ORIGINAL ARTICLE

Respiratory symptoms, lung function, and nasal cellularity in Indonesian wood workers: a dose-response analysis

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Objectives: It was hypothesised that inflammation plays a dominant part in the respiratory effects of exposure to wood dust. The purpose of this study was to relate the nasal inflammatory responses of workers exposed to meranti wood dust to (*a*) levels of exposure, (*b*) respiratory symptoms and (*c*) respiratory function.

Methods: A cross sectional study was carried out in 1997 in a woodworking plant that used mainly meranti, among 982 workers exposed to different concentrations of wood dust. Personal sampling (n=243) of inhalable dust measurements indicated mean exposure in specific jobs, and enabled classification of 930 workers in three exposure classes (<2, 2–5, and >5 mg/m^3) based on job title. Questionnaires were used to screen respiratory symptoms in the entire population. Lung function was measured with two different techniques, conventional flow-volume curves and the forced oscillation technique. Nasal lavage was done to assess inflammation in the upper respiratory tract.

Results: A negative trend between years of employment and most flow-volume variables was found in men, but not in women workers. Current exposure, however, was not related to spirometric outcomes, respiratory symptoms, or nasal cellularity. Some impedance variables were related to current exposure but also with better function at higher exposure.

Conclusions: Exposure to meranti wood dust did not cause an inflammation in the upper respiratory tract nor an increase of respiratory symptoms or decrease of lung function. These data do not corroborate the hypothesis that inflammation plays a part in airway obstruction induced by wood dust.

Among the various types of organic dusts to which humans are exposed, wood dust is one of the world's most important, as it is harvested or processed in almost all countries for its traditional use for fuel and construction material. At a mean exposure of around 1 mg/m^3 wood dust is considered to be a mucous membrane irritant and may cause allergy, asthma, chronic obstructive pulmonary disease (COPD) and (nasal) cancer, mostly adenocarcinomas.[1–3] Although no clear distinction in health risks between different wood species can be made, hardwood species seem to constitute greater health risks than softwood for most health effects. Exposure to hard wood dust (beech, oak), alone or in combination with soft wood dust, is strongly associated with nasal adenocarcinomas.[1] Other respiratory disorders, except for asthma, are not associated with specific wood types and risk factors. Respiratory effects induced by wood dust are assumed to follow roughly the same mechanisms as other organic dusts—such as grain dust and cotton dust—through the release of inflammatory mediators from inflammatory and epithelial cells.[4–7] However, no data on these mechanisms relative to exposure to wood dust in animals or humans are currently available. Therefore we set out to investigate the hypothesis that chronic inflammation induced by wood dust itself or compounds in it acts as the driving force behind the respiratory effects of wood dust. Based on this hypothesis the research target was to investigate the inflammatory response in the nose in workers exposed to softwood dust and relate this to (*a*) exposure concentrations, (*b*) respiratory symptoms, and (*c*) respiratory function.

METHODS AND STUDY DESIGN

General aspects

A cross sectional study was carried out between November 1996 and November 1997 in a plywood and wood working plant and an internal control population. The plant is near Surabaya (Indonesia) and employs 4100 workers in eight different units (footnote table 1). Exposure for individual workers was estimated with a job exposure matrix,[8] as the level of exposure was mainly determined by the job category and its specific activities, and less by the unit. Meranti was the main type of wood being processed (>90% of production by mass). Exposure to other types of wood were encountered but such jobs were excluded for the reason that some wood types—for example, ramin—are well known to induce allergic responses. Job exposures (table 1) were assessed by taking 240 personal air samples (6 h time weighted average) over a 4 month period. Only those jobs or functions were selected with more than 10 workers and a low time and place variance (GSD <2.5) to avoid misclassification. Portable pumps (Dupont P-2500, Gillian) and sampling heads for inhalable dust (PAS-6, Casella) equipped with glass fibre filters at a flow rate of 2 l/min were used. The detection limit (0.48 mg/m^3) was calculated from the mean (+3 SD) of 40 blank filters, run during the sampling period. Exposure data enabled classification and selection of 1000 workers based on job title in different current exposure classes for further health effect screening. A questionnaire was used to estimate respiratory symptoms, smoking, and years of employment. Subsequently, nasal lavage (NAL) and lung function were done at the same time.

Abbreviations: COPD, chronic obstructive pulmonary disease; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; PEF, peak expiratory flow volume; MMEF, maximal mid-expiratory flow; FD, frequency dependence; f_0, the frequency at which X equals zero; NAL, nasal lavage; FOT, forced oscillation technique

Table 1 Overview of functions, number of employees/job (K), those selected for screening (k), and the geometric mean (GM) and geometric standard deviation (GSD) for that job based on the measurement number (N)

Category	Value (mg/m³)	Unit*	Function–subfunction	K	*k*	N	GM (mg/m³)	GSD	Glue† (0/1)	M/F‡ (%)
I	0–2.0	HO	Administration	57	57	11	0.35	1.98	0	20/80
		FW	Assembly	60	60	7	0.88	2.15	1	0/100
		BB	Veneer preparation	86	24	12	1.12	1.44	0	0/100
		FW	Slicer	12	10	4	1.20	1.48	0	80/20
		BB	Lumber core	40	11	4	1.27	1.39	0	20/80
		CB	Assembly	34	10	2	1.48	1.53	1	0/100
		PW	Veneer peeling	238	62	14	1.52	1.83	0	80/20
		SD	Assembly	4	4	3	1.55	1.62	1	80/20
		BB	Assembly	36	10	9	1.58	2.04	1	100/0
		PW	Assembly	192	60	6	1.70	1.16	1	100/0
		PW	Veneer drying	196	50	12	1.71	1.57	0	50/50
		LD	Boring	7	7	4	1.71	1.13	0	100/0
		SD	Finishing	19	6	3	1.72	1.33	0	80/20
		PW	Grading	95	27	10	1.86	1.97	0	100/0
		PW	Veneer preparation	374	116	16	1.90	1.47	1	0/100
		WW	Moulding	14	14	9	1.93	1.61	0	100/0
			Subtotal	1464	528	126				
II	2.0–5.0	BB	Grading	19	19	5	2.11	1.35	0	100/0
		SD	Sanding	9	9	2	2.20	1.07	0	100/0
		SD	Panel	8	8	4	2.32	1.34	0	100/0
		LD	Slat's§	8	8	33	2.41	1.46	0	0/100
		PW	Composer	97	97	10	2.84	1.36	1	50/50
		LD	Assembly	11	11	6	2.91	1.58	1	100/0
		FW	Repair	23	23	2	2.96	1.87	0	0/100
		SD	Component mixing	14	14	11	3.13	1.38	0	100/0
		PW	Finishing	120	120	15	3.27	2.31	1	100/0
		MD	Cross cut	20	20	5	3.54	1.51	0	100/0
		CB	Veneer-crosscut	10	10	3	4.36	1.19	0	80/20
		PB	Inspection-grading	8	8	3	4.85	1.43	1	100/0
		CB	Veneer-handcut	20	10	4	4.87	1.37	0	80/20
			Subtotal	367	357	73				
III	>5.0	LD	Finishing	13	13	8	5.21	1.64	1	80/20
		PB	Chipping	27	27	7	5.95	1.79	1	100/0
		MD	Finishing	17	17	6	5.96	3.21	1	80/20
		CB	Finishing-bandsaw	7	7	5	7.43	3.02	0	100/0
		MD	Finger joint	14	14	7	7.47	1.90	1	80/20
		PB	General cleaning	7	7	3	8.39	1.71	1	100/0
		PB	Hot press	9	9	4	11.71	2.40	1	100/0
		PB	Sanding line	21	21	4	12.23	1.65	1	100/0
			Subtotal	115	115	44				
			Total	1946	1000	243				

*HO, head office; FW, fancy wall; BB, block board; CB, curved board; PW, plywood I; LD, louvre door (subunit of woodworking); SD, solid door (subunit of woodworking), MD, moulding (subunit of woodworking), WW, wood working; PB, particle board; †possible exposure to formaldehyde is indicated by the variable glue (0, no glue used; 1, glue used); ‡M/F is the estimated ratio of male/female workers in each job; §specific job including sawing (cross cut), sanding, and sorting of small wooden panels.

Health effect screening

Health effect screening was done between 21 July 1997 and 27 October 1997. Workers were screened in small groups (10–15/day) each morning (during the shift) between 8.00 and 12.00. As workplaces were stratified, workers from different units and functions were spread over the screening period (4 months) as much as possible. Screening was started by completion of a questionnaire on respiratory symptoms and checking of personal characteristics (MJ). After that subjects underwent NAL (MJ), impedance measurements (PL), and finally flow-volume curves (SH) (tables 2 and 3).

Forced expiratory flow-volume curves were recorded and evaluated according to the criteria of the American Thoracic Society (expiration >6 seconds) with a portable Jaeger Mastercope equipped with a pneumotachograph. At each point, three recordings within 5% (or a 100 ml range) forced expiratory volume in 1 second (FEV_1) were obtained from each subject. All flow-volume values were related to Indonesian reference values, calculated from algorithms shown in the appendix. No Indonesian predicted values for maximal mid-expiratory flow (MMEF) were available. Calibration of the pneumotachograph was done at 4 hour intervals in ambient conditions and volume for body temperature, pressure, and saturation (BTPS) correction. Variables used for analysis were forced vital capacity (FVC),FEV_1 , FEV_1/FVC ratio, peak expiratory flow (PEF), and MMEF. Impedance of the respiratory system was measured with the forced oscillation technique as described previously.[9 10] The mean values were taken of three successive measurements, including resistance at 8 Hz (R8) and at 28 Hz (R28), the difference between R28 and R8 (FD, frequency dependence) of resistance (signifying the course of the resistance versus frequency curve), the reactance at 8 Hz (X8), and the resonance frequency (f_0, the frequency at which X equals zero). A negative FD and an f_0 exceeding 15 Hz are usually regarded as indicative for airway obstruction.[9] The equipment was calibrated at 4 hour intervals, and NAL was performed as described previously.[5 11]The NAL fluid was immediately put on ice, and subsequently centrifuged at 600 g for 10 minutes. Fifty microlitres of the cell pellet after centrifugation of the NAL (500 μl) was used to measure the number of cells after formaline (50 μl, 1.1%) fixation, and calculated as the number of total cells/lavage as well as the number of cells/ml of recovered fluid.

Table 2 Demographic characteristics and respiratory symptoms of all screened subjects into three exposure categories and available data on exposure class (values are mean (SEM) or percentages)

	Category I (<2.0)	Category II (2–5) mg/m³	Category III (>5 mg/m³)	Total
Men	243	182	71	496
Age (y)	31.70 (0.42)	32.14 (0.51)	27.72 (0.68)*	31.15 (0.30)
Length (cm)	162.0 (0.40)	161.1 (0.41)	161.3 (0.7)	161.5 (0.27)
Weight (kg)	57.0 (0.53)*	55.0 (0.6)	54.5 (0.8)	55.9 (0.37)
Smoking (%)	51.0	50.5	46.4	50.0
Employment (y)	10.43 (0.34)	10.13 (0.41)	5.93 (0.54)*	9.68 (0.25)
Cumulative exposure (mg/m³.y)	15.65 (0.53)*	35.45 (1.43)	35.57 (3.22)	26.09 (0.89)
Glue (%)	42.0†	56.6	50.7	49.0
Cough (%)	21.3	28.0	19.7	23.5
Bronchitis (%)	4.9	3.4	1.4	3.9
Shortness of breath (%)	3.3	5.0	4.3	4.1
Wheezing (%)	1.2	1.7	2.8	1.6
Women	329	89	16	434
Age (y)	28.91 (0.31)	28.16 (0.54)	27.38 (1.49)	28.70 (0.27)‡
Length (cm)	150.80 (0.28)	150.4 (0.6)	151.1 (1.5)	150.72 (0.25)‡
Weight (kg)	50.28 (0.47)	49.8 (0.8)	49.9 (1.6)	50.16 (0.39)‡
Smoking (%)	0.6	0	6.3*	6.9§
Employment (y)	8.36 (0.28)†	7.27 (0.47)†	5.81 (0.80)†	8.04 (0.24)‡
Cumulative exposure (mg/m³.y)	11.48 (0.45)*	25.45 (1.66)†	34.87 (4.78)†	15.47 (0.63)‡
Glue (%)	60.0	49.0	30.0	57.0§
Cough (%)	23.6	18.0	18.8	22.3
Bronchitis (%)	3.7	6.7	6.3	4.4
Shortness of breath (%)	3.7	3.4	6.3	3.7
Wheezing (%)	1.2	2.2	12.5	1.8

*p<0.05, ANOVA least SD *v* the two other categories; †p<0.05, ANOVA least SD *v* one other category; ‡p<0.001 ANOVA, *v* men; §p<0.05, Kolmogorov-Smirnov *v* distribution in men.

Statistical methods

Mean exposures are expressed as the geometric mean (GM) and geometric SD (GSD) as exposure data are log normally distributed. One way analysis of variance (ANOVA) on log transformed data was used to evaluate differences in exposure based on unit or job description. Based on the low variation coefficients in lung function testing (<10%) and the expected lung function decline (>10%) reported in earlier studies on wood dust, no power calculation was made to describe the chance of false negatives. The group sizes (I: 572, II: 271, and III: 87) were considered sufficient to detect small differences as significant. Considerable attention was spent to avoid misclassification through calculations of variation in exposure category cut offs. This was done with ANOVA, and calculation of variation with the formula:

$$\text{variation} = \sigma^2_{bg} / (\sigma^2_{wg} + \sigma^2_{bg})$$

in which σ^2_{bg} is the variance between groups (categories) and σ^2_{wg} is the variance within groups.

Overlap was tested with Bonferroni testing ($p < 0.05$, two sided). Differences in lung function data between exposure categories and men or women, and smokers or non-smokers were evaluated with one way ANOVA (least SD, $p < 0.05$, two sided) and with χ^2 testing to compare respiratory symptom profiles between groups. Multiple linear (or logistic) regression was used to describe the effect of current or cumulative exposure on lung function (or symptoms) and nasal cellularity, thereby correcting for smoking, age, duration of enployment, and possible confounders such as exposure to glue. Adjusted βs were used as indicator of the strength of association with each variable. All statistical evaluations were done with SPSS-PC for Windows, version 7.0.

RESULTS

Exposure assessment and categories

Measurements of personal air samples (n=243) were used to calculate the GM and GSD in the different units and of specific jobs in various units (table 1). The data consistently showed low GSD (<2.0) indicating limited variability in these jobs. The highest exposures (>5 mg/m³) were found in the units producing particle board, curved board, and in wood working but the mean values were not always representative as not all jobs were measured in each unit. In table 1 the exposure of various jobs in units is given in an increasing order of concentration. Calculation of variation between units (n=6) was 0.44 (ANOVA), and for jobs (n=25) it was 0.46 (ANOVA). Subsequently several reclassification scenarios were evaluated leading to largely similar variation (0.54–0.65) of seven different scenarios and cut offs. The initial classification showed the highest variation (0.65) but no significant difference between the first three categories. Therefore we chose to combine the first three exposure categories into one (<2 mg/m³), and leave the categories 2–5 mg/m³ and >5 mg/m³ as they were. Although the variation was somewhat lower (0.54) than for the initial classification (0.64), exposure differences between all categories were significant (ANOVA, Bonferroni, $p < 0.05$). Further analyses of the cohort for current exposure were done with these three classes (low, middle, high) of exposure to inhalable wood dust as shown in table 1.

General characteristics

From the 1000 recruited workers, 982 subjects were screened and drop out (n=18, 1.8%) was mainly caused by illness and late refusal to cooperate. The characteristics of the final study cohort (n=930), after exclusion of those with missing personal characteristics or job description are in table 4 and showed a striking difference in smoking behaviour between men (50% smokers) and women (0.7% smokers). Also, women were significantly younger and had a shorter duration of employment than men (ANOVA, $p<0.05$). Small but significant differences between exposure categories were found for age, duration of employment, and weight. Also a difference was noted in the proportion of workers exposed to glue in the low exposure group (higher in women, lower in men), and a significantly shorter employment period in the

Table 3 Lung function characteristics and nasal lavage data of all screened subjects classified into three categories (values are mean (SEM) or percentages of specific group in case of airflow obstruction)

	Category I <2.0 mg/m³	Category II (2–5) mg/m³	Category III (>5 mg/m³)	Total
Men:				
Flow-volume	234	180	65	479
FEV_1 (%)	102.4 (1.0)*	105.8 (1.1)	106.8 (1.4)	104.3 (0.7)
FVC (%)	101.8 (0.8)	104.5 (1.2)	105.1 (1.4)	103.3 (0.6)
MEF (%)	81.9 (1.6)	84.7 (1.7)	85.2 (2.7)	83.4 (1.1)
PEF (%)	79.0 (1.1)	77.6 (1.2)	79.8 (1.6)	78.6 (0.7)
FEV_1/FVC	85.0 (0.5)	86.1 (0.6)	87.9 (1.0)†	85.8 (0.4)
PEF <70%	57 (34.3%)	51 (28.3%)	16 (24.6%)	124 (25.9%)
MEF <70%	76 (32.4%)	48 (26.7%)	16 (24.6%)	140 (29.2%)
Forced oscillation technique	212	151	66	429
Resonance frequency (Hz)	9.78 (0.19)	9.59 (0.20)	9.20 (0.24)	9.62 (0.12)
AvR (hPa)	2.41 (0.04)	2.37 (0.07)	2.28 (0.08)	2.38 (0.03)
Frequency dependence (R28-R8)	0.017 (0.002)	0.017 (0.002)	0.020 (0.002)	0.017 (0.001)
X8	–0.15 (0.02)	–0.09 (0.04)	–0.123 (0.03)	–0.13 (0.02)
Frequency dependence <0	42 (19.8%)	23 (15.2%)	7 (10.6%)	72 (16.8%)
Resonance frequency >15 Hz	7 (3.3%)	4 (2.6%)	0	11 (2.6%)
Nasal lavage	224	165	67	456
Log total cells	3.72 (0.05)	3.57 (0.06)	3.72 (0.11)	3.66 (0.04)
Volume (ml)	6.70 (0.08)	6.56 (0.10)	6.59 (0.16)	6.64 (0.06)
Women:				
Flow-volume	317	89	15	421
FEV_1 (%)	100.0 (0.8)	101.4 (1.5)	101.4 (4.3)	100.4 (0.7)
FVC (%)	101.6 (1.4)	99.7 (1.2)	101.0 (4.1)	101.2 (1.1)
MEF (l/s)	78.1 (1.1)	80.7 (2.4)	82.3 (5.2)	78.8 (1.0)
PEF (%)	76.0 (1.1	74.1 (1.7	84.5 (4.8	75.9 (1.0
FEV_1/FVC	88.6 (0.5)	90.5 (0.9)	89.3 (1.5)	89.0 (0.4)
PEF <70%	116 (36.6%)	36 (40.5%)	3 (20%)	155 (36.8%)
MEF <70%	109 (34.4%)	28 (31.5%)	2 (13.3%)	139 (33.6%)
Forced oscillation technique	272	75	15	362
Resonance frequency (Hz)	9.61 (0.12)	9.44 (0.26)	9.17 (0.48)	9.56 (0.11)
AvR (hPa)	3.34 (0.04)	3.34 (0.10)	3.05 (0.14)	3.33 (0.04)
Frequency dependence (R28-R8)	0.025 (0.015)	0.026 (0.003)	0.030 (0.006)	0.026 (0.001)
X8	–0.18 (0.02)	–0.20 (0.04)	–0.056 (0.06)	–0.183 (0.02)
Frequency dependence <0	36 (13.2%)	10 (13.3%)	1 (6.7%)	47 (13.0%)
Resonance frequency >15 Hz	5 (1.8%)	1 (1.3%)	0	6 (1.6%)
Nasal lavage	296	75	14	385
Log total cells	3.72 (0.05)	3.68 (0.10)	3.27 (0.18)†	3.69 (0.04)
Volume (ml)	6.98 (0.06)	6.86 (0.12)	7.02 (0.37)	6.96 (0.05)

*p<0.05, ANOVA least SD *v* the two other categories; †p<0.05, ANOVA least SD *v* category 1.

highest exposure category (5–6 years) for both men and women compared with the other categories and the general working population (men: 9.7 years; women: 7.9 years). This was reflected in a significant trend of cumulative exposure with exposure category in women, but not in men.

Nasal cellularity

Nasal lavage was successful in most people, but the statistical analysis of cell numbers was limited to those people who showed a detectable (>10.000) cell number with our procedure (n=437). No difference was found in recovery of NAL between men and women or between exposure categories (table 2). However, a significantly lower cell count was detected in women in the highest exposure category ($p< 0.05$, ANOVA, least SD test). To study whether nasal cellularity was related to lung function or respiratory symptoms several statistical approaches were used. Firstly, no differences in lung function variables or respiratory symptoms were found between subjects with or without detectable cell numbers in NAL. Although mean cell numbers were higher in subjects with shortness of breath or cough, these differences were not significant (ANOVA, $p>0.3$). Multiple linear regression with nasal cellularity either as a descriptor or as a dependent variable could not show significant relations with current exposure or exposure-years when corrected for age, weight, duration of employment, and recovered volume. To increase statistical power, subjects were divided into quartiles based on log transformed total nasal cell count, but this approach did not show consistent differences in exposure or respiratory symptoms and function between these four groups.

Respiratory symptoms

Among respiratory symptoms phlegm was more frequent in smokers (36.7%) than in non-smokers (30%). In the female population (0.7% smokers) phlegm was reported in 27% of all cases. However, no respiratory symptoms were related to smoking when tested in a logistic regression with age, years of exposure, and exposure to glue (formaldehyde) as possible other factors. No relation with exposure category was found for chronic bronchitis (total incidence 4.1%). Finally, logistic regressions with the presence of symptoms as a dichotomous variable and smoking, age, sex, and various exposure indices (level, cumulative, working-years) as independent variables did not show exposure as a significant descriptor.

Lung function measurements

Flow-volume curves of 900 subjects and impedance measurements of 791 subjects were used for statistical analysis (table

Table 4 Results of multiple linear regression analysis including smoking, exposure to glue (possibly formaldehyde), duration of exposure, age, and current exposure (three categories) as independent variables for the lung function variables and nasal cellularity (in the outcomes (total adusted R^2 or adjusted βs) a differentiation is made between male and female workers)

	Years of exposure		Current exposure			
Lung function	R^2	β Adjusted	R^2	β Category I	β Category II	β Category III
FEV_1 (l):						
Men	0.341	–0.199*	0.353	0.079	0.177**	0.177*
Women	0.248	–0.042	0.262	NS	NS	NS
FVC (l):						
Men	0.296	–0.115**	0.315	0.05	0.134	0.127
Women	0.127	0.02	0.140	0.153	0.132	0.076
FEV_1/FVC (%):						
Men	0.058	–0.140**	0.068	0.07	0.138	0.119
Women	0.087	–0.073	0.100	–0.09	–0.01	–0.03
MEF (l/s):						
Men	0.083	–0.141**	0.090	0.028	0.095	0.050
Women	0.055	–0.012	0.073	0.167	0.195	0.170
PEF (l/s):						
Men	0.121	–0.080	0.125	0.219**	0.191	0.143
Women	0.063	0.022	0.097	0.290**	0.256**	0.234*
Resonance frequency:						
Men	0.068	0.053	0.099	–0.505*	–0.538*	–0.416*
Women	0.113	0.072	0.123	–0.300**	–0.294**	–0.147
Average resistance (R):						
Men	0.061	–0.013	0.072	–0.220	–0.250	0.220**
Women	0.037	–0.001	0.045	0.202	0.176	0.030
Reactance (X):						
Men	0.025	0.033	0.051	0.386*	0.453*	0.295*
Women	0.100	–0.072	0.111	0.308**	0.256	0.177**
Frequency dependence:						
Men	0.010	–0.117	0.028	0.340**	0.330**	0.250**
Women	0.029	–0.059	0.041	0.020	0.030	0.040

*p<0.05; **p<0.01.

3). More measurements were available but excluded because of missing personal characteristics (n=44, and 31 respectively). For impedance an additional 30 subjects were excluded due to technical problems (17), non-compliance (four), and insufficient repeats (nine). The FEV_1 and FVC were normal compared with Indonesian reference values (appendix) but MEF and PEF (77%) were low. No difference in flow-volume variables was found between the exposure categories and if trends were visible they typically showed better lung function at increasing current exposure. Similar findings were noted for impedance variables, but here differences did reach significance for f_0 and reactance (table 4). As an alternative to current exposure, years of employment was used as a rough estimate of cumulative exposure to wood dust and was further explored by multiple linear regression analysis relating lung function and personal characteristics. The outcomes showed a negative association between years of employment and spirometric indices but only in male workers. Statistical significance for years of employment was obtained for FVC, FEV_1, FEV_1/FVC, and MEF (table 4), with the highest adjusted variance obtained for FVC and FEV_1. On the other hand, impedance variables that were significantly different between current exposure classes lost significance in the multiple logistic regression with years of employment. Finally, a multiple linear regression with cumulative exposure as an index integrating years of employment and current exposure category, could not show an association with lung function indices (data not shown).

Airway obstruction

If 70% of predicted value for PEF or MEF was used as a criterion of airway obstruction, 26%–29% of the male workers and 33%–37% of female workers would be obstructive compared with 2.6% of men and 1.8% of women based on the Tiffeneaux-index (FEV_1/FVC <70%). Subsequent testing to compare male smokers and non-smokers could not detect a significant difference in PEF, MEF, and Tiffeneaux index over the various exposure categories (χ^2 test) or as a total group (ANOVA). Again a reverse trend was found towards more obstruction in non-smokers for all variables. The percentage obstruction as defined by an FD <0 and f_0 >15 Hz resulted in 2% obstructive people, which increased to 6% when lowering the f_0 criterion for obstruction to 13 Hz. Suprisingly, less cases with obstruction were found in smokers (5.8%) than among non-smokers (7.7%) although the difference was small and not significant. It was also noticed that the frequency dependency criterion (FD<0) would lead to many more obstructive people (16.7% men; 13.0% women) than when the resonance frequency criterion of 15 Hz was used (table 2). The difference in FD based obstruction between male and female workers was found to be significant (χ^2< 0.05).

DISCUSSION

This cross sectional study in 930 workers in the wood working industry mainly exposed to meranti wood dust has not been able to show a clear relation between current exposure or cumulative exposure (median:17.5; range: 9–26 mg/m^3 .years) to inhalable wood dust and nasal inflammation or various lung function indices. On the other hand years of employment was a significant predictor of loss of lung function measured by spirometric indices, but only among men. Among the women, who did not smoke at all, no effect of years of employment on lung function was found. The absence of a relation in women can be explained by a negative trend of the percentage of women with increasing exposure, the lower exposure-years, and the use of a protective mask by women in general.

Our hypothesis that nasal cellularity, which was used as an index of inflammation in the upper respiratory tract,[5 11–13] is a

causal mechanism between exposure to wood dust and airway obstruction, is not corroborated by these findings. In a single nasal lavage of 841 workers, in which 50% show detectable cells, no significant relation between cell counts and respiratory variables or exposure could be found. In earlier studies, Ahman *et al*[14] could not show nasal inflammation (neutrophil percentage) in 24 industrial art teachers exposed to wood dust compared with controls. Naive volunteers, when exposed to respirable wood dust up to 0.13 mg/m^3 only showed a mild inflammatory response based on increased concentrations of interleukin-6 in NAL.[15] It needs to be mentioned, however, that variability within and between NAL variables are considerable and that repeated measurements as have been done previously[5 11] in cotton dust and chlorine exposure would have been more reliable. Also complementary more specific markers—such as interleukin (IL-8 and IL-6) and myeloperoxidase—might be used to further evaluate nasal inflammation.

Previous studies have reported conflicting data on baseline lung function, respiratory symptoms, and (cumulative) exposure to wood dust. A similarly sized study among 652 red cedar workers[16] showed that pulmonary function variables were related to exposure to dust but not to duration of employment. A later 11 year follow up of the same cohort showed a significant association between decreases in lung function and time in three exposure groups was around 0.4 mg/m^3.[17] Among subsequent studies in medium size cohorts (n=100–200) several have found no overall relation between lung function variables and cumulative exposure index[18–21] in similar exposure ranges, whereas others[22 23] described increased respiratory symptoms and a reduction of spirometric indices in workers exposed to wood dust. Differences may be due to variations in wood type and handling, climatic conditions, misclassification of exposure, and confounding by exposure. In our study most workers were exposed to meranti, a tropical wood which is considered to be a softwood based on it density and hardness.[1] Exposure to other types of wood known to induce asthma was excluded from this study. In some jobs coexposure to formaldehyde was present but a nested case-control study in workers in exposure category I (<2 mg/m^3) showed that workers with coexposure to formaldehyde (n=286) versus those only exposed to wood dust (n=280), showed no increased symptoms or decreased lung function (data not shown). The confounding effect of smoking could be evaluated twice in this study as half of the men smoked whereas the women in this population did not smoke. Male smokers did not show lower lung function indices than male non-smokers, which is probably explained by the type of cigarette (kretek), in which smoke is usually not inhaled.

The outcomes of the forced oscillation technique as an independent method to assess airway obstruction confirmed the positive trend in lung function with increasing current exposure. Previously we found an increased sensitivity of this method to detect airway obstruction compared with spirometry in grain workers[6] but not in chemical workers and workers exposed to inorganic dusts.[10] We then suggested that an airway obstruction caused by endotoxin containing particles would extend to the peripheral airways, and be more readily detected by the forced oscillation technique. With the conventional criteria for airway obstruction only a few workers (2%–3%) were obstructive, which is much lower than in our earlier work using both techniques in European industrial workers (8% for FEV_1 <80%; 10% for FD <0, and f_0 >15 Hz). However, if the negative frequency dependency was used as a criterion for obstruction about 17% of men and 12% of women would be obstructive. This discrepancy is confirmed by a lack of correlation between FEV_1 (or any other spirometric index) and frequency dependence.

Several explanations can be given for the mostly negative outcomes of this study. An obvious reason would be the possible misclassification of subjects over the exposure categories. This is indicated by the significances (in spirometric indices) found with years of employment, which disappeared after multiplication with current exposure to calculate cumulative exposure. However, similar analyses with other exposure categories confirmed the current outcomes and therefore misclassification is not considered as the main reason for our findings. Also a similar approach with narrower exposure classes was used successfully in a smaller cohort of 243 sawmill workers.[17] Another explanation might be job changes after early adverse effects in highly exposed workers, but this was not done in this company. The use of protective masks, especially among women, might be another reason why current exposure does not reflect real exposure and causes the absence of most relations in women. Unfortunately, the wearing of these masks was not scored on an individual basis but only described in the initial workplace surveys. A healthy worker and healthy smoker effect has been noted in many studies before[24] and explains why smokers (more present in the high exposure group) have a better lung function than non-smokers and ex-smokers early in exposure. This effect might explain the positive trend in male workers, as the cumulative exposure of this group and the total group (17 mg/m^3.y) should be considered as low compared with other studies.

In conclusion, this study shows minimal effects of current exposure to meranti wood dust on lung function indices as measured with independent methods and nasal inflammation. A negative effect of years of exposure on lung function indices was found in male workers only and is not related to nasal cellularity.

APPENDIX: REFERENCE VALUES FOR FLOW-VOLUME INDICES IN INDONESIAN PEOPLE

These equations have been calculated from a survey among 1892 men and 1636 women in the Pneumobile project, Indonesia 1992, by three Indonesian Universities in collaboration with Oregon University and Boehringer Ingelheim. No Indonesian predicted values for MMEF were available.

For men

FEV_1 (l)=−4.10074+0.04664×age (y)+0.03947×duration of employment (y)+1.4969×C−0.07433×(C×age)±0.39138

FVC (l)=−5.44018+0.06114×age (y)+0.04849×height (cm)+1.62398 ×C−0.07768×(C×age)±0.4105

PEFR (l/s)=−10.86040+0.12766×age (y)+0.11169×height (cm) −0.0000319344×age^3±1.70935

FEV_1/ FVC (%)=96.63286−0.36507×age (y)±6.22024,

in which: C=1 for age >21, and C=0 for age <21 years

For women

FEV_1(l)=−2.3938+0.01684×age (y)+0.02935×height (cm)+0.85319 ×C−0.03894×(C×age)±0.27248

FVC (l)=−3.37068+0.02824×age (y)+0.03583×height (cm)+1.00051 ×C−0.04546×(C×age)±0.30431

PEFR (l/s)=−5.12052+0.09006×age (y)+0.06980×height (cm) −0.00145669×age^2±1.77692

FEV_1/FVC (%)=97.89444−0.31804×age (y)±5.75235

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