): "Recognition of Health Hazards in Industry: Grinding, Polishing and Buffing." New York: Wiley and Sons, pp 71-76.
- Correa P, Haenszel W, Cuello C, Tannenbaum S, Archer M (1975): A model for gastric cancer epidemiology. *The Lancet* 2:58.

- Decoufflé P (1978): Further analysis of cancer mortality patterns among workers exposed to cutting oil mists. *JNCI* 61:1025–1030.
- Dubrow R, Wegman DH (1984): Cancer and occupation in Massachusetts: a death certificate study. *Am J Ind Med* 6:207–230.
- Ely TS, Scott FT, Hearne FT, Stille WT (1970): A study of mortality, symptoms, and respiratory function in humans occupationally exposed to oil mist. *J Occup Med* 12:253–261.
- Fleiss J (1981): "Statistical Methods for Rates and Proportions." 2nd ed. New York: Wiley & Sons.
- Goldsmith AH, Vorpahl KW, French KA, Jordan PT, Jurinski NB (1975): Health hazards from oil, soot and metals at a hot forging operation. *Am Ind Hyg Assn J* 37:217–226.
- Gordon T, Kannel W. (1984): Drinking and mortality—the Framingham study. *Am J Epidemiol* 120:97–107.
- Jarvholm B, Lavenius B (1981a): A cohort study on cancer among workers exposed to an antirust oil. *Scand J Work Environ Health* 7:179–184.
- Jarvholm B, Lillienberg L, Stallsten G, Thiringer G, Axelson O (1981b): Cancer morbidity among men exposed to oil mist in the metal industry. *J Occup Med* 23:333–337.
- Jarvholm B, Lillienberg L, Axelson O (1982a): The risk of digestive cancer in workers using synthetic abrasive products. *J Occup Med* 24:562–563.
- Jarvholm B, Thiringer G, Axelson O (1982b): Cancer morbidity among polishers. *Br J Ind Med* 39:196–197.
- Kupper LL, McMichael AJ, Symons AJ, Most BM (1978): On the utility of proportional mortality analysis. *J Chronic Dis* 31:15–22.
- Mantel N, Haenszel W (1959): Statistical aspects of analysis of data from retrospective studies of disease. *JNCI* 22:710–748.
- Mason TJ, McKay FW (1974): "U.S. Cancer Mortality by County: 1950–1969." Washington: U.S. Department of Health, Education and Welfare, Publication No. (NIH) 74–615.
- McDowall ME (1984): A mortality study of cement workers. *Br J Ind Med* 41:179–182.
- Monson R (1974): Analysis of relative survival and proportional mortality. *Comp Biomed Res* 7:325–332. Computer program and reference rates: USDR, Version 58.
- Namura A (1982): Stomach. In Schottenfeld D, Fraumeni J (eds): "Cancer Epidemiology and Prevention." Philadelphia: WB Saunders, pp 624–637.
- National Cancer Institute (1981): "Surveillance, Epidemiology and End Results: Incidence and Mortality Data, 1973–77." Monograph 57. Washington.
- National Institute of Occupational Safety and Health (1977): "National Occupational Hazard Survey," Volume III. (Survey analysis and supplemental tables pp 216–229) DHEW (NIOSH) publication No. 78-114, Cincinnati.
- Schottenfeld D, Winawer S (1982): Large intestine. In Schottenfeld D, Fraumeni J (eds): "Cancer Epidemiology and Prevention." Philadelphia: W B Saunders, pp 703–722.
- Silverstein M, Park R, Marmor M, Maizlish N, Mirer F (1988): Mortality among bearing plant workers exposed to metal working fluids and abrasives. *J Occup Med*: (in press).
- Sparks P, Wegman D (1980): Cause of death among jewelry workers. *J Occup Med* 22:733–736.
- Springborn RK (ed) (1967): "Cutting and Grinding Fluids: Selection and Application." Dearborn, MI: American Society of Tool and Manufacturing Engineers.
- Staszewski J, Haenszel W (1965): Cancer mortality among the Polish-born in the United States. *JNCI* 35:291–297.
- Vena JE, Sultz HA, Fiedler RC, Barnes RE (1985): Mortality of workers in an automobile engine and parts manufacturing complex. *Br J Ind Med* 42:85–93.
- Wang JD, Wegman DH, Smith T (1983): Cancer risks in the optical manufacturing industry. *Br J Ind Med* 40:177–181.
- Waterhouse JAH (1972): Lung cancer and gastrointestinal cancer in mineral oil workers. *Ann Occup Hyg* 15:43–44.
- Wegman DH, Eisen E (1981): Causes of death among employees of a synthetic abrasive product manufacturing company. *J Occup Med* 23:748–754.