Western Red Cedar Dust Exposure and Lung Function: A Dose-Response Relationship

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The relationship between levels of cumulative red cedar dust exposure and decline in lung function was explored in an 11-yr follow-up study of 243 sawmill workers who participated in at least two occasions. We also studied 140 office workers in a similar manner as control subjects. Workers with asthma were excluded from the analysis. During the period of the study, 916 personal and 216 area samples of dust were collected from the sawmill. Cumulative wood dust exposure was calculated for each sawmill worker according to the duration and exposure in each job, based on the geometric mean of all dust measurements for that job. Average daily dust exposure was calculated by dividing the total cumulative exposure by the number of days of work. Workers were divided into low-, medium-, and high-exposure groups with mean daily level of exposure of < 0.2, 0.2 to 0.4, and > 0.4 mg/m^3, respectively. Sawmill workers had significantly greater declines in FEV_1 and FVC compared with office workers adjusted for age, smoking, and initial lung function. A dose-response relationship was observed between the level of exposure and the annual decline in FVC. We conclude that exposure to Western red cedar dust is associated with a greater decline in lung function which may lead to development of chronic airflow limitation. Noertjojo HK, Dimich-Ward H, Peelen S, Dittrick M, Kennedy SM, Chan-Yeung M. Western red cedar dust exposure and lung function: a dose-response relationship.

AM J RESPIR CRIT CARE MED 1996;154:968–73.

Exposure to wood dust is a common occurrence in many countries, particularly where forestry is a major industry. In 1990, the forest industry was directly responsible for 275,000 jobs in Canada, and the corresponding figure for the United States was about 400,000 (1). In recent years, there have been several studies of the respiratory effects of wood dust exposure (2–7). However, most of these studies did not have measurements of dust concentration needed for assessment of a dose-response relationship.

Western red cedar (*Thuja plicata*) is found in the Pacific Northwest. Exposure to the dust of this wood is known to give rise to asthma (8). In 1982, a cross-sectional study of the respiratory health of red cedar sawmill workers showed that cedar sawmill workers had a significantly higher prevalence of chronic respiratory symptoms and lower lung function compared with a group of control subjects even after excluding subjects with asthma from the analysis, suggesting that exposure to cedar dust may give rise to chronic airflow obstruction (9). We now present the results of an 11-yr follow-up study of this group of sawmill workers and explore the relationship between levels of cumulative exposure and levels of decline in lung function.

(*Received in original form November 27, 1995 and in revised form February 27, 1996*)

Supported by National Health and Research Development Program, Health Canada, Workers' Compensation Board of British Columbia.

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Am J Respir Crit Care Med Vol 154. pp 968–973, 1996

METHODS

Study Population

Workers employed in a sawmill in Vancouver were first studied in 1982. This mill handled all kinds of wood until 1980 when the mill started to process only Western red cedar. Follow-up studies were carried out in 1983, 1984, 1988, and 1993. After the first study had been undertaken in 1982, half of the workforce was laid off because many of the jobs became mechanized. As a result, while there were 656 workers taking part in the first study, subsequent studies had 325, 317, 341, and 241 participants, respectively. With the exception of the 1993 survey, during each survey more than 80% of the workforce invited to participate were tested. In 1993 only 77% of the invited workforce were tested.

Workers from the City Hall in Vancouver were studied as control subjects. Surveys were conducted on this group of workers in 1978, 1980, 1982, 1985, 1989, and 1991. There were 144, 119, 123, 90, 65, and 128 participants in each of the surveys, representing about 70% of invited participants on each occasion.

There were only 278 sawmill workers and 153 control subjects who took part in at least two surveys during the period of the study. Of these, 20 sawmill workers and 11 control subjects were diagnosed by doctors as having asthma; they were excluded from the analysis. Another 10 sawmill workers did not provide an adequate job history for the calculation of cumulative exposure; five sawmill workers and two office workers changed their smoking habits during the study period and they were also excluded. The final analysis consisted of 243 sawmill workers and 140 control subjects. The minimum duration of follow-up was 48 mo and the maximum 156 mo.

Health Component

Questionnaire. All workers completed a questionnaire during each survey administered by trained interviewers. The questionnaire on respiratory symptoms was derived from the American Thoracic Society (ATS-DLD-78) adult questionnaire for chronic respiratory disorders (10). Questions on occupation included a description of current and previous jobs, the job title, and the job location either in the same sawmill or in other industries.

The following definitions were used:

Chronic cough—cough present on most days for at least 3 consecutive months of the year.
Chronic phlegm—phlegm production on most days for at least 3 consecutive months of the year.
Dyspnea—shortness of breath when hurrying on level ground or walking up a slight hill.
Wheeze—wheeze apart from colds.
Chronic bronchitis—chronic cough and phlegm for at least 2 yr.
Current smokers—those who were cigarette smokers during the initial and final surveys.
Ex-smokers—those who gave up cigarette smoking prior to the first survey and had remained as such during the final survey.
Nonsmokers—those who were lifelong nonsmokers.

Measurement of lung function. Spirometry was performed at the work site on all occasions using the same water-sealed Collins spirometer (Braintree, MA). The techniques used were those recommended by the American Thoracic Society (11). At least three acceptable forced expiratory maneuvers were obtained. Forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) were measured. The largest FVC and FEV_1 were used in the analysis. Measurements were converted to BTPS. Prediction equations were obtained from the data of Crapo (12) and a factor of 0.88 was used for correction for nonwhites.

Allergy skin tests. Prick skin tests were done using three common allergens: house dust mite, mixed Pacific grass pollen, and cat epidermal antigen together with saline and histamine as negative and positive controls. Skin tests were read at 15 min and the largest diameter of the weal was measured. A positive reaction was defined as one with an average weal diameter 3 mm greater than the saline control. A subject was considered atopic if he reacted to one or more of the common allergens.

Industrial Hygiene Component

Measurement of airborne dust concentrations was carried out by the Occupational Hygiene Department of the Workers' Compensation Board of British Columbia. Both personal and area sampling were done during each survey. Cassettes with polyvinyl chloride membrane filters 37 mm in diameter with a pore size of 0.8 μm were used. The cassettes were connected to a sampling pump and air was drawn through at a rate of 2 L/min. Personal sampling was carried out throughout an 8-h work shift on workers with representative job titles. Dust concentration expressed in milligram per cubic meter was calculated by measuring the change in the weight of the filter before and after sampling divided by the volume of air drawn through.

Calculation of Levels of Cumulative Dust Exposure

A total of 916 (81%) personal and 216 (19%) area samples were collected over a 12-yr period. The number of samples collected and dust levels in the sawmill over the year are shown in Table 1. A total of 252 (22.3%) were below the detection limit of 0.05 mg/m³ of the analysis method. In the analysis, a value equal to the detection limit was substituted for these samples. Analyses were also carried out using half of the detection limit value and no differences were found in the results of the analyses. A small number of samples ($n = 26$) were judged to be technically invalid (e.g., fingerprints on the filter) and they were excluded. The method used to calculate cumulative exposure for each individual was similar to those used in a previous study (13). Briefly, each job since 1980 (i.e., since cedar processing was started) was assigned an estimated dust exposure based on the geometric mean value of all dust measurements for that job. However, there were certain jobs for which personal sampling was not done. For these jobs, dust exposure was assigned based on area sampling. For the 243 workers who took part in at least two surveys, there were a total of 168 job titles. Cumulative dust exposure was calculated for each sawmill worker using the following formula:

$$\text{Sum of (days worked in job category i} \times \text{exposure for job category i)}$$

An estimate of overall average dust exposure per day was then determined for each worker by dividing the calculated cumulative dust exposure by the total number of days of employment in the sawmill. Each worker was then classified into three exposure groups: low with average exposure of < 0.2 mg/m³/d; medium with average exposure of 0.2 to 0.4 mg/m³/d; and high with average dust exposure of > 0.4 mg/m³/d. Table 1 shows the results of dust concentration of jobs in three exposure groups (geometric mean, SD) according to the year of measurement. There were no significant differences in dust concentrations in the sawmill across time. In the 1980s, sampling was carried out with equal frequency on all jobs. In 1993, dust measurements were focused on jobs with higher exposure and repeated sampling was carried out on these jobs as well. This could be the reason for the slightly higher dust levels found in 1993 compared with 1988 and the apparent lack of reduction in dust level compared with 1982. Examples of various job titles classified under the three exposure groups are also shown in Table 1.

Dust sampling was not carried out in the municipal hall where the civic workers worked over the years.

Analysis

Analysis was carried out on a personal computer using SPSS for DOS version 4.0 (SPSS Inc., Chicago, IL). In order to normalize the distribution of dust levels, geometric mean values were employed for calculations.

Descriptive analysis was carried out on the characteristics of the sub-

TABLE 1

TOTAL NUMBER OF VALID DUST MEASUREMENTS*

	1982	1983	1984	1988	1993
Job area sampled, n	14	15	17	10	15
Job titles sampled, n	74	64	59	35	51
Type of samples, n (%)					
Personal	334 (100)	128 (64.3)	104 (54.7)	115 (87.1)	235 (84.8)
Area	—	71 (35.7)	86 (45.3)	17 (12.9)	42 (15.2)
Low-exposure jobs sampled, n†	16	29	51	21	17
Geometric mean ± SD mg/m³	0.12 ± 0.06	0.08 ± 0.05	0.09 ± 0.05	0.08 ± 0.05	0.15 ± 0.04
Arithmetic mean ± SD mg/m³	0.12 ± 0.05	0.08 ± 0.05	0.08 ± 0.04	0.09 ± 0.05	0.18 ± 0.06
Medium-exposure jobs sampled, n‡	25	32	16	14	24
Geometric mean ± SD mg/m³	0.29 ± 0.07	0.30 ± 0.06	0.30 ± 0.05	0.30 ± 0.07	0.29 ± 0.06
Arithmetic mean ± SD mg/m³	0.29 ± 0.06	0.31 ± 0.06	0.30 ± 0.05	0.32 ± 0.06	0.31 ± 0.07
High-exposure jobs sampled, n§	37	23	14	5	25
Geometric mean ± SD mg/m³	1.09 ± 1.08	0.77 ± 0.85	2.00 ± 2.49	0.69 ± 0.34	0.74 ± 0.15
arithmetic mean ± SD mg/m³	1.08 ± 1.08	0.77 ± 0.84	1.99 ± 2.48	0.69 ± 0.34	0.85 ± 0.67
For all jobs, n	334	199	190	132	277
Mean of geometric means ± SD	0.38 ± 2.68	0.22 ± 2.71	0.16 ± 3.41	0.16 ± 2.55	0.33 ± 1.97
Mean of arithmetic means ± SD	0.63 ± 0.86	0.35 ± 0.52	0.45 ± 1.22	0.24 ± 0.24	0.48 ± 0.51
Samples below detection limit, n (%)	14 (4.2)	59 (29.6)	98 (51.6)	65 (49.2)	16 (5.8)

* No significant differences in dust concentration across time for three exposure groups by Kruskal-Wallis nonparametric analysis.
† Low exposure < 0.2 mg/m³/d; examples: boom man, barker operator, automatic trimmerman.
‡ Medium exposure 0.2–0.4 mg/m³/d; examples: slasher-spotter, trimmer-spotter, edgerman, benchman.
§ High exposure ≥ 0.4 mg/m³/d; examples: rig tail sawyer, powerhouse.

TABLE 2

CHARACTERISTICS OF STUDY SUBJECTS ACCORDING TO EXPOSURE GROUPS*

		Sawmill Workers†		
	Office Workers	Low	Medium	High
n	140	115	85	43
Age, yr	44.8 ± 10.9	46.5 ± 9.8	47.0 ± 10.8	47.9 ± 11.3
Height, cm	177.1 ± 7.3	175.8 ± 6.3	175.3 ± 7.0	175.2 ± 5.8
Race: White‡	127 (90.7)	82 (71.3)	75 (88.2)	42 (97.7)
Atopy	6 (12.2)	13 (21.3)	6 (14.3)	1 (8.3)
Months of employment at the time of initial survey	133.7 ± 123.9	119.0 ± 103.1	131.3 ± 101.2	158.8 ± 102.7
Months of exposure to cedar dust in the sawmill at the time of initial survey	–	21.9 ± 6.3	23.6 ± 10.2	25.5 ± 11.4
Ever worked in other sawmill§	–	64 (56.6)	37 (44.6)	14 (35.0)
Smoking status‡				
Nonsmokers	37 (26.4)	54 (47.0)	37 (43.5)	13 (30.2)
Ex-smokers	88 (62.9)	37 (32.2)	37 (43.5)	18 (41.9)
Current smokers	15 (10.7)	24 (20.9)	11 (12.9)	12 (27.9)
Months of follow-up	93.4 ± 50.3	92.0 ± 31.0	90.3 ± 30.5	83.4 ± 25.5
Total months of cedar dust exposure in the sawmill‖	–	133.0 ± 57.1	133.7 ± 54.2	119.6 ± 34.8
Level of dust exposure (geometric mean ± SD), mg/m^3/d	0	0.13 ± 0.04	0.30 ± 0.05	0.61 ± 0.41

* Values shown for continuous vairables are mean ± SD; number and percentage for categorical variables.
† Low < 0.2 mg/m^3/d. Medium 0.2–0.4 mg/m^3/d. High > 0.4 mg/m^3/d.
‡ $p < 0.05$, differences between four exposure groups by chi-square test.
§ $p < 0.05$, differences between three exposure groups by chi-square test.
‖ $p < 0.05$ differences between three exposure groups by ANOVA.

jects. Frequency and cross-tabulation procedures were employed to summarize the data. Chi-square tests and analysis of variance were used to detect differences in characteristics between exposure groups.

The relationships between exposure, smoking, and initial lung function tests were analyzed using analysis of covariance. The decline in lung function for each worker was calculated as the difference in lung function between the first and the last study. The decline in lung function and exposure was analyzed using multiple regression controlling for age, height, race, initial lung function, and smoking. Age, height, and initial lung function were entered as continuous variables; race and smoking were entered as indicator variables.

RESULTS

Characteristics of Study Subjects

The characteristics of the sawmill workers according to exposure groups (low, medium; and high) and the control subjects are shown in Table 2. At the time of the initial survey, the four groups were similar in age and height. The high-exposure group had the lowest prevalence of atopy but the difference was not significant. On the average, sawmill workers were followed for a shorter period compared with control subjects. Workers in the high-exposure group had a longer duration of employment in the current sawmill. A significantly higher proportion of workers in the low-exposure group had worked in other sawmills before employment in the current sawmill ($p < 0.05$). Some of the sawmill workers were also exposed to red cedar dust before employment in the current sawmill; the duration of exposure to cedar dust was not different between groups (2 yr on the average, data not shown).

TABLE 3

PREVALENCE OF RESPIRATORY SYMPTOMS (N AND %) DURING THE INITIAL SURVEY BY EXPOSURE GROUPS

		Sawmill Workers		
	Office Workers	Low	Medium	High
n	140	115	85	43
Chronic cough	23 (16.4)	13 (11.3)	7 (8.2)	2 (4.7)
Chronic phlegm	20 (14.3)	12 (10.4)	7 (8.2)	3 (7.0)
Wheezing	14 (10.0)	15 (13.0)	8 (9.4)	4 (9.3)
Dyspnea	23 (16.4)	18 (15.7)	13 (15.3)	9 (20.9)
Chronic bronchitis	22 (15.7)	11 (9.6)	6 (7.1)	2 (4.7)

The duration of follow-up was the same in all workers in the four exposure groups. At the time of the follow-up examination, the total duration of exposure to cedar dust was longest in the high-exposure group.

Respiratory Symptoms and Lung Function Results during the Initial Survey

The prevalence of respiratory symptoms and chronic bronchitis during the initial survey according to exposure groups is shown in Table 3. At the onset of the study, workers in low-exposure groups had a higher prevalence of respiratory symptoms than workers in the higher exposure category except for dyspnea. Smokers tended to have a higher prevalence of dyspnea, wheeze, and chronic bronchitis than ex-smokers and nonsmokers in most exposure groups (data not shown). The results of lung function tests according to exposure and smoking groups during the initial survey are presented in Table 4. There were no significant differences in FEV_1 between various exposure groups, adjusted for smoking. Among current smokers, however, there was a significant difference in FEV_1 across the four exposure groups. Among office workers, current smokers had significantly lower lung function compared with nonsmokers and ex-smokers. The effect of smoking was not consistent among sawmill workers.

TABLE 4

LUNG FUNCTION MEASUREMENTS DURING THE INITIAL SURVEY BY EXPOSURE AND SMOKING GROUP

		Sawmill Workers		
	Office Workers	Low	Medium	High
n	140	115	85	43
% predicted FEV_1				
Nonsmokers	97.1 ± 14.5	94.2 ± 12.9	98.6 ± 13.8	98.2 ± 9.6
Ex-smokers	97.0 ± 12.1	97.6 ± 10.9	95.3 ± 13.5	92.0 ± 13.3
Current smokers*	85.6 ± 13.0	88.3 ± 17.1	100.4 ± 10.9	97.7 ± 14.7
% predicted FVC				
Nonsmokers	100.9 ± 13.0†	97.6 ± 13.3	99.0 ± 12.4	98.7 ± 10.3
Ex-smokers	100.0 ± 13.2	101.1 ± 10.4	97.0 ± 13.8	93.4 ± 10.7
Current smokers	89.2 ± 13.5	90.8 ± 13.2	104.2 ± 13.7	103.2 ± 16.4

* $p \leq 0.02$, difference between exposure groups by analysis of variance.
† $p \leq 0.02$, difference between smoking groups by analysis of variance.

TABLE 5

ANNUAL DECLINE IN LUNG FUNCTION BY EXPOSURE AND SMOKING GROUPS

		Sawmill Workers		
	Office Workers	Low	Medium	High
n	140	115	85	43
ΔFEV_1, ml/yr				
Nonsmokers	−8.1 ± 52.4	−25.7 ± 32.2	−29.3 ± 47.3	−22.3 ± 25.8
Ex-smokers	−21.7 ± 48.0	−27.0 ± 41.2	−42.0 ± 29.0	−44.0 ± 61.6
Current smokers	−24.8 ± 25.9	−43.8 ± 42.7	−64.5 ± 40.2	−32.5 ± 32.8
ΔFVC, ml/yr				
Nonsmokers	−16.6 ± 48.5	−17.6 ± 34.6	−21.0 ± 49.5	−26.7 ± 38.3
Ex-smokers	−4.6 ± 81.6	−25.7 ± 55.3	−34.4 ± 51.2	−35.5 ± 56.6
Current smokers	−4.1 ± 48.0	−9.0 ± 58.7	−31.9 ± 32.9	−40.3 ± 41.1

Longitudinal Decline in Lung Function

The annual decline in lung function by exposure and smoking groups is shown in Table 5. Multiple regression analysis comparing the sawmill workers and the control subjects adjusted for age, race, height, initial lung function, and smoking showed that sawmill workers had a significantly greater annual decline in FEV_1 and FVC compared with the control subjects (coefficients for FEV_1 and FVC were −12.1 and −14.6 respectively, p values 0.01 and < 0.05 respectively). The effects of varying degrees of exposure on the annual decline in lung function adjusted for age, height, initial FEV_1, and smoking are shown in Table 6. Age, height, and initial lung function and current smoking were found to be important factors affecting longitudinal decline in FEV_1. After adjusting for these variables, the rates of decline in FEV_1 in the medium exposure group remained significantly greater compared with the rate in the control subjects. The rate of decline in FVC was significantly associated with age, initial FVC, and exposure but not with smoking. There was a dose-response relationship between the degree of exposure and the decline in FVC. No interaction between smoking and exposure on the decline in FEV_1 and FVC was found.

Comparison of Those Who Were Followed and Those Who Were Not

The initial characteristics of workers who were and those who were not followed on at least one occasion are shown in Table 7. Sawmill workers who were not followed had significantly more respiratory symptoms and lower FEV_1 compared with those who were followed on at least one occasion. For office workers, such differences were not found.

TABLE 6

MULTIPLE REGRESSION ANALYSIS ON FACTORS AFFECTING THE DECLINE IN LUNG FUNCTION

	ΔFEV_1 (*ml/yr*)		ΔFVC (*ml/yr*)	
Independent Variables	b	SE b	b	SE b
Age, yr	−1.1*	0.2	−1.8*	0.3
Height, cm	1.1*	0.4	0.8	0.5
Initial FEV_1, ml	−0.02*	0.00		
Initial FVC, ml			−0.02*	0.00
Exposure†				
High	−8.7	7.7	−21.3*	10.3
Medium	−16.9*	6.0	−15.8*	8.0
Low	−9.7	5.6	−10.9	7.5
Smoking‡				
Ex-smokers	−4.0	5.2	12.0	6.9
Current smokers	−16.2*	6.6	7.0	8.9
White versus nonwhite	−4.8	6.8	−10.9	9.2
Constant	−99.4	62.0	26.4	86.2

* $p < 0.05$. b = regression coefficient.
† Compared with office workers.
‡ Compared with nonsmokers.

DISCUSSION

It is well known that exposure to many types of wood dusts can give rise to asthma (14). Chronic respiratory effects of exposure to wood dust have not been studied extensively. There have been only a few studies on the respiratory health effects of exposure to wood dust (2–7). Whitehead (2) conducted an epidemiologic study on 354 workers exposed to hardwood dust (mostly maple), and on 220 workers exposed to varying levels of soft wood dust (pine). These workers did not have exposure to other industrial agents such as adhesives and finishing agents. There was a dose-response relationship between the degree of exposure and the prevalence of workers with low lung function. Paggiaro and coworkers (4) studied respiratory symptoms and lung function of 239 workers exposed to wood dust in a furniture plant. Nonsmoking workers had higher prevalence rates of cough, phlegm, and wheeze compared with a group of control subjects derived from a population sample. Although the mean lung function results were within normal limits, a lower FEV_1 was found in subjects with a longer duration of employment. These findings suggest that both hardwood and softwood exposure is associated with airflow obstruction.

Acute changes in lung function over the course of a work shift have been reported. Furniture and cabinet workers exposed to different types of wood dust had a significantly greater cross-shift fall in FEV_1 than a group of unexposed workers (3, 5). Acute shift change in lung function has been shown to predict longitudinal decline in lung function in grain and cotton workers (15–17); the relevance of acute shift changes in lung function in woodworkers has yet to be explored.

The health effects of exposure to Western red cedar dust have been studied more extensively than other wood dust. The most common lung disease from exposure to Western red cedar is asthma (8). The chemical in the dust responsible for the asthmatic reaction has been identified as plicatic acid, a compound with a molecular weight of only 440 daltons (14). There are many other chemicals in Western red cedar (18) such as tropolones and nezukone that have not been studied. In previous cross-sectional studies, we found that red cedar sawmill workers had a significantly higher prevalence of chronic cough and phlegm and lower lung function compared with a group of other sawmill workers not handling Western red cedar (19) and compared with office workers (9). The decrease in lung function was not due to the increased prevalence of workers with asthma as exclusion of asthmatics from the analysis did not influence the results. In a 2-yr follow-up study, we also found that red cedar sawmill workers

TABLE 7

COMPARISON OF WORKERS WHO WERE FOLLOWED AND THOSE WITH NO FOLLOW-UP DURING THE INTERVAL SURVEY*

	Office Workers		Sawmill Workers	
	Followed	No Follow-up	Followed	No Follow-up
n	143	39	248	507
Age, yr	44.7 ± 10.9	43.3 ± 13.0	39.3 ± 10.3†	42.5 ± 15.6
Height, cm	177.5 ± 7.5	178.9 ± 6.7	176.5 ± 6.6	176.4 ± 6.9
Smoking status				
Nonsmokers	46 (32.2)†	14 (35.9)	110 (44.4)†	186 (36.7)
Ex-smokers	63 (44.1)	9 (23.1)	67 (27.0)	120 (23.7)
Current smokers	34 (23.8)	16 (41.0)	71 (28.6)	201 (39.6)
Respiratory symptoms				
Chronic cough	23 (16.1)	6 (15.4)	25 (11.5)	94 (21.2)†
Chronic phlegm	20 (14.0)	9 (23.1)	23 (10.5)	86 (19.3)†
Wheezing	14 (9.8)	5 (12.8)	27 (10.9)	99 (19.5)†
Dyspnea	19 (13.3)	6 (15.4)	42 (16.9)	133 (26.2)†
Lung function				
% predicted FEV_1	103.6 ± 14.4	99.9 ± 11.4	94.9 ± 13.3	92.5 ± 14.8†
% predicted FVC	105.3 ± 14.5	102.9 ± 10.8	97.4 ± 12.8	96.5 ± 13.3

* Continuous variables show the value of mean ± SD. Categorical variables show the frequency (column percent).
† $p < 0.05$.

had a greater annual decline in FEV_1 and FVC compared with office workers (20). In this 11-yr follow-up study, we found that sawmill workers without asthma had a greater decline in FEV_1 and FVC than office workers. These findings confirmed that exposure to Western red cedar dust is associated with chronic effects on the lungs that are independent of asthma.

It is possible that the method we used to calculate cumulative exposure, i.e., multiplying the duration in each job by the mean dust concentration of each job over the period of study, has resulted in misclassification of job titles in exposure groups. This misclassification bias is more likely to lead to lack of dose-response relationship between exposure and the annual decline in lung function. Despite this, we found a dose-response relationship between the degree of exposure and the annual decline in FVC but not in FEV_1. In our longitudinal study of grain workers, we also found that exposure to grain dust was associated with a significant reduction in FVC similar in magnitude to the reduction in FEV_1 (21). Studies of cotton dust (22) and grape workers (23) have shown excessive reductions in FVC as well. The decrease in FVC probably reflects changes in small airways.

The office workers were first studied in 1978 and followed at three yearly intervals until 1991 while the sawmill workers were studied between 1983 and 1993. It is possible but rather unlikely that the difference in timing of the studies between the two groups might have influenced the results. Office workers had lower initial adjusted FEV_1, particularly among current smokers, and over the period of follow-up examination they lost less lung function compared with the sawmill workers.

Studies of grain workers showed that those who participated in the 12-yr longitudinal study had better lung function than those who were not tested repeatedly (21). In this study, sawmill workers who were not followed had more respiratory symptoms and lower lung function than those who were examined subsequently. It is also interesting to note that even at the onset of the study, selection had taken place as workers who had higher exposures over the study period had a lower prevalence of atopy, respiratory symptoms, and chronic bronchitis with a higher mean lung function than those in the low-exposure group.

A "healthy" smoker effect has also been reported in many studies and the topic has been reviewed by Becklake and Lalloo (24). In our study, current smokers in the high-exposure group had better lung function than nonsmokers and ex-smokers at the onset of the study, suggesting that these smokers were healthier and tolerated both high exposure and smoking.

The permissible concentration for Western red cedar dust in British Columbia is 2.5 mg/m³. The degree of exposure to wood dust for workers in this sawmill was relatively low. Despite this low level of exposure, a greater decline in lung function was found compared with the control subjects. This suggests that the current permissible concentration established by the Workers' Compensation Board of British Columbia is too high to prevent the development of chronic obstructive lung disease as well as being too high to prevent the development of asthma, as we have found previously (25).

We conclude that chronic exposure to Western red cedar dust is associated with a greater decline in lung function that is not due to the presence of asthma.

Acknowledgment: The writers thank Mr. W. Calder and Ms. L. Northcott of the management, the local Health and Safety Committee, the International Union of Woodworkers of America, and the Occupational Hygiene Department of the Workers' Compensation Board of British Columbia for their cooperation to make this study possible.

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