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AN INDEX OF PAST ASBESTOS EXPOSURE AS APPLIED TO CAR AND BUS MECHANICS

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Abstract—Different ways to describe historic fibre exposure from asbestos-containing friction materials were studied and compared for a group of 103 car and bus mechanics with more than 20 years employment and 15 years of asbestos exposure. A model was constructed to calculate cumulative asbestos exposure from friction materials including duration, intensity and exposure last year. The model is a combination of an additive and a multiplicative model, where an asbestos index was constructed that takes both near field and far field exposure into consideration. The model was based upon data from the international literature and quantitative asbestos measurements performed 1976–1988 in Swedish car repair workshops. The fibres were counted by phase-contrast microscopy with fibre criteria of length $> 5\ \mu m$ and aspect ratio $\geq 3:1$. The mechanics' fibre exposure at 398 repair workshops during a period of 48 years were calculated using the model. The mean cumulative exposure was estimated to be 2.6 f ml^{-1} • year. The annual cumulative exposure was highest for truck mechanics in the early 1960s. The car mechanics had a time-weighted average fibre exposure range of 0.11–0.41 f ml^{-1} (mean 0.21 f ml^{-1}) in 1965 compared to 0.003–0.08 f ml^{-1} (mean 0.021 f ml^{-1}) in 1985. In order to validate the model, the mechanics' fibre exposure estimated using the model were compared with representative asbestos exposure measurements for car mechanics during the 1960s and the 1970s (correlation coefficient = 0.69). Five lung physiological variables (FVC, TLC, FEV_1, TL_{co} and CV%) were used to study exposure–response relationships. None of the exposure parameters suggested any significant relationship between exposure and decrease in lung function.

INTRODUCTION

Asbestos exposure can cause a variety of lung disorders. Lung cancer is an effect of high asbestos exposure levels in the past (Selikoff and Lee, 1978), while other diseases may be the result of more recent exposures. Therefore, it is important to characterize asbestos exposure over long periods. Information on cancer and other diseases from studies of low-level asbestos exposures is inadequate. Car mechanics are generally regarded as a low exposed group; no increased risk of lung cancer was found (Hansen, 1989). Mesotheliomas have been observed (Rödelsperger *et al.*, 1986; Woitowitz and Rödelsperger, 1994), but there is no support for any increased risk for car mechanics or garage workers (McDonald and McDonald, 1980; Teta *et al.*, 1993; Järvholm and Brisman, 1988; Wong, 1992). Lung function data have not been studied systematically with well described exposures. High levels of asbestos exposure can cause lung fibrosis (Selikoff and Lee, 1978); it is, however, unknown if low dose exposure can result in fibrosis. Murphy *et al.* (1972) demonstrated changes in small airways owing to asbestos

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exposure but the level of asbestos exposure that may cause airway effects has not been satisfactorily described.

The aim of this study was to construct a model to estimate the cumulative asbestos exposure from friction materials, to apply the model to one type of employment (car mechanics) with low asbestos exposure at different working places, and finally to compare the model with other types of exposure and determine its relationship to lung function variables. This study is an expansion of a recently published study (Dahlqvist *et al.*, 1992), as bus mechanics have been included to increase the exposure range.

Friction materials in clutches and brakes for vehicles have contained about 30–70% asbestos fibres since 1930 (Kauppinen and Korhonen, 1987). During repair and changing of friction linings there can be exposure to asbestos fibres worn from the linings. This has been demonstrated in several studies (Hatch, 1970; Lorimer *et al.*, 1976; Knight and Hickish, 1970; Rohl *et al.*, 1976; Kauppinen and Korhonen, 1987). In the middle of the 1980s approximately 25 000 workers were employed as car and bus mechanics in Sweden and thus exposed to asbestos fibres. Asbestos-free brakes' linings were introduced in the beginning of the 1980s.

Different methods can be used to describe past exposure depending on the data sources available. Semi-quantitative or quantitative models have been used (Stewart and Herrick, 1991), but no model exists which could fit closely Swedish car mechanics. Asbestos exposures during different job activities have been studied, but the exposure pattern over longer periods has not been adequately investigated for car mechanics.

STUDY SUBJECTS AND METHODS

Study group

A study group was selected from the local health records of the Local Vehicle Health Service in Stockholm and the local bus transportation company. Lung function examinations and individual exposure assessments were made. The criteria for selection were: male; older than 40 years; and more than 20 years of employment as car and/or bus mechanics. Those who had been involved in spray painting or body repair activities or had asbestos exposure from other sources were excluded. Ninety-five car and eight bus mechanics fulfilled the selection criteria. Smoking data were collected by interview (Dahlqvist *et al.*, 1992). The subjects were classified as smokers, non-smokers and ex-smokers groups, and the amount smoked was expressed in pack-years. Twenty-six were non-smokers, 39 had never been exposed to diesel exhausts and just five were free from both diesel and tobacco-smoke exposure.

The car mechanics had worked at 386 different repair workshops and the bus mechanics at 12 bus repair workshops. The workplaces represented a wide range from small old-fashioned car repair workshops to large recently constructed repair workshops with good ventilation. Until 1975 most of them had used compressed air for cleaning the brake shoes. During the observation period 1938–1986 the mechanics had worked at an average of four workplaces (range 1–14 workplaces). The mean employment time was 29 years (20–48 years).

Reference equations for lung function were derived from a control group of 83 suburban bus drivers without asbestos exposure who were investigated in the same way (Dahlqvist *et al.*, 1992). Twenty-seven of them were non-smokers.

Exposure assessment

The exposure was estimated by the following procedure:

(1) construct a model to describe cumulative asbestos exposure by using an 'asbestos index', and estimate the cumulative asbestos by the model;
(2) cumulative exposure was compared to other ways of describing exposure; employment time–duration and exposure time–duration;
(3) the model was applied to the 103 car and bus mechanics and exposure estimates correlated with lung function data.

Employment duration is often used as a simple estimate of exposure if no other data are available. The information concerning employment time was collected from company records and also checked by questionnaires obtained from the study subjects.

Exposure duration time was calculated with additional information from questionnaires and interviews, described in the Appendix, e.g. job activities and location. With the information about more specified job-activities for we could exclude employment periods with no asbestos exposure.

Model construction

The model was designed to calculate asbestos exposure from work with friction materials such as dust from clutches and break shoes. It has been described in detail in Swedish (Plato *et al.*, 1991), and is more briefly summarized in the Appendix.

By reviewing the international literature, a set of parameters that influence the asbestos exposure of car and bus mechanics was selected. The magnitude of the multipliers associated with those variables was estimated and chosen from a large series of past measurements covering representative values for different work activities, technical equipment, ventilation, technical standard and workshop sizes. The derivation is discussed in more detail in Table A1 of the Appendix. The coefficients were used in an equation that takes task activity as well as background exposure (general shop exposure) into consideration. The model was created as a combination of an additive and a multiplicative model (Table A2 in the Appendix) and makes calculation of cumulative exposure possible. The equation in the model expresses the quantative exposure in an asbestos index. Asbestos index (AI) = general shop exposure + task activity exposure, for each mechanic, for each year, summed for all years of employment as a vehicle mechanic.

Model validation

The model was validated using representative Swedish measurements in car and bus repair shops for the period 1976–1988. The fibre measurement criteria using phase-contrast optical microscopy were: length $>5\ \mu m$, diameter $\leq 3\ \mu m$ and aspect ratio $\geq 3:1$. Ten reports, including 23 8-h measurements (personal sampling) at different car repair shops, were selected from the data bank of industrial measurements at the Swedish National Board of Occupational Health to validate the efficiency of the model. These investigation reports were selected because they contained sufficient information on work activity, production rate and other information needed to choose coefficients in the model. Many reports in the databank did not contain adequate information and could not be used. The coefficients and equations in the Appendix were applied for those 23 measurements. Asbestos indices (AI) were calculated and plotted against the measured fibre level in the transformed curve (Fig. 1).

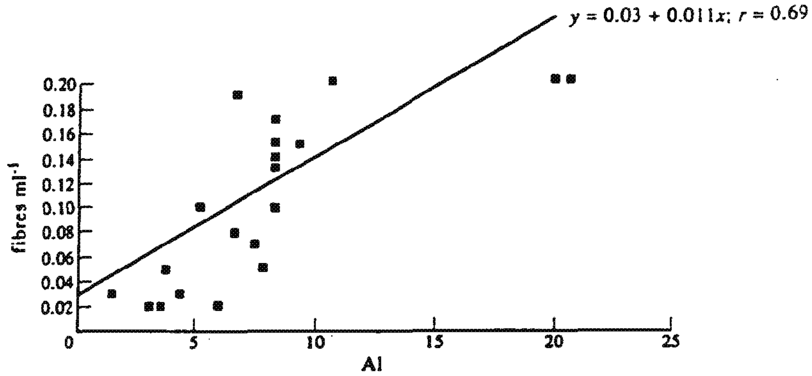

Fig. 1. Transformation curve. Comparison between the constructed asbestos index (AI) and asbestos fibre level from 23 historic 8-h measurements.

The calculated asbestos index was related to asbestos fibre level by the statistically significant regression line $y=0.029+0.011\,x$, shown in Fig. 3. The correlation coefficient was $r=0.69$ for all observations ($N=23$). This demonstrates that a quantitative relationship exists between f ml^{-1} and the AI. It also shows that the exposure was generally low.

Application

The model was used to characterize the exposures of 103 car and bus mechanics. Each subject answered a questionnaire which asked about the repair shops where they had worked, job activities and employment time. The self-administered questionnaire was expanded with a standardized personal interview. Two industrial hygienists asked 38 additional questions for each workplace in a subject's work history. The questions included the following topics: room conditions (11 questions); treatment/handling of brake shoes (eight questions); work activities involved with repair (13 questions); and activities of the bystanders (six questions). The people interviewed also had to estimate the duration of work to replace brake shoe linings, number of changes from year to year, grinding of brake lining, time and end year for use of compressed air, and use of respiratory protection. For each decade they also estimated the general condition of the work area and dustiness from different work operations using a five-level ranking scale with the existing condition as the reference point. The aim of the personal interview was to collect information that could have influenced early exposure, such as work activities that generate high exposure peaks and also the possibilty of dispersing the fibre in dusts found in brake drums and clutch housings.

The AI was calculated by using Equation (A1) in Table A2 of the Appendix. Work activity and task frequencies during the whole working life of the mechanics were taken into consideration for each individual. By use of the validation curve (Fig. 1) the AI could be converted to approximate f ml$^{-1}*$year. Annual and cumulative asbestos exposure values were estimated for each of the 103 mechanics, who participated in the medical investigation. Cumulative exposure during their total times as mechanics was expressed as mean and range for the whole group. Life-time-weighted average exposure was calculated as a time-weighted mean exposure for each individual.

Lung function

The mechanics and unexposed controls underwent examination using lung function tests by Dahlqvist *et al.* (1992). Dynamic spirometry was used to measure vital capacity (VC, $N = 103$) and forced volume in 1 s (FEV_1, $N = 103$); static spirometry was used to measure total lung capacity (TLC, $N = 103$); nitrogen breath wash-out was used to measure closing volume in per cent of vital capacity (CV%, $N = 92$) and carbon monoxide single breath wash-out was used to measure transfer factor (TL_{co}, $N = 90$). Reference equations for calculation of predictive values for the lung function variables were derived from 83 non-asbestos exposed suburban traffic bus drivers. Smoking (pack-years), age and height were studied as potential confounding variables.

Exposure–response analysis

Regression analyses were done to examine the relationship between the cumulative asbestos exposure and effects on lung function. Dependent variables were observed values divided by predicted values for FEV_1, TL_{co}, TLC, VC and CV%. Independent variables were length of employment, cumulative exposure and exposure duration.

Student's t-test was used for significance tests in the regression analyses.

RESULTS

Exposure

The mean employment time was 29 years (range 20–48 years), and mean exposure time 26 years (range 14–48 years), normal distribution $W = 0.98$ (Shapiro–Wilk statistic). The correlation between employment time and exposure time was $r = 0.92$. The distribution of cumulative exposures for the car and bus mechanics (103 persons) as calculated with the model using their employment at 398 repair workshops during 48 years, is shown in Fig. 2. The mean was 2.6 f ml^{-1} * year (range 0.1–11.6

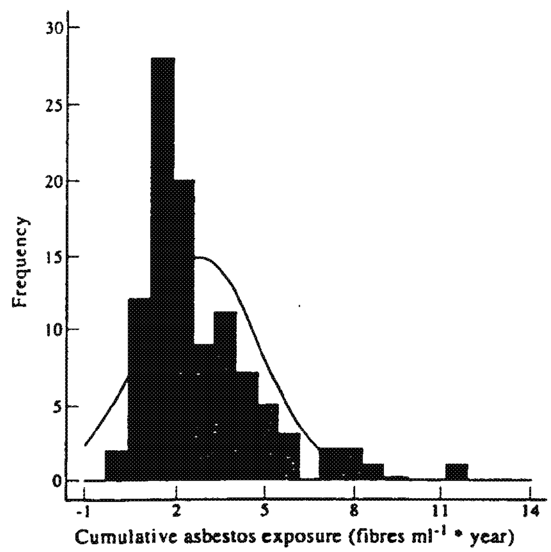

Fig. 2. Distribution of cumulative asbestos exposure for 103 vehicle mechanics. Mean cumulative exposure = 2.6 f m^{-1} * year. Log-normal distribution, $W = 0.98$ (SAS).

f ml^{-1} • year). The annual mean exposure had a range between 0.01 and 0.46 f ml^{-1} since 1938. The time-weighted average for all car mechanics over the period was 0.09 f ml^{-1}. The annual asbestos exposure decreased during the 1960s and 1970s (Fig. 2). This decrease was more pronounced for cars (from 0.10 to 0.02 f ml^{-1}) than for trucks (0.39–0.12 f ml), mainly because of step-wise changes to disc brakes that generate lower exposure in small cars.

During the period 1938–1986 the mean asbestos fibre exposure was 3.5 times higher for those who had been working with trucks compared to those who had only been working with cars, and the bus mechanics had a 1.6 times higher asbestos exposure than the car mechanics in 1984 (Fig. 3). In 1964 the car mechanics had an exposure 0.04–0.17 f ml^{-1} (mean 0.10 f ml^{-1}), compared to 0.18–0.46 f ml^{-1} (mean 0.36 f ml^{-1}) for the truck mechanics.

Most of the mechanics started their career with truck repair activities that generate higher exposure levels. The Swedish truck mechanics worked more hours per week with friction materials than the bus mechanics. The annual asbestos exposure for bus mechanics was lower than for truck mechanics (Fig. 3).

The variation in annual asbestos exposure levels for the 95 car mechanics showed that occupation is a poor way to characterize exposure, and the correlation coefficient was only $r = 0.41$. The regression line for cumulative asbestos exposure vs employment time was $y = -0.793 + 0.123\,x$, shown in Fig. 4. Consequently, long employment time or exposure duration does not necessarily mean high cumulative asbestos exposure.

Exposure–response relationship for lung function

The exposed group had a significant decrease in TL_{co} with 12.5% ($P < 0.01$), Table 1, but the decrease was not significantly correlated to either cumulative asbestos exposure or employment time, Table 2. No other lung function variable was significantly decreased or correlated with exposure level (Tables 1 and 2). The unexposed population had on average a normal lung function compared to reference values (Dahlqvist et al., 1992).

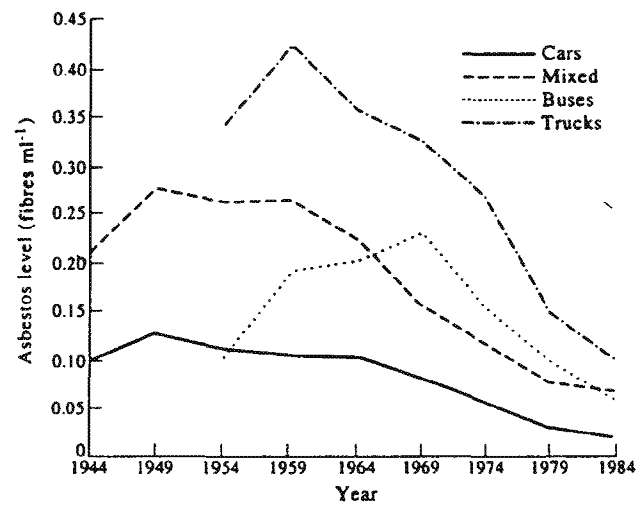

Fig. 3. Calculated annual mean asbestos exposure levels (f ml^{-1}) for different vehicle mechanics ($N = 103$).

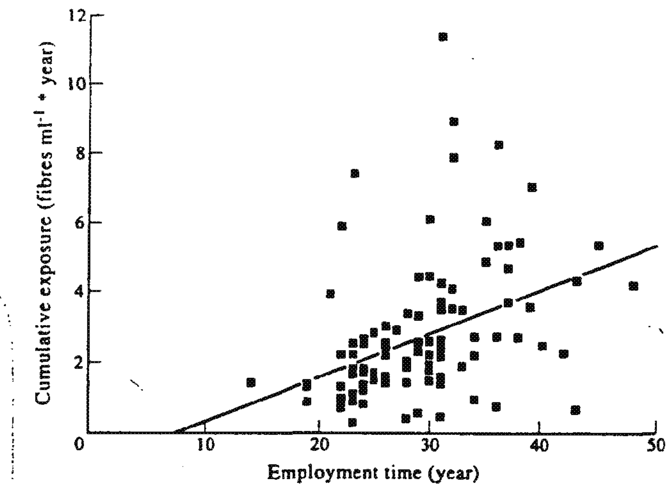

Fig. 4. Correlation employment time vs cumulative asbestos exposure for 103 vehicle mechanics: $y = -0.793 + 0.123x$; $r = 0.41$.

Table 1. Mean and standard deviation for observed/predicted (O/P) values of five lung function variables for 103 car and bus mechanics. Predicted values from 83 non-asbestos exposed bus driver

Value	N	O/P	SD
TL_{co}	90	87.5*	23.8
TLC	103	100.7	11.2
FVC	103	99.2	12.0
CV%	92	94.6	19.2
FEV_1	103	99.9	12.8

$*P < 0.01$.

DISCUSSION

A model was developed to estimate past exposure from asbestos friction materials for Swedish vehicle mechanics. The model was based on estimations of multipliers for different exposure variables derived from the worker's task activities and background activities in the workshop. The constructed model was applied on interview data from 103 mechanics. The mean cumulative asbestos exposure for this population was [illegible] f ml * year. Despite the perception that car and bus mechanics constitute a homogeneous group, the variation in exposure was wide, 0.1–11.6 f ml * year. Annual asbestos exposure estimates showed a three times higher mean exposure in 1964 compared to 1984. A statistically significant 13% decrease in mean TL_{co} was observed for the exposed group compared to the non-asbestos exposed control group. However, no exposure–response relationship was observed between either cumulative asbestos exposure or employment time and any of the lung function variables TL_{co}, TLC, FEV_1, CV% or VC.

Table 2. Regression coefficients for lung function variables vs asbestos exposure

Exposure	N	Correlation coefficient	r^2 (%)	Intercept a	Slope b
Cumulative exposure					
CV%	91	0.106	1.12	91.8*	1.08
TL_{co}	89	−0.001	0.02	87.9**	−0.16
FVC	102	−0.079	0.62	100.5	−0.48
TLC	102	−0.138	1.92	102.9	−0.78
FEV_1	102	−0.055	0.31	100.9	−0.36
Years of employment					
CV%	91	0.093	0.86	86.6	0.28
TL_{co}	89	−0.016	0.03	89.3	−0.06
FVC	102	−0.057	0.32	102.4	−0.11
TLC	102	−0.082	0.68	105.0	−0.15
FEV_1	102	0.030	0.09	98.1	0.06

*$P>0.05$.
**$P<0.01$.

The following text will discuss the quality of the exposure assessment including the fibre analysis, the compatibility with studies from other countries, and the relationship with the lung function variables.

Qualitative vs semi-quantitative exposure assessment

For most mechanics, employment time data from company records correlated closely to the exposure time from interviews or questionnaires (correlation coefficient 0.92). Some mechanics had been car-electricians, car conditioners or worked in other non-asbestos exposed tasks, for example, supervisors. Their job title in the company records, however, was still car mechanic which partly explains why the correlation was not perfect. Job title combined with job activities might give a higher correlation.

The variability in exposure between different car mechanics is due to the product of a large variety to working activities, working methods and shops. The annual mean asbestos exposure of the 95 car mechanics was 0.09 f ml^{-1} (range 0.01–0.46 f ml^{-1}). To use occupational titles alone to describe exposure would produce large misclassifications with a maximum factor of 45 between the highest and the lowest exposure in the job title.

The variation was also large for cumulative exposure (0.1–11.6 f ml$*$year). Employment time or time in exposed work correlated weakly in this study with cumulative exposure ($r=0.41$), see Fig. 4. Duration of exposure (close to employment time) was 14–48 years, which means that differences in exposure can be explained by employment time by a factor of only 3. The exposure was high in the past and has diminished owing to improved technology and ventilation. The fact that the workshops have improved favours those who have worked only during the last 20 years. The correlation between cumulative exposure and exposure time has been poor in several studies (Blair and Stewart, 1990; Smith, 1992).

Additional questions can be asked during data collection to reduce misclassification of exposure. From the magnitude of coefficients in the exposure model (Table A1 in the Appendix), it is theoretically possible to have AI range by a factor of 120, using Equation (A1) with either all lowest coefficients or all with highest value. To get more precise exposure information, the interviewer can ask for type of vehicle and thereby reduce the theoretical variability by a factor of 40. By putting more precise questions about working methods the distribution is decreased to 13, and questions about repair shops conditions will reduce it by a factor of 4. Work activities after 1975 give a general reduction by a factor of 1.5. Each factor (type of vehicle, type of brakes, etc.) in direct questions reduce the variability by a third. Cumulative exposure assessment is time and resource consuming, which can be reduced by using a systematic questionnaire technique. Additional information can be obtained by interviews and is important to reduce misclassification.

Validation of the model vs historic measurements

Errors might have occurred when estimating the value for each variable in the historic exposure equation. The correlation in the validation was 0.69 between asbestos index and measured asbestos levels. A reason for this relatively low value is imprecision in low levels of asbestos. It would have been advantageous to have measurements from the 1950s and the 1960s for validation of the larger values of the coefficients in the model, but such data were not available. Another reason can be poor choices for the multipliers or variability in the actual effects of the factors. One important source of error can be differences in fibre counting techniques between laboratories. The fact that the same laboratory did most of the fibre counting diminished the error in the calibration curve. We think that the correlation was good in spite of the usual systematic and random errors in industrial hygiene sampling strategy and fibre counting.

All fibres are not asbestos fibres

The debris from brake shoes and clutch linings contains a large number of fibres with length $< 1\ \mu m$ (Plato *et al.*, 1991). These short fibres may not have the same biological activity as the long fibres. Brake dust at workplaces has been characterized by size and chemical contents (Jacko and DuCharme, 1973). Qualitative analyses by transmission electron microscopy suggest that brake dust mainly contains short fibres (length $< 1\ \mu m$) that are also so thin that they are invisible with optical microscopy. In a study by Rohl *et al.* (1976) 84% of the fibres were shorter than 0.4 μm. Williams and Muhlbaier (1982) observed that 99.9% of the original mass of asbestos fibres were broken down at high temperature to non-fibrous magnesium silicates during the brake process. Rohl *et al.* (1976) observed that only 1% of the fibres in the debris met the definition of asbestos fibres. The morphology of asbestos may be changed during the temperature increase in the brake process (Davis and Coniam, 1973). At 650°C the asbestos configuration is transferred to forsterite (Koshi *et al.*, 1969) which is fibrogenic in lung tissue (Hayashi, 1974; Sakabe *et al.*, 1971).

Woitowitz and Rödelsperger (1991) concluded from animal experiments that exposure to dust from worn brake linings seems to be less hazardous than from unused asbestos.

In this study asbestos was defined as the airborne fibres released from friction materials (brake pads and shoes, clutch linings), with length $> 5\ \mu m$ and aspect ratio $\geq 3{:}1$. Friction materials (brake shoes, pads, clutch linings) contain 30–70% chrysotile asbestos. The fibre counting was performed by phase-contrast optical microscopy (PCOM). Qualitative analysis of fibre composition needs scanning electron microscopy (SEM) with an energy dispersive detector. The fibre calculations in the validation samples were counted by PCOM and assumed to be asbestos fibres, which has overestimated the true numbers.

Furthermore, the model makes the assumption that the morphological changes during heating do not change the potency of the asbestos fibres. When exposure-response curves between different studies are compared, such analytical factors should be taken into account.

The braking process creates heat that can change the morphology of the fibres and convert parts of the asbestos to other fibres with different crystalline structure. This results is an overestimation of the asbestos exposure in the constructed model but does not effect the exposure-response relationships in this study. It also does not account for the different effects of other materials.

Comparisons with exposure studies from other countries

The mean cumulative exposure was estimated as 2.6 f ml^{-1} * year. Rödelsperger *et al.* (1986) calculated a mean of 0.53 f ml^{-1} * year during 1965–1985 in German car workshops based on calculations from recent measurements. Most of the subjects in our study had, however, started their car mechanics career in small workshops with poor conditions where they worked frequently with trucks. Changes in ventilation control, better equipment and use of asbestos brake pads instead of break shoes and non-asbestos pads have decreased the mean exposure substantially during the period 1965–1985.

The total time that the car mechanics work with brake shoes is only a few hours per week, which leads to a low overall time-weighted average exposure, 0.02 f ml^{-1} during 1982–1986. Sheeky *et al.* (1989) has published mean values between 0.004 and 0.016 f ml^{-1} (PCOM analysis) during brake drum repair operations where engineering control has been taken into consideration. Kauppinnen and Korhonen (1987) found the average asbestos exposure to be less than 0.05 f ml^{-1} during the repair of passenger car brakes. During the brake shoe operations there were high exposure levels but the TWA calculation was still low.

Our model gave values similar to the Finnish values, which further validates the model. Measurements in 1976 of Swedish bus mechanics (Krantz, 1976) gave values twice as high as those of Finnish bus mechanics in 1985, but the Swedish bus mechanics had a 30% lower exposure value in 1985, calculated from the model, owing to new work routines.

Lung function

The transfer factor (TL_{co}) was lower than expected in the car mechanics but no other pulmonary function measures differed from those expected and there was only a weak non-significant exposure-response relationship between cumulative asbestos exposure and CV%. This is in accordance with Marcus *et al.* (1987), who did not find any changes in lung function variables FEV_1 and FVC of car mechanics when compared to office workers. Ohlson and Hogstedt (1985) observed effects on FVC and FEV_1 for asbestos exposure levels at 1–2 f ml^{-1}, which is 10 times higher than the exposure level for car mechanics.

Exposures other than asbestos might have caused the decrease in TL_{co}, for example, exhaust, welding fume, general dust, including silica dust, but no data were collected for those potential confounders, and the exposure levels for these materials would not be correlated with the fibre exposures. Such exposures might have affected all mechanics but probably not the bus drivers (control group).

Dahlqvist *et al.* (1992) found a exposure–response relationship for log-cumulative asbestos exposure and CV% based on 50 of the car mechanics. When the group was increased to include both car and bus mechanics ($N = 103$) the significance disappeared.

CONCLUSIONS

—It was possible to make a model for estimation of past asbestos exposure and to validate it. This approach may be useful in other applications.

—The car and bus mechanics had a relatively low overall asbestos exposure, at least during more recent years. It had been higher in the past, but even the truck mechanics were exposed at a low level compared to most asbestos exposed groups.

—No significant effects on lung function were demonstrated from these low levels in this study.

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REFERENCES

Bentley, M. Z. (1970) Control of the use of asbestos containing friction materials. *Ann. occup. Hyg.* **13**, 31–32.

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

Cherrie, J. and Dodgson, J. (1986) Past exposures to airborne fibres and other potential risk factors on the European manmade mineral fibres production industry. *Scand. J. Wk Environ. Hlth* **12**, Suppl. 1, 26–33.

Dahlqvist, M., Alexandersson, R. and Hedenstierna, G. (1992) Lung function and exposure to asbestos among vehicle mechanics. *Am. J. ind. Med.* **22**, 59–68.

Davis, J. M. G. and Coniam, S. W. (1973) Experimental studies on the effect of heated chrysolite asbestos and automobile brake lining dust injected into the body cavities of mice. *Expl molec. Path.* **19**, 339–353.

Esmen, N. A. (1979) Retrospective industrial hygiene surveys. *Am. ind. Hyg. Ass. J.* **40**, 58–65.

Hansen, E. (1989) Mortality of auto mechanics. A ten year follow-up. *Scand. J. Wk Environ. Hlth* **15**, 43–46.

Hatch, D. (1970) Possible alternatives to asbestos as a friction material. *Ann. occup. Hyg.* **13**, 25–29.

Hayashi, H. (1974) Cytotoxicity of heated chrysotile. *Environ. Hlth Perspect.* **9**, 267–270.

Jacko, M. G. and DuCharme, R. T. (1973) Brake emission measurements from brake and clutch linings from selected mobile sources. U.S. Environment Protection Agency Report 1973; 68-04-0020.

Järvholm, B. and Brisman, J. (1988) Asbestos associated tumours in car mechanics. *Br. J. ind. Med.* **45**, 645–646.

Kauppinen, T. and Korhonen, K. (1987) Exposure to asbestos during brake maintenance of automotive vehicles by different methods. *Am. ind. Hyg. Ass. J.* **48**, 499–504.

Knight, K. L. and Hickish, D. E. (1970) Exposure to asbestos during brake maintenance. *Ann. occup. Hyg.* **13**, 17–20.

Knight, K. L. and Hickish, D. E. (1979) Investigation into alternative forms of control for dust generated during the cleaning of brake assemblies and drums. *Ann. occup. Hyg.* **13**, 37–39.

oshi, K., Hayashi, H. and Sakabe, H. (1969) Biological and mineralogical studies on serpentine minerals in heat treated state. *Ind. Hlth* **7**, 66–85.

Krantz, S. (1976) Asbestos exposure at community bus repair shops. Report for National Institute of Occupational Health, Solna, Sweden (in Swedish).

Lorimer, W. V., Rohl, A. N., Miller, A., Nicholson, W. J. and Selikoff, I. J. (1976) Asbestos exposure of brake repair workers in the United States. *Mount Sinai J. Med.* **43**, 207–218.
Marcus, K., Järvholm, B. and Larsson, S. (1987) Asbestos-associated lung effects in car mechanics. *Scand. J. Wk Environ. Hlth* **13**, 252–254.
Marsh, G. M. (1987) A strategy for merging and analyzing work history data in industry wide occupational epidemiological studies. *Am. ind. Hyg. Ass. J.* **48**, 414–419.
McDonald, A. and McDonald, C. (1980) Malignant mesothelioma in North America. *Cancer* **46**, 1650–1656.
Murphy, R. H. L., Gaensler, E. A., Redding, R. A., Belleau, R., Keelan, P. J., Smith, A. A., Goff, A. M. and Ferris, B. G., Jr (1972). Low exposure to asbestos. Gas exchange in ship pipe coverers. *Archs Environ. Hlth* **25**, 253–264.
Nicholson, W. J. (1982) Estimates of occupational mortality from past and projected exposure to asbestos. In *Proceedings of the World Symposium on Asbestos*, 25–27 May 1982, pp. 136–149. Canadian Asbestos Information Center, Montreal, Canada.
Ohlson, C. G. and Hogstedt, C. (1985) Lung cancer among asbestos cement workers. A Swedish cohort study and review. *Br. J. ind. Med.* **42**, 397–402.
Plato, N., Krantz, S. and Alexandersson, R. (1991) Asbestos exposure in car and bus repair shops—basic data for a lung function study. *Arbete och Hälsa* **30**, 1–23 (in Swedish).
Riala, P., Kalliokoski, P., Pyy, L. and Wickström, G. (1984) Solvent exposure in construction and maintenance painting. *Scand. J. Wk Environ. Hlth* **10**, 263–266.
Rohl, A. N., Langer, A. M., Klimentidis, R., Wolff, M. S. and Selikoff, I. J. (1977) Asbestos contents of dust encountered in brake maintenance and repair. *Proc. R. Soc. Med.* **70**, 32–37.
Rohl, A. N., Langer, A. M., Wolff, M. S. and Weisman, I. (1976) Asbestos exposure during brake lining maintenance and repair. *Environ. Res.* **12**, 110–128.
Rödelsperger, K., Jahn, H., Bruckel, B., Manke, J., Paur, R. and Woitowitz, H. J. (1986) Asbestos dust exposure during brake repair. *Am. J. ind. Med.* **10**, 63–72.
Sakabe, H., Kosho, K. and Hayashi, H. (1971) On the cell toxicity of mineral dust. In *Inhaled Particles III* (Edited by Walton, W. H.), pp. 423–435. Unwin Bros, Old Woking, Surrey.
Selikoff, I. J. and Lee, D. H. (1978) *Asbestos and Disease*. Academic Press, New York.
Sheeky, J. W., Cooper, T. C. and O'Brien, D. M. (1989) Control of asbestos exposure during brake drum service. *Appl. ind. Hyg.* **4**, 313–319.
Smith, T. J. (1992) Occupational exposure and dose over time: Limitations of cumulative exposure. *Am. J. ind. Med.* **21**, 35–51.
Stewart, P. and Herrick, R. (1991) Issues in performing retrospective exposure assessment. *Appl. occup. Environ. Hyg.* **6**, 421–427.
Teta, M. J., Lewinsohn, H., Meigs, W., Vidone, R., Mowad, L. and Flannery, J. (1983) Mesothelioma in Connecticut 1955–1977. *J. occup. Med.* **25**, 749–756.
Torney, C. R. and Barnhart, W. L. (1976) Performance evaluation of protective equipment used in paint spraying operations. Contract HSM 99-72-96. U.S. Department of Health Education and Welfare, NIOSH, Cincinnati, Ohio.
Williams, R. L. and Muhlbaier, J. L. (1982) Asbestos brake emissions. *Environ. Res.* **29**, 70–82.
Woitowitz, H.-J. and Rödelsperger, K. (1991) Chrysolite asbestos and mesothelioma. *Am. J. ind. Med.* **19**, 551–553.
Woitowitz, H.-J. and Rödelsperger, K. (1994) Mesothelioma among car mechanics? *Ann. occup. Hyg.* **38**, 635–638.
Wong, O. (1992) Chrysotile asbestos, mesothelioma, and garage mechanics. *Am. J. ind. Med.* **21**, 449–451.

APPENDIX

A model for construction of a historical asbestos index assessment

The cumulative index for asbestos exposure was calculated using a three-step model, combining additive and multiplicative components. Coefficients for eight variables representing job activity, technology level, workshop conditions and time (Table A1), were put into an exposure matrix. The model has been described earlier in detail in Swedish (Plato *et al.*, 1991).

Step 1. An inventory was made of past measurements and a review of the international literature was carried out concerning previously published measurements to provide the base for estimating the values of coefficients in Step 2.

Step 2. An exposure matrix was constructed to calculate the relative asbestos exposure. Parameters that were determined to have some influence of the exposure, for example, type of vehicle, room ventilation, working activity and working intensity were ranked and given coefficients. The coefficients for each parameter were estimated from data in a number of internationally published reports (Bentley, 1970; Hatch, 1970; Knight and Hickish, 1970, 1979; Lorimer *et al*., 1976; Rohl *et al*., 1977; Rödelsperger *et al*., 1986; Kauppinen and Korhonen, 1987). The exposure matrix is based on the principle that was applied by Marsh (1987), after a method developed by Esmen (1979). The exposure vectors have been estimated from a geometric ranking scale illustrated in Table A1. The extremes for each variable were first selected with geometric steps because no direct data were available. The choice of the size of the coefficients is explained below.

Type of vehicle (K_v, range 1–3). A truck has about three times bigger brake lining surface compared to a car and thus generates three time more fibres (Rohl *et al*., 1976). Coefficient 2 was selected for cars and trucks due to a larger influence of truck fibres.

Rooms (K_g, range 1–3). The variability of exposure in the workrooms in this study has been estimated to a factor of 3 from the best to the worse condition. Riala *et al*. (1984) earlier applied a factor of 5 to unventilated rooms compared to ventilation by open windows during painting operation. The respirable asbestos-fibre distribution pattern is equivalent to that of vapours (Nicholson, 1982). The worst rooms were ventilated by opening garage doors during the summer and were given a coefficient of 3.

Working activities (K_w, range 1–3). A factor of 3 has been applied in order to separate the best and the worst working activities as a mean for 8 h activity. Compressed air and machinery grinding give the highest exposure. The exposure shows a large variation between drum and disc brakes, depending on the longer working time spent with drum brakes (Kauppinen and Korhonen, 1987; Rohl *et al*., 1977; Hatch, 1970; Knight and Hickish, 1979; Lorimer *et al*., 1976; Nicholson, 1982).

Working frequency (K_f, range 1.8–3.0). The frequency of different working operations (drum or disc brakes) has been estimated to have a coefficient of 3. This was estimated from the mean value from different studies, where drum brakes and disc brakes were evaluated during equivalent cleaning techniques.

Table A1. Coefficient table for the exposure matrix

Variable	Multiplier (coefficient)	Comment
1. General shop		
Type of vehicle (K_v)	3.0	Work with truck or bus
	2.0	Work with truck and car
	1.0	Work with just passenger car
Repair shop rooms (K_g)	3.0	Small, bad conditions, no ventilation
	2.4	Small, bad conditions, poor ventilation
	1.8	Normal, mechanical ventilation medium
	1.3	Good condition, big size, good ventilation
	1.0	Big size, excellent condition and ventilation
2. Task activities		
Work activities (K_w)	3.0	Compressed air blowing, drilling, riveting, grinding with no exhaust
	2.6	Compressed air blowing, grinding with separate exhaust
	2.2	Brushing, drilling, riveting, grinding, without separate exhaust
	1.7	Brushing, grinding with separate exhaust
	1.3	Brushing, water spray
	1.0	Water spray
	0	No activity with fibre material
Frequence of work (K_f)	3.0	Daily drum brake activity
	1.8	Daily disc brake or low frequence drum brakes
	1.0	Low frequence disc brakes
Other factors (K_o)	1.5	Work as vehicle mechanic before 1975
	1.0	Work as vehicle mechanic after 1975

Notes:
(1) Subject job activities changed across time, K_v and K_w, and the employer (shop) changed.
(2) Shops changed across time, K_g, K_v and K_f as they expanded and changed the type of vehicle and repair work they would do.

Many of the subjects reported very high dust generation during short periods of work on clutch removal. During the braking operation on a car nearly 80% of the asbestos fibres and the debris will leave the brake drum and go out into the environment, whereas the dust from clutch activity stays within the transmission. The clutch often has a total friction surface and amount of debris comparable to the brake linings in the car.

Other factors (K_o, range 1.0–1.5). Information on the asbestos dust hazard was widely disseminated around 1975 and the introduction of new asbestos regulation rules generally improved the working conditions resulting in a general decrease of 33% compared to the conditions before that period.

The use of a face mask (repairatory protection) has an exposure reduction factor of 0.3 for activities where a half-mask respirator was worn (Torney and Barnhart, 1976). However, face masks were not used during the period of interest, so were not included in the model.

With the coefficients in Table A1 and the ranking scale all the exposure situations can be classified for each. The ranking scale is geometric in order to give a similar distribution between the coefficients. This method was used because measurements were missing for many historical exposure situations.

Step 3. The model takes into consideration that the mechanic is both primarily exposed by his own work task activity and exposed from far-field air contaminants (general workshop exposure). Equation (A1) is constructed from the model by Dodgson and Cherrie by using multipliers (Cherrie and Dodgson, 1986). Literature studies (Rohl *et al.*, 1977) indicate that the background level has an influence on the total exposure. To include task activity as well as background exposure, a combination of additive and multiplicative model was constructed, shown in Table A2. The asbestos exposure has been expressed in the relative unit 'asbestos index' (AI). The equation could then be used for each mechanic for annual exposure calculation. The AI has to be converted into f ml^{-1} by using a transformation curve. That curve was created using 18 Swedish reports. By using information in the reports the coefficients were estimated and the AI were calculated.

Table A2. Equation for calculation of asbestos index, AI, by using the matrix in Table A1

Model asbestos index, AI = general shop + task activity

Variables for general shop exposure (FE) = $K_v * K_g$

Variables for task activity exposure (NE) = $K_v * K_w * K_f * K_o$

for each car mechanics, for each year, summed over all years with work as a vehicle mechanic.

$$\mathrm{AI} = \sum_{\text{start year}}^{\text{end year}} (K_v * K_g) + (K_v * K_w * K_f * K_o) \quad \text{(A1)}$$

Note: AI calculated based on each subject's personal work history and of the shops where he/she worked.

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