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Validity of Exposure in One Job as a Surrogate for Exposure in a Cohort Study

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Frequently, information pertaining to only one job is available or used to evaluate risk estimates of disease in occupational epidemiologic research. The amount of misclassification that such a practice could create has not, however, been examined. We used data from a mortality study of workers employed in 10 formaldehyde-producing or -using plants to address how closely several parameters of exposure based on the first, longest, or last job held in a company compared with those based on the worker's entire employment history at the plant. The best predictor for cumulative formaldehyde exposure at the plant was the longest job at that plant, with a correlation coefficient (r) of 0.70. The correlation with average exposure over the worker's employment was 0.77 for the first job and 0.74 for the longest and last jobs. Peak exposures and highest exposure levels experienced in the plant were more closely related to the first job ($r = 0.72$ and $r = 0.74$). The highest correlation with any of the measures was never with the last job. Variation between plants for each of these comparisons, however, was wide. These findings indicate that the use of a single job as a surrogate for exposure received at a particular worksite can result in different degrees of misclassification for different exposure measures. Even though the correlations were generally high, the associated misclassification of exposure could lead to a substantial underestimation of the relative risks in some situations. In this report two hypothetical examples show what effect the misclassification rates could have on estimates of disease risks.

Key words: exposure assessment, formaldehyde, occupational risk, surrogate estimates

INTRODUCTION

In epidemiologic research of occupationally caused diseases, investigators often depend on job titles to evaluate workplace exposures. In many studies, full work histories may be collected. Sometimes, however, only one job title is available, because collection and analyses of a complete occupational history is time consuming or because information on only the usual or current occupation is available. Occasionally, even when information on all jobs is collected, only the longest held job is used in analyses. Furthermore, validity of job information can be quite different, depending on the source of information, such as death certificates, company or other

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records, self-reports, or the next of kin [Chang and Wang, 1988; Bourbonnais et al., 1988; Pershagen and Axelson, 1982; Illis et al., 1987; Bond et al., 1988; Stewart et al., 1987; Baumgarten et al., 1983; Rona and Mosbech 1989; Rosenberg et al., 1987; Nelson et al., 1987; Alderson, 1972; Schumacher, 1986; Swanson et al., 1984; Gute and Fulton, 1985; Schade and Swanson, 1988; Turner et al., 1987; Olsen et al., 1990; Steenland and Beaumont, 1984]. It is not clear how well any single job reflects the working lifetime exposure, an important measure when evaluating chronic diseases, such as cancer. Exclusion of several jobs held for only short durations may not seriously affect a summary exposure parameter, such as cumulative exposure. If a single job, however, does not reflect long-term exposure to the particular exposure of interest, severe misclassification could occur and causal associations would be missed.

We used data from a mortality study of workers employed in 10 formaldehyde-producing or -using plants to investigate how different exposure measures based on the first, longest, or last job held in a company compared with those based on the entire employment history of the subject while at the plant.

MATERIALS AND METHODS

The study cohort and methods have been described elsewhere [Blair et al., 1986]. Briefly, the cohort consisted of 26,561 persons first employed between 1934 and 1965 in 10 formaldehyde-producing or -using plants. Follow-up started January 1, 1966 and ended January 1, 1980. Work histories were obtained from company records. The study industrial hygienists conducted walk-through surveys, interviewed long-term workers, and carefully reviewed present and past monitoring data, and information about changes in production, engineering controls, job tasks, and the use of personal protective equipment. For each job/department/plant/calendar year combination, the industrial hygienists estimated the average 8-hour time-weighted average (TWA) in parts per million (ppm) and whether exposure to formaldehyde-containing resins and molding compounds, and to liquid formaldehyde solutions, was likely to have occurred [Stewart et al., 1986]. The level of potential peak exposures was assigned to one of the following categories: <0.1, 0.1–0.5, >0.5–2.0, >2.0–4.0, and >4.0 ppm.

For each subject, various surrogates for formaldehyde dose (referred to here as *exposure parameters*) were calculated based on these assessments, including:

1. cumulative exposure (the sum of the products of the TWA multiplied by the length of time at that exposure) in ppm;
2. average exposure of the individual over his/her exposed employment at the facility (cumulative exposure divided by the exposure duration) in ppm;
3. highest exposure (the highest TWA held in any job) in ppm;
4. peak exposure (the highest categorical peak level of exposure) in ppm;
5. duration of particulate exposure (the total duration of all jobs with exposure to particulates containing formaldehyde) in years; and
6. duration of liquid exposure (the total duration of all jobs with exposure to solutions containing formaldehyde) in years.

Each of these exposure measures was calculated using information on all jobs held and separately for 3 specific jobs, i.e., the first job, the longest job, and the last job.

Several approaches were used to compare the exposure estimate in a single job to the estimate for the entire employment history. First, to determine how much of the cumulative exposure was received in the 3 jobs of interest compared to that received in the subject's entire employment, the percent of cumulative exposure experienced in the first, longest, and last job was calculated for each subject. The percent for each job was averaged over all subjects within the plant to derive the average percent in that plant. Second, an analysis was performed to determine how subjects were ranked by their exposure for the individual jobs and for the entire employment history. Subjects were ranked by quartiles for the 3 jobs identified above and for the entire employment using each of the 6 exposure parameters (except peak exposure, which was composed of 5 categories). Quartiles were selected because categories of high, medium, low, and none are often used in epidemiologic analyses. The Spearman correlation coefficient was used to determine the correlation between the exposure parameters derived for the first, longest, and last job, and for those of the entire employment. Correlations were also calculated after excluding subjects who worked $\leq$ 1 year (short-term workers), because the first job of workers who were employed for short periods of time could also have been their longest or last job at these plants.

The percent agreement was also calculated for the quartiles mentioned above (entire employment vs. single job) to see how agreement/disagreement varied between the categories. These data were used to calculate how this degree of misclassification would alter the relative risks from cumulative exposure in two hypothetical examples. Gart's method was used to calculate 95% confidence intervals [Gart and Thomas, 1963], and Mantel's chi-square test was used to calculate the linear trend test statistics for relative risks [Mantel, 1963].

RESULTS

Descriptive statistics are shown in Table I. The mean number of jobs held per worker was 6.9. The average duration of employment was 8.9 years (ranging from 3.5 years to 23.7 years per plant), and for those ever exposed to formaldehyde, the average duration of exposure was 8.8 years (not shown). The duration of the first job was 17% (1.5 years) of the entire employment duration; the longest job was 44% (3.9 years), and the last job was 26% (2.3 years). Of the 25,683 study subjects, 9,559 (37%) worked less than 1 year (ranging from 0.5% to 54% per plant). Among workers employed longer than 1 year, the average duration of employment was 13.9 years, and for those exposed to formaldehyde the average duration of exposure was 14.4 years. The last job was the longest job for 41% of the 16,124 subjects employed longer than 1 year. The first job was also the longest job for 27% of the subjects, and 14% held only one job. Variation among plants was great. The five plants which had the longer average duration of employment (9.1–23.7 years) had lower proportions of short-term workers.

The percentage of cumulative formaldehyde exposure in the first, longest, and last job to the cumulative formaldehyde exposure over the entire employment was 45% for the first job, 60% for the longest job, and 49% for the last job (Table II). After excluding short-term workers, these percentages were 25%, 44%, and 31%, respectively. The longest job always had the highest percentage of cumulative exposure, ranging from 38% to 79% (after exclusion of short-term workers, from 27% to 64%). The percentage of cumulative formaldehyde exposure contributed by one of

TABLE I. Description of Study Data in 10 Plants Producing or Using Formaldehyde[a]

Plant	No. of subjects[b]	No. of subjects ≤1 year	Mean no. of jobs	Duration (years)			
				Employed	First job	Last job	Long. job
All	25,683	9,559 (37%)[c]	6.9	8.9 (13.9)[d]	1.5 (17%)[e]	2.3 (26%)[e]	3.9 (44%)[e]
1	4,262	1,838 (43%)	5.8	6.1 (10.4)	0.6 (10%)	1.9 (31%)	2.8 (46%)
2	786	87 (11%)	3.4	13.5 (15.1)	2.3 (17%)	6.0 (44%)	8.1 (60%)
3	2,392	1,107 (46%)	3.0	4.3 (7.7)	1.6 (37%)	1.5 (35%)	2.2 (51%)
4	1,704	124 (7%)	8.3	19.0 (20.4)	3.9 (21%)	3.9 (21%)	7.5 (40%)
5	745	4 (0.5%)	7.8	23.7 (23.8)	4.6 (19%)	7.7 (33%)	11.6 (49%)
6	5,274	1,736 (33%)	8.7	9.1 (13.4)	1.2 (13%)	1.7 (19%)	3.8 (42%)
7	4,232	2,033 (48%)	4.4	6.5 (12.1)	1.6 (25%)	2.5 (39%)	3.4 (52%)
8	1,679	899 (54%)	4.1	5.7 (11.8)	1.0 (18%)	1.7 (18%)	2.8 (49%)
9	1,934	1,040 (54%)	2.1	3.5 (7.3)	1.1 (31%)	1.8 (51%)	2.3 (66%)
10	2,675	691 (26%)	17.6	14.4 (19.3)	1.0 (7%)	1.9 (13%)	4.5 (31%)

[a]Blair et al. (1986).
[b]Subjects with unknown jobs have been excluded.
[c]% of total number for the plant.
[d]After exclusion of short-term workers (employed ≤ 1 year).
[e]% of total employment.

the jobs tended to be lower in the plants where the average duration of employment was longer than in the plants where the average duration was shorter.

The correlation coefficients (r) for formaldehyde exposure received between each of the jobs (first, longest, and last job) and the entire employment are shown in Table III for the total population and by plant. The first row within each cell presents the correlation coefficient for all subjects, whereas the second includes only workers who were employed longer than 1 year.

When evaluating cumulative formaldehyde exposure based on the entire employment, the highest agreement was observed with the longest job ($r = 0.70$), with smaller correlations for the first ($r = 0.48$) and last job ($r = 0.57$). This pattern of the highest agreement with the longest job and the lowest agreement with the first job was seen in all plants except plant 8, where the last job had the lowest agreement. Variation between the plants was wide, however, with correlations between cumulative exposure based on all jobs and that based on the longest job ranging from $r = 0.46$ to $r = 0.93$. The first job was poorly correlated ($r = -0.10$) with cumulative exposure for the entire employment in plant 4.

TABLE II. Percentage of Cumulative Exposure Received in Three Specific Jobs Compared to Cumulative Exposure Over All Jobs in 16,124 Workers Employed >1 Year[a]

Plant	First job	Longest job	Last job
All	45% (25%)	60% (44%)	49% (31%)
1	49% (18%)	56% (38%)	45% (29%)
2	38% (31%)	66% (62%)	54% (49%)
3	62% (44%)	72% (58%)	63% (46%)
4	20% (16%)	40% (37%)	28% (25%)
5	20% (20%)	38% (38%)	25% (25%)
6	38% (20%)	53% (39%)	36% (20%)
7	64% (40%)	76% (58%)	68% (46%)
8	60% (33%)	72% (51%)	58% (28%)
9	63% (31%)	79% (64%)	68% (47%)
10	30% (16%)	41% (27%)	35% (20%)

[a]Proportions after excluding short-term workers (employed ≤ 1 year) in parentheses.

There was little difference in the correlations between average formaldehyde exposure in the first, longest, and last job compared with the average exposure for the entire employment (0.77 for the first job and 0.74 for the longest and last job). The correlations by plant were generally larger than 0.70, except for plants 4 and 10, and were usually similar for the different jobs.

Comparing the exposure level in the first, longest, and last job with the highest TWA exposure level experienced in any job showed a correlation of 0.74 with the first, 0.62 with the longest, and 0.63 with the last job. In 8 of the 10 plants, this pattern of the highest correlation being with the first job held. Correlations were moderate to high except for plants 4 and 10.

Comparison of the level of peak exposures received in the first, longest, and last jobs with the highest peak level potentially experienced showed correlations of 0.72 for the first, 0.63 for the longest, and 0.64 for the last job. No pattern was evident by plant, although the last job tended to be less strongly correlated. Correlations were moderate to high except for plants 4 and 10.

Workers in eight of the plants had exposure to formaldehyde-containing particulates. Correlations for duration of particulate exposure in the first, longest, and last job and duration of particulate exposure for the entire employment were generally high for all three jobs (about $r = 0.70$). No clear pattern was present for the different plants. Correlations for the single jobs were usually similar and moderate to high, except for plants 4 and 10.

Correlations between duration of liquid formaldehyde exposure in the various jobs and duration of liquid exposure for the entire employment were about $r = 0.65$ for all three jobs. In six of the plants, the highest agreement was with the longest job, the second highest agreement was with the last job, and the worst agreement was with the first job. Variation of correlations was wide across the plants.

After short-term workers were removed from the analysis, correlations for all six measures were usually somewhat lower, but the ranking of the various jobs remained generally the same.

Evaluation of the percent agreement between the subject's rankings by quartiles

TABLE III. Correlation Coefficients (r) for Comparison of Exposure in the First, Longest, and Last Job With Exposure Over the Entire Employment in 10 Formaldehyde-Producing or -Using Plants[a]

	Cumulative TWA			Average TWA			Highest TWA			Peak level			Duration particulates			Duration liquid		
Plant	First	Long	Last	First	Long	Last	First	Long	Last	First	Long	Last	First	Long	Last	First	Long	Last
All	.48	.70	.57	.77	.74	.74	.74	.62	.63	.72	.63	.64	.73	.72	.71	.64	.64	.65
	.40	.68	.52	.67	.66	.67	.69	.54	.56	.63	.54	.56	.72	.72	.71	.59	.65	.63
1	.41	.69	.61	.65	.73	.79	.76	.44	.47	.80	.50	.50	.47	.62	.56	.65	.59	.58
	.38	.70	.56	.54	.56	.71	.75	.40	.45	.77	.44	.46	.47	.66	.57	.60	.60	.57
2	.31	.83	.59	.64	.83	.80	.55	.50	.38	.57	.60	.51	.51	.83	.84	.32	.77	.62
	.22	.80	.53	.58	.80	.77	.53	.48	.35	.51	.53	.44	.51	.84	.84	.23	.75	.60
3	.53	.80	.66	.88	.91	.82	.75	.76	.78	.61	.74	.82	—	—	—	.68	.75	.71
	.31	.66	.51	.82	.88	.73	.65	.66	.68	.48	.64	.75	—	—	—	.59	.69	.61
4	−.1	.62	.45	.34	.77	.62	.08	.43	.38	.28	.41	.38	.41	.34	.39	.0	.61	.45
	−.1	.63	.47	.31	.76	.60	.08	.44	.40	.26	.39	.36	.39	.29	.35	.0	.64	.49
5	.67	.81	.72	.74	.81	.72	.74	.70	.66	.41	.69	.62	—	—	—	.62	.82	.74
	.67	.80	.72	.74	.81	.72	.74	.69	.66	.41	.69	.61	—	—	—	.61	.82	.74
6	.51	.79	.53	.70	.82	.73	.65	.54	.53	.71	.54	.49	.46	.57	.57	.57	.49	.46
	.41	.71	.47	.61	.77	.68	.62	.49	.50	.65	.44	.38	.37	.51	.51	.52	.43	.40
7	.70	.83	.75	.87	.88	.84	.87	.74	.73	.88	.78	.77	.71	.80	.72	.66	.74	.78
	.59	.79	.68	.82	.87	.81	.85	.68	.66	.84	.69	.68	.60	.79	.63	.55	.69	.70
8	.60	.85	.53	.85	.88	.78	.86	.70	.63	.86	.67	.53	.71	.80	.68	.53	.69	.67
	.36	.70	.30	.65	.80	.64	.78	.51	.43	.78	.47	.26	.58	.72	.59	.40	.61	.60
9	.71	.93	.76	.90	.95	.91	.75	.74	.71	.85	.91	.87	.88	.76	.73	.85	.87	.88
	.53	.87	.65	.84	.92	.87	.71	.75	.70	.76	.86	.77	.83	.66	.65	.74	.81	.83
10	.04	.46	.26	.47	.42	.43	.40	.19	.18	.43	.31	.33	.07	.38	.26	.06	.46	.38
	.14	.61	.35	.38	.24	.28	.41	.14	.12	.40	.25	.25	.17	.58	.41	.12	.66	.50

[a]First row includes all subjects; second row excludes workers of <1 year.

TABLE IV. Misclassification Matrix Between Cumulative TWA for the Entire Employment and Cumulative TWA for the Longest Job, in Quartiles in a Study of Formaldehyde Plant Workers

Entire employment	Exposure categories: Longest job				
	1	2	3	4	Total
1	3805[a]	2606	0	1	6412
	.5934[b]	.4064	.0000	.0002	
2	741	3414	2273	0	6428
	.1153	.5311	.3536	.0000	
3	1128	320	3517	1457	6422
	.1756	.0498	.5476	.2269	
4	745	77	636	4963	6421
	.1160	.0120	.0990	.7729	
Total	6419	6417	6426	6421	25683

[a]Frequency; [b]conditional probability.

for the three jobs and the entire employment showed similar results for the various measures as the correlation coefficients. As an example, Table IV presents the frequencies and conditional probabilities for cumulative formaldehyde exposure in the longest job vs. cumulative exposure for the entire employment.

HYPOTHETICAL CALCULATIONS

Using degrees of agreement in Table IV, we evaluated how this misclassification would affect hypothetical relative risks. It was assumed that there were 10,000 people in each exposure category, and a distribution of cases and noncases was achieved to obtain two different "true" examples of exposure-response relationships (Table V). The resulting (distorted) relative risks were calculated. Assume, for example, that the true exposure-response relationship was 1.00, 1.20, 1.40, and 1.60, which is a significant trend (χ^2 test for trend = 7.64, $p = 0.006$). With the degree of misclassification shown above, the observed risk estimates would be 1.00, 0.98, 1.16, and 1.35, and the trend would be of borderline significance ($\chi^2 = 3.74$, $p = 0.053$). If the true exposure-response relation was higher, i.e., 1.00, 2.00, 4.00, and 6.00, the effect of misclassification, however, would be much greater, i.e., 1.00, 0.79, 1.58, and 2.50. However, the interpretation of the trend test would not be affected ($\chi^2 = 218.56$, $p < 0.001$ and $\chi^2 = 103.68$, $p < 0.001$, respectively).

A similar analysis was performed using the distribution of jobs from plant 10 on the longest job, because it was in this plant that the greatest degree of misclassification occurred. If the true exposure-response relationship was 1.00, 1.20, 1.40, and 1.60 (trend same as above), the observed relative risks would be 1.00, 0.81, 0.99, and 1.24, and the trend would no longer be significant ($\chi^2 = 1.57$, $p = 0.21$). For a true relationship of 1.00, 2.00, 4.00, and 6.00 (trend same as above), the observed relative risks would be 1.00, 0.37, 0.91, and 1.96 ($\chi^2 = 48.8$, $p = 0.001$).

DISCUSSION

The purpose of occupational epidemiologic studies is to identify new risk factors for adverse health effects in the workplace, and one of the criteria for establishing

TABLE V. Example for Distortion of Relative Risks (RR) Using the Misclassification Scheme From Table IV

True RR	1.00	1.20	1.40	1.60
(95% CI)		(0.8–1.7)	(1.0–2.0)	(1.1–2.3)
True case distr.	50	60	70	80
True noncase distr.	9950	9940	9930	9920
Dist.[a] case distr.	58	57	67	78
Dist. noncase distr.	9945	9936	9936	9923
Dist. RR	1.00	0.98	1.16	1.35
(95% CI)		(0.7–1.4)	(0.8–1.6)	(1.0–1.9)
True RR	1.00	2.00	4.00	6.00
(95% CI)		(1.4–2.8)	(2.9–5.5)	(4.5–8.1)
True case distr.	50	100	200	300
True noncase distr.	9950	9900	9800	9700
Dist. case distr.	111	87	175	277
Dist. noncase distr.	9892	9906	9828	9724
Dist. RR	1.00	0.79	1.58	2.50
(95% CI)		(0.6–1.0)	(1.2–2.0)	(2.0–3.1)

[a]Distorted.

causality is evidence of a dose-response relationship. The dose actually received into the body and subsequently delivered to the organ of interest is usually not known. Therefore, an estimate of exposure is typically used as a surrogate for dose.

To establish dose-response relationships, it is critical to estimate the dose as precisely as possible, especially for small risks, which we are likely to see in the future [Rappaport and Smith, 1991]. In the past, associations of chemical exposure with development of disease have been found by evaluating risks by job title or industry. More recently, researchers have taken a step further in such investigations by evaluating risks using semiquantitative or quantitative exposure estimates, which enhance statistical power [Siemiatycki et al., 1989].

Study design may affect whether an association with disease is found. Cumulative exposure is often used as the surrogate measure of cumulative dose because of its expected link to chronic disease etiology, but depending on the pathogenic mechanisms of the disease, other measures of exposure might be important. Different measures do not necessarily correlate with each other [Blair and Stewart, 1990] and, thus, they might provide different estimates of risk. Reliance upon a single measure of exposure, therefore, may mislead the investigator. For these reasons we evaluated several measures. Another study design characteristic that may affect the quality of exposure assessment is the type of job history obtained. Often, information on only one job is obtained. Investigators conducting case-control and death certificate studies may request only the usual job, and record linkage studies may be based on the most recent job.

In this report we compare the rankings of various parameters of formaldehyde exposure from a single job to that of the entire employment history in one plant. Exposure parameters which have been used in epidemiologic studies were evaluated.

The degree of correlation could be influenced by the number of short-term workers per plant, the number of overlapping jobs (where the first job is the last or longest job, or the last job is the longest job), the number of jobs held by each worker, and the average duration of employment. In this study we found that, in general, the

more short-term workers were employed at a plant, the higher were the correlations between exposure in a single job and the entire employment. This situation occurred because the duration of a single job and the duration of the entire employment were more similar for short-term workers than they were for workers employed longer. Discrimination between correlations for the first, last, or longest jobs in this study, therefore, became more difficult when these jobs were actually the same job. In our study, for 41% of the workers employed longer than 1 year, the last job was also their longest; overlapping with the first job was generally less usual. Plants with higher numbers of jobs per worker or a longer employment duration tended to have lower correlations between exposure in a single job and exposure over the entire employment. In our study, we also saw all combinations of the above-mentioned peculiarities, but we were not able to evaluate these interactions in more depth because of the small number of plants. These findings suggest that investigators should take into consideration the number of short-term workers before relying upon a single job to categorize the extent or duration of the exposure.

We also found that the job (first, longest, or last) that best approximated the complete work history depended upon the exposure parameter being examined. For cumulative exposure, the longest job was most closely related to the work history, but the first job tended to be associated with the highest 8-hour formaldehyde level and peak exposures. No differences between the first, last, and longest jobs were seen for the average exposure or for the duration of particulate and liquid exposure. The correlations between the exposure parameters based on individual jobs and those based on a complete work history in a plant were typically about 0.6–0.7. It is important to note, however, that the highest correlation was never with the last job. Although the patterns were usually fairly consistent, considerable variation existed among plants regarding the strength of correlations.

Use of a single job to estimate exposure in this study would have led to varying estimates of risks, depending on the degree of misclassification. In a hypothetical situation using the entire cohort, we found that the amount of misclassification resulting from use of the longest job compared to all jobs could reduce risk estimates for cumulative exposure marginally in low-risk situations, and somewhat more substantially in high-risk situations. In addition, the trend test went from being significant to being of borderline significance in the low-risk analysis. In the second hypothetical example, plant 10 was used because it was the plant with the most severe degree of misclassification for the longest job. In this example, the effect of the misclassification on the relative risks was more substantial. The strength of the association was greatly reduced because an excess was seen only in the highest exposure category. Also, the trend for the lower risks was no longer significant. These changes could have been greater for less well-correlated exposure parameters than cumulative exposure or the longest job.

How relevant these findings are to other studies depends upon several factors. First, the definition of a job could influence the correlation with total exposure. We defined a job as an entry recorded in the company's records, regardless of the length of time. An individual, however, might define a job quite differently, for example, by combining similar jobs, e.g., assistant operator, operator, and chief operator. This type of definition would change the duration of the job, which could, therefore, change the correlation with the different measures. Second, we used employment at one worksite as a surrogate for "working lifetime" employment. Most workers,

however, are likely to be employed in more than one plant during their lifetime. Depending on the study design and population studied, true lifetime exposure to occupational exposures could be very different.

In conclusion, our findings show that, in this study, for cumulative exposure the longest job was the best choice if one had depended on only one job. For average exposure, all jobs were of similar value. For peak and highest exposures, the first job yielded less misclassification. The correlations, however, varied widely from plant to plant. Exposure information from only one job usually yielded not more than 60% of the total exposure and often much less. In two hypothetical examples, we showed what effect this misclassification would have had on relative risks. In these examples, higher risks were more affected in absolute terms than lower risks. Use of the trend test, however, would have changed the interpretation of the exposure-response relationship from being significant in the lower set of risks to being nonsignificant. This finding suggests that use of one job to estimate cumulative exposure could seriously affect the interpretation of a study. It would be useful to evaluate the comparability of exposure for single jobs to total exposure in other data sets.

REFERENCES

Alderson MR (1972): Some sources of error in British occupational mortality data. Br J Ind Med 29:245–54.

Baumgarten M, Siemiatycki J, Gibbs GW (1983): Validity of work histories obtained by interview for epidemiologic purposes. Am J Epidemiol 118:583–591.

Blair A, Stewart PA (1990): Correlation between different measures of occupational exposure to formaldehyde. Am J Epidemiol 131:510–516.

Blair A, Stewart PA, O'Berg M, Gaffey W, Walrath J, Ward J, Bales R, Kaplan S, Cubit D (1986): Mortality among industrial workers exposed to formaldehyde. J Natl Cancer Inst 76:1071–1083.

Bond GG, Bodner KM, Sobel W, Shellenberger RJ, Flores GH (1988): Validation of work histories obtained from interview. Am J Epidemiol 128:343–351.

Bourbonnais R, Meyer F, Thériault G (1988): Validity of self-reported work history. Br J Ind Med 45:29–32.

Chang P-J, Wang J-D (1988): The accuracy of occupational histories obtained from spouse. In: Hogstedt C, Reuterwall C (eds): "Progress in Occupational Epidemiology." Amsterdam: Elsevier Science, pp. 53–62.

Illis WR, Swanson GM, Satariano ER, Schwartz AG (1987): Summary measures of occupational history: A comparison of latest occupation and industry with usual occupation and industry. Am J Public Health 77:1532–1534.

Gart JJ, Thomas DG (1963): Numerical results on approximate confidence limits for odds ratios. J R Stat Sec B 34:441–447.

Gute DM, Fulton JP (1985): Agreement of occupation and industry data on Rhode Island death certificates with two alternative sources of information. Public Health Rep 100:65–72.

Mantel N (1963): Chi-square tests with one degree of freedom: Extension of the Mantel-Haenszel procedure. J Am Stat Assoc 58:690–700.

Nelson DE, Swanson GM, Grossbart A, Schwartz AG, Brix K, Fine LJ (1987): Occupation and industry data obtained from death certificates: The effect and influence of case selection. J Occup Med 29:52–56.

Olsen GW, Brondum J, Bodner KM, Kravat BA, Mandel JS, Mandel JH, Bond GG (1990): Occupation and industry on death certificates of long term chemical workers: Concordance with work history records. Am J Ind Med 17:465–481.

Pershagen G, Axelson O (1982): A validation of questionnaire information on occupational exposure and smoking. Scand J Work Environ Health 8:24–28.

Rappaport SM, Smith TJ (eds.) (1991): "Exposure Assessment for Epidemiology and Hazard Control." Cincinnati, OH: Amer. Conf. Gov. Ind. Hyg.

Rona RJ, Mosbech J (1989): Validity and repeatability of self reported occupational and industrial history from patients in EEC countries. Int J Epidemiol 18:674–679.

Rosenberg CR, Mulvihill MN, Fischbein A, Blum S (1987): An analysis of the validity of self reported occupational histories using a cohort of workers exposed to PCBs. Br J Ind Med 44:702–710.

Schade WJ, Swanson GM (1988): Comparison of death certificate occupation and industry data with lifetime occupational histories obtained by interview: Variations in the accuracy of death certificate entries. Am J Ind Med 14:121–136.

Schumacher MC (1986): Comparison of occupation and industry from death certificates and interviews. Am J Public Health 76:635–637.

Siemiatycki J, Dewar R, Richardson L (1989): Costs and statistical power associated with five methods of collecting occupation exposure information for population-based case-control studies. Am J Epidemiol 130:1236–1245.

Steenland K, Beaumont J (1984): The accuracy of occupation and industry data on death certificates. J Occup Med 26:288–296.

Stewart PA, Blair A, Cubit DA, Bales R, Kaplan SA, Ward J, Gaffey W, O'Berg MT, Walrath J (1986): Estimating historical exposures to formaldehyde in a retrospective mortality study. Appl Ind Hyg 1:34–41.

Stewart WF, Tonascia JA, Matanoski GM (1987): The validity of questionnaire-reported work history in live respondents. J Occup Med 29:795–800.

Swanson GM, Grossbart A, Schwartz GM, Burrows RW (1984): An assessment of occupation and industry data from death certificates and hospital medical records for population based cancer surveillance. Am J Public Health 74:464–467.

Turner DW, Schumacher MC, West DW (1987): Comparison of occupational interview data to death certificate data in Utah. Am J Ind Med 12:145–151.