



Comparison of First, Last, and Longest-Held Jobs as Surrogates for All Jobs in Estimating Cumulative Exposure in Cross-Sectional Studies of Work-Related Asthma

GEZA BENKE, PhD, MALCOLM R. SIM, MBBS, DEAN P. MCKENZIE, BA(HONS),
EWAN MACFARLANE, MPH, ANTHONY DEL MONACO, MPH, JAN L. HOVING, PhD,
AND LIN FRITSCHI, MBBS, PhD

BACKGROUND: Previous occupational studies have used exposure in most recent job as a surrogate for all jobs or “total work history” exposure. This method may not be valid for diseases in which disability brought on by one job may influence later work history, such as asthma. We investigated different surrogates for total work history for the outcome of asthma symptoms.

METHODS: In a cross-sectional study, we quantitatively compared three exposure surrogates (last job, first job, and longest-held job) with the total cumulative work exposure (all jobs) in a cohort of 1778 aluminium industry workers. The chemical exposures we compared were total fluoride dust, inspirable dust, and sulfur dioxide with the respiratory symptoms of wheeze, chest tightness, and rhinitis.

RESULTS: When extrapolated over time, all surrogates quantitatively overestimated the gold standard “all jobs” for all three exposures investigated. For the symptom of wheeze, last job was found to be the worst surrogate for all jobs for the three exposure types investigated. Prevalence ratios for fluoride exposure and the symptom of occupational wheeze were last job 1.07 (95% confidence interval, 0.92–1.26), longest job 1.10 (0.94–1.30), first job 1.14 (0.97–1.35), and all jobs 1.27 (1.05–1.53).

CONCLUSIONS: Although last job has been found to be a satisfactory surrogate for all jobs in cancer studies, we do not recommend the use of this metric in studies of chronic diseases where development of disability may occur with early exposure. We found that both first job and longest job held were better metrics in studies where the adverse health effect may influence the job history of subject.

Ann Epidemiol ■;■:■. © 2007 Elsevier Inc. All rights reserved.

KEY WORDS: Exposure Assessment, Respiratory Symptoms, Asthma, Occupational Epidemiology, Fluorides.

INTRODUCTION

In retrospective occupational cohort, case-control, and cross-sectional studies, often the only work information available for subjects is the current or last job held with the company. Therefore, if we wish to estimate cumulative exposure over a subject's entire work career with that company, the assumption is made that the subject has stayed in that same job for the whole time that he or she was employed by the company. A similar situation arises in studies of mortality rates, which use the usual or last occupation as recorded on the death certificate to assign exposure to

subjects. This assumption is not always valid and it is very likely that this involves some exposure misclassification (1, 2). If similar nondifferential exposure misclassification is present in case-control and cross-sectional studies, then it is likely to result in a diminution of the odds or prevalence ratio and the risk of missing a real association. However, differential misclassification may also occur where subjects who develop symptoms are transferred from exposed to unexposed jobs that are then recorded as the last job. In this case, the exposure of symptomatic subjects will most likely be underestimated as they are more likely to change jobs from a high exposure to a low exposure job.

The validity of using last job as a surrogate for all jobs in estimating cumulative exposure has previously been investigated (3–5). The findings by Vetter et al. (3) suggested that the use of surrogates for exposure could result in different degrees of misclassification. Baris and Armstrong (4) found that cumulative exposure tended to be underestimated by using last job, primarily because of employees moving from exposed to nonexposed jobs during the course of their working career. However, last job was found to be very useful in correctly identifying the most highly exposed subjects, and it

From the Department of Epidemiology and Preventive Medicine, Monash University, The Alfred, Commercial Road, Melbourne, VIC 3004, Australia (G.B., M.R.S., D.P.M., E.M. A.D.); Coronel Institute of Occupational Health, Academic Medical Center, Universiteit van Amsterdam, PO Box 22700, 1100 DE, Amsterdam, The Netherlands (J.L.H.); and Western Australian Institute for Medical Research 5th Floor, Rear 50 Murray Street, Perth, 6000, Australia (L.F.).

Address correspondence to Geza Benke, Department of Epidemiology and Preventive Medicine, Monash University, The Alfred, Commercial Road, Melbourne, VIC 3004, Australia. Tel.: +61 3 99030583; fax: +61 399030556. E-mail: geza.benke@med.monash.edu.au.

Received April 4, 2007; accepted June 18, 2007.

was also found that those who ended their working life in exposed jobs had been in these sorts of jobs throughout their career. However, Sun et al. (5) concluded that the use of the surrogate of last job may not only lead to overestimation of exposure for low risk jobs but also underestimation of exposure for high risk jobs.

These studies (3–5) are most applicable for causes of disease or death that are not preceded by disability (e.g., cancer). However, their findings may be questionable for occupational diseases of shorter latency such as asthma, where development of the disease and resultant disability while still working may influence the subsequent work history of the subject.

The main objective of the present study was to compare cumulative exposures based on the surrogates “last job,” “first job,” and “longest job,” with total actual cumulative exposure for work history using “all jobs” as the gold standard. Using these different surrogates of cumulative exposure, we then evaluated which exposure metrics best predicted the prevalence of asthma symptoms in a cross-sectional study of respiratory disease in the aluminium industry.

METHODS

Subjects

Healthwise is a study program that has established a retrospective and prospective cohort to investigate links between several chemical exposures and cancer, mortality and respiratory disease in the aluminium industry. The methods have been previously reported and are only briefly described here (6). The cross-sectional survey part of the Healthwise study program was undertaken between May and August 1995 and involved 1778 current employees in two aluminium smelters in Victoria, Australia. Each employee who agreed to participate in the study was interviewed by a trained research nurse. Demographic and lifestyle information was collected, which included smoking history and alcohol consumption.

Symptoms

A modified version of the Medical Research Council questionnaire on work-related respiratory symptoms was administered. Although five symptoms were investigated, we show analysis only of the three commonest reported. Subjects were classified as having work related symptoms if they reported wheeze, rhinitis, or chest tightness anytime in the previous 12 months and the symptoms were better on days off work, on holidays or at the beginning of a shift. This allowed for the calculation of period prevalence.

Exposure

A detailed job dictionary was compiled for each site, which was used to obtain a history of work with the aluminium

company from each employee, including the operating center and department for each job, dates when each job started and finished, and each task that was performed as part of that job.

Retrospective quantitative exposure measurement results were available for most jobs from 1977 to the time of the study. The construction of the Job Exposure Matrix (JEM) has been previously described and is only briefly outlined here (7). The JEM was constructed by collation of all air monitoring measurements for 39 chemicals and dusts. In each cell of the JEM was the average exposure for the job for each year that the job was worked. In this analysis, we only present the results for total fluoride gas and dust, sulphur dioxide and inspirable dust. The average exposure in each job in the job dictionary, since the commencement of the job at each smelter, was then tabulated for each year. For the years prior to measurements, back extrapolation was undertaken from 1977 back to 1962.

The JEM was then used to calculate mean exposure for the three surrogates “last job,” “longest job,” and “first job” for each subject, for cumulative exposure expressed as mg/m^3 . The mean exposure for each of the three surrogates was then multiplied by the total number of years that the subject reported working with the company, to calculate metrics expressed as cumulative exposure in mg/m^3 years. Total cumulative exposures for the surrogates were then compared with the total cumulative exposure based on “all jobs,” the gold standard, in mg/m^3 years.

Statistical Analysis

To measure agreement between the exposure metrics, percentage agreement and intraclass correlation (ICC) were calculated for the quartiles of cumulative exposure for all jobs and the three surrogates of exposure (8) with the SPSS statistical package (9). The percentage agreement was the number of instances where both the “all jobs” gold standard and the surrogate metric led to the same classification for quartiles of cumulative exposure. Unlike the standard Pearson product moment correlation coefficient, the ICC can be used to measure agreement (8, 10). When applied to a given set of data, ICC will give almost identical results to the weighted kappa measure of agreement (11), if the latter uses quadratic weights (12). We employed the two-way mixed effects model of intra-class correlation measuring absolute agreement (8), with observations as a random factor, and measures (all jobs and other surrogates) as a fixed factor.

After comparison of the surrogates of exposure with the cumulative exposure for “all jobs,” we compared the surrogates of exposure with the gold standard using prevalence ratios (PRs) for three work-related respiratory symptoms, that is, wheeze (13, 14), chest tightness, and rhinitis. PRs were

obtained using log-binomial regression (15, 16), as recommended by Behrens et al. (17) and Skov et al (14) and previously employed in a similar analysis of this dataset (6). The Stata statistical package was used to calculate prevalence ratios adjusting for age and smoking status, for example, never, former, and current (18).

RESULTS

There were 1778 participants in the survey (89.4% participation rate) of whom 9.1% were women. Median duration of exposure was 10 years, and subjects had a median of two reported jobs. Generally, all the surrogate metrics underestimated the number of workers exposed when compared with the gold standard of “all jobs” (Table 1). The underestimation was greatest for “last job.” Except for “last job” and fluorides, all the surrogates overestimated the median cumulative exposures of those exposed compared with the gold standard, with the largest overestimation occurring for the “first job” surrogate. Interestingly, when we repeated the analysis and included the nonexposed into the quartile analysis, we found the opposite result, that is, the surrogates all underestimated the median exposure in each of the quartiles. This is caused by the high number of subjects classified as unexposed by the surrogates.

The agreement, as expressed by the ICC, between the cumulative exposure calculated using the gold standard against each of the other three exposure surrogates (Table 2). The “longest job” surrogate had the best ICC for all three surrogates with “all jobs” and the lowest ICC was for “first job.” Percentage agreement was best for fluorides across all three surrogates, but the ICC was best for inspirable dust for the “longest” and “last job” surrogates.

Across all three exposures, the “last job” surrogate consistently resulted in the lowest period PRs for the symptom of wheeze (Table 3). However, “first job” resulted in the highest PRs. Also, importantly for wheeze, statistical significance was only achieved for the gold standard across all three exposures and none of the three surrogates. Chest tightness appeared to be less strongly related to the exposures, because the prevalence ratios were closer to one and the larger confidence intervals were caused by fewer numbers. The “last

TABLE 2. Agreement of cumulative exposure surrogates compared with cumulative exposure for “All jobs”

	%Agreement ^a	ICC ^b (95% CI)
First job		
Total Fluorides	71.1	0.80 (0.78–0.83)
SO ₂	53.2	0.72 (0.68–0.75)
Inspirable dust	60.2	0.77 (0.75–0.80)
Longest job		
Total Fluoride	82.7	0.87 (0.84–0.90)
SO ₂	70.7	0.86 (0.79–0.90)
Inspirable dust	76.5	0.88 (0.83–0.91)
Last job		
Fluoride	83.0	0.84 (0.82–0.86)
SO ₂	73.9	0.84 (0.80–0.87)
Inspirable dust	80.0	0.86 (0.83–0.88)

^aCalculated by the number of instances where “All jobs” and surrogate metric led to the same classification.

^bIntraclass correlation coefficient (ICC) for quartiles of cumulative exposure.

job” surrogate also appeared to display the lowest period PRs for chest tightness. There does not appear to be a relationship between rhinitis and any of the three exposures and the results were very consistent across all three metrics and the gold standard for this symptom.

To further investigate the findings of Table 3, we calculated the interquartile prevalence ratios for wheeze, the most commonly reported symptom by the subjects. For all three exposures, all three surrogate metrics overestimated symptom prevalence for reported wheeze for unexposed subjects (Table 4). The exposure quartile PRs for the surrogates were found to be lower for almost all exposures compared to the gold standard metric “all jobs.” The worst performing metric appeared to be the “last job” surrogate. Dose–response relationships were found for all the metrics, but the surrogates all displayed prevalence ratios below unity for the first quartile for each of the exposures and the dose-response relationships were weaker.

DISCUSSION

In this cross-sectional study of respiratory symptoms in the aluminium industry, we investigated exposure to total fluorides, sulfur dioxide and inspirable dust, comparing surrogate

TABLE 1. Number exposed (and %), median cumulative exposure and interquartile range (IQR) for inspirable dust, SO₂, and total fluorides of for the gold standard and surrogate cumulative exposure metrics (n = 1778)

Exposure type	Based on all jobs (gold Standard)		Based on longest job (surrogate)		Based on last job (surrogate)		Based on First Job (Surrogate)	
	No. Exposed (%)	Median of exposed mg/m ³ .years (IQR 25–75%)	No. Exp.(%)	Median of exposed mg/m ³ .years (IQR 25–75%)	No. Exp. (%)	Median of exposed mg/m ³ .years (IQR 25–75%)	No. Exposed (%)	Median of exposed mg/m ³ .years (IQR 25–75%)
Total fluorides	1203 (67.7)	0.86 (0.14–2.76)	962 (54.1)	0.95 (0.18–2.99)	912 (51.3)	0.72 (0.14–2.68)	1003 (56.4)	1.08 (0.25–3.26)
SO ₂	1013 (57.0)	2.24 (1.06–4.59)	767 (43.1)	2.55 (1.72–5.94)	708 (39.8)	2.43 (1.39–5.47)	817 (46.0)	3.39 (1.83–7.71)
Inspirable dust	1296 (72.9)	8.60 (2.88–20.31)	1074 (60.4)	10.09 (4.10–22.52)	1032 (58.0)	8.67 (3.35–20.59)	1087 (61.1)	11.27 (4.98–23.91)

TABLE 3. PRs for total fluorides, SO₂, and inspirable dust, adjusted for age and smoking for the cumulative exposure metrics and the three symptoms, wheeze, chest tightness, and rhinitis

Exposure type	Exposure metric	Wheeze (95% CI)	Chest tightness (95% CI)	Rhinitis (95% CI)
Fluorides	Total jobs	1.27 (1.05–1.53)	1.23 (0.98–1.53)	0.91 (0.77–1.07)
	Last job	1.07 (0.92–1.26)	1.05 (0.86–1.27)	0.91 (0.78–1.06)
	First job	1.14 (0.97–1.35)	1.12 (0.92–1.37)	0.89 (0.77–1.04)
	Longest job	1.10 (0.94–1.30)	1.12 (0.92–1.36)	0.90 (0.77–1.05)
SO ₂	Total jobs	1.23 (1.04–1.45)	1.17 (0.97–1.43)	0.87 (0.75–1.02)
	Last job	1.02 (0.87–1.20)	0.89 (0.73–1.08)	0.95 (0.81–1.11)
	First job	1.16 (0.99–1.35)	1.17 (0.97–1.41)	0.90 (0.77–1.05)
	Longest job	1.14 (0.98–1.34)	1.02 (0.84–1.23)	0.91 (0.78–1.07)
Inspirable dust	Total jobs	1.24 (1.02–1.52)	1.23 (0.97–1.55)	0.91 (0.77–1.08)
	Last job	1.05 (0.89–1.24)	1.03 (0.85–1.26)	0.91 (0.78–1.07)
	First job	1.15 (0.97–1.37)	1.12 (0.92–1.38)	0.91 (0.78–1.06)
	Longest job	1.10 (0.93–1.30)	1.12 (0.91–1.37)	0.91 (0.78–1.06)

exposure metrics to the gold standard of total cumulative exposure. Our aim was to determine how the surrogate exposure metrics predicted differences in asthma symptoms.

In our comparison of the surrogates for total cumulative exposure with the gold standard for cumulative exposure of “all jobs” worked by subjects, we found that use of exposure metrics based solely on longest job, last job or first job all tended to under-estimate the number of subjects exposed. However, the “last job” surrogate underestimated exposure status in more subjects compared to the other two surrogates. Best agreement with “all jobs” was found with the surrogate of “longest job.” All the surrogates overestimated the cumulative exposure for exposed subjects.

When we calculated the period prevalence ratios for the three surrogates and “all jobs” with the respiratory symptoms of workplace wheeze and chest tightness, the highest prevalence ratios were found for “all jobs.” The surrogates were all biased towards the null result.

Compared with “all jobs,” “first job” appeared to marginally outperform the surrogate “longest job” for the two symptoms (wheeze and chest tightness) related to the three different exposures investigated. Using the “last job” tended to be the poorest surrogate with the exposure of total fluoride showing the best results for this surrogate.

Our results suggest that in studies of respiratory disease and workplace exposures the favoured surrogate for ‘total jobs’ should be “first job” then perhaps “longest job” and lastly “last job.” It must be emphasized that the outcomes included occupational wheeze, which is a strong predictor of occupational asthma. First or early exposure is likely to be more important in causing occupational asthma than later exposure.

Much of the literature in the evaluation and use of surrogates for “all jobs” has focused on cancer as the main outcome under investigation. In an early study (19), investigating telephone line work and the occurrence of leukemia, “last job” was used for categorical analyses of “all jobs,” as 85% of records with complete job histories

demonstrated agreement for “last job.” Although this may seem a plausible path for analysis, it can be seen from our results that significant misclassification may have occurred if instead asthma symptoms were the outcome of interest.

A validity study investigating formaldehyde exposure in 10 formaldehyde-producing or using plants found that the best predictor for cumulative formaldehyde exposure (or “all jobs”) at the plant was the “longest job” (3). They found that the highest correlation with any measures they investigated in the study was *never* for “last job.” Simulated calculations indicated that if “longest job” was used as a metric, then the “true relative risk” of 1.60 would decrease to 1.35. Our results were similar but not as strong with the fourth quartile of Fluoride exposure using total jobs PR = 1.42 and for longest job we found PR = 1.22.

Baris and Armstrong (4) investigated the use of “last job” only as a surrogate for the complete employment history (“all jobs”) in a study investigating magnetic field exposure in an electrical utility in Québec. They concluded and concurred with Matanoski et al. (19) that the use of “last job” was a good method to assess exposure in electrical industries where the exposed jobs are skilled jobs. Furthermore, exposures in the electrical industries remain quite constant over many years in comparison with chemical exposures. Baris and Armstrong (4) did, however, concede that their conclusions may only be valid for their mortality study for cancer, which is not usually preceded by disabling morbidity, which suggests that introduced misclassification by using “last job” may be a cause for concern in the situations in which causes of death may be preceded by disability. Occupational asthma may be such a situation in which exposure in the first job can cause or exacerbate the onset of asthma which in turn may result in the subject moving to an unexposed or lower exposed job.

Sun et al. (5) recently presented results from simulations for the metrics “only,” “longest,” or “last job” for a hypothetical and actual cohort of rubber workers, in a lung cancer mortality study. The simulated cohort consisted of 30,000

workers, all with at least 30 years follow-up time. Standardized mortality ratio results were presented and the simulated data showed that 'last job' may lead to overestimation for low-risk jobs and underestimation for high-risk. An important observation by Sun et al. (5) was that in the simulated part of the cohort only 10% of workers never changed jobs compared with 50% in the empirical study they conducted. In our study, 46.7% of subjects changed jobs, which suggests that the greater the percentage of workers with only one job in a study the less the overestimation of median exposure when using exposure surrogates.

The findings in the present study must be considered in light of the classic "survivor effect" found in cross-sectional studies. Our study was a cross-sectional one in which all subjects were interviewed once and self-reported their job histories. There may have been workers that self-selected themselves out of our study by suffering symptoms and leaving the workplace prior to our interview period. This would tend to reduce the prevalence ratios and dose-response estimates. In particular, we believe that this factor would tend to decrease the dose-response relationship for the "first job" surrogate in this study.

A major strength of the current study is that we have used actual data and presented prevalence ratios that clearly show the dose-response relationships for the various metrics. The extent of misclassification and likely loss of statistical significance by using surrogate exposure metrics for respiratory symptoms can be clearly seen in the case of work-related wheeze. Where associations were not found between exposure and a respiratory symptom, such as rhinitis, we found that the use of exposure surrogates made little difference to the prevalence ratios.

Although the "healthy worker effect" for respiratory disease has been suggested in the literature, none have quantitatively described the effect on prevalence ratios (20–21).

Most previous cancer studies have relied upon simulations or hypothetical calculations of misclassification or relied only on summary standardized mortality ratios (3, 5).

In future studies researchers should be more circumspect about using "last job" as a surrogate of "all job" or cumulative work history exposure, if the disease being investigated has a short latency period. When the development of disability from the occupational disease under investigation can occur early in a job history and influence later job changes (usually to a lower exposed job), we do not recommend the use of the surrogate of "last job." Much of the previous literature has been focussed on cancer investigations or has involved exposures which have not changed markedly over time, such as magnetic field exposure, and in these circumstances, "last job" is likely to cause less misclassification than when associations of chemical exposure and occupational asthma and other occupational diseases of shorter latency are being investigated.

This study was funded by Alcoa World Alumina Australia and Portland Aluminium.

REFERENCES

1. Alderson MR. Some sources of error in British occupational mortality data. *Br J Ind Med.* 1972;29:245–254.
2. Checkoway H, Pearce NE, Kriebel D. *Research Methods in Occupational Epidemiology.* 2nd ed. New York: Oxford University Press; 2004:42–49.
3. Vetter R, Stewart PA, Dosemeci M, Blair A. Validity of exposure in one job as a surrogate for exposure in a cohort study. *Am J Ind Med.* 1993;23:641–651.
4. Baris D, Armstrong BG. Exposure to magnetic fields estimated from last job held in an electrical utility in Québec, Canada: a validation study. *Occup Environ Med.* 1996;53:334–338.
5. Sun Y, Taeger D, Weiland SK, Keil U, Straif K. Job titles and work areas as surrogate indicators of occupational exposure. *Epidemiology.* 2003;361–367.
6. Fritschi L, Sim MR, Forbes A, Abramson MJ, Benke G, Musk AW, et al. Respiratory symptoms and lung-function changes with exposure to five substances in aluminium smelters. *Int Arch Occup Environ Health.* 2003;76:103–110.
7. Benke G, Sim M, Fritschi L, Aldred G. Beyond the job exposure matrix (JEM): the task exposure matrix (TEM). *Ann Occup Hyg.* 2000;44:475–482.
8. McGraw KO, Wong SP. Forming inferences about some intraclass correlation coefficients. *Psychol Methods.* 1996;1:30–46.
9. SPSS Inc. *SPSS for Windows, version 12.* Chicago, IL: SPSS, Inc.; 2003.
10. Streiner DL, Norman GR. *Health Measurement Scales: a Practical Guide to their Development and Use.* 2nd ed. New York: Oxford University Press; 1995:115–116.
11. Cohen J. Weighted kappa: nominal scale agreement with provision for scaled disagreement or partial credit. *Psychol Bull.* 1968;70(213):220.
12. Fleiss JL, Cohen J. The equivalence of weighted kappa and the intraclass correlation coefficient as measures of reliability. *Educ Psychol Meas.* 1973;33:613–619.
13. Lee J, Chia KS. Estimation of prevalence rate ratios for cross-sectional data: An example in occupational epidemiology [letter] *Br J Ind Med.* 1993;50:861–862.
14. Skov T, Deddens J, Petersen MR, Endahl L. Prevalence proportion ratios: estimation and hypothesis testing. *Int J Epidemiol.* 1998;27:91–95.
15. Dobson AJ. *An Introduction to Generalized Linear Models.* 2nd ed. Boca Raton, FL: Chapman & Hall/CRC; 2000.
16. McCullagh P, Nelder JA. *Generalized Linear Models.* 2nd ed. London: Chapman & Hall, London; 1989.
17. Behrens T, Taeger D, Wellmann J, Keil U. Different methods to calculate effect estimates in cross-sectional studies. A comparison between prevalence odds ratios and prevalence ratio. *Methods Inf Med.* 2004;43:505–509.
18. StataCorp. *Stata Statistical Software. Version 8* College Station, TX: StataCorp; 2002.
19. Matanoski GM, Elliot E, Breyse P, Lynberg MC. Leukemia in telephone linemen. *Am J Epidemiol.* 1993;137:609–619.
20. Tupi K, Vohlonen I, Terho EO, Husman K. Effects of respiratory morbidity on occupational activity among farmers. *Eur J Respir Dis Suppl.* 1987;152:206–211.
21. Post W, Heederick D, Houba R. Decline in lung function related to exposure and selection processes among workers in the grain processing and animal feed industry. *Occup Environ Med.* 1998;55:349–355.