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Acute Pulmonary Responses Among Automobile Workers Exposed to Aerosols of Machining Fluids

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Previous investigations of workers exposed to machining fluids have shown increased rates of cough and phlegm and have shown that these exposures may cause occupational asthma. To examine acute responses to these agents, cross-shift lung function changes related to machining fluid aerosols among 89 machine operators at two factories producing automobile parts were measured and compared with the findings for 42 unexposed assembly workers studied similarly at the same factories. Workers wore a personal air-sampling device on a Monday and Friday of a working week, and spirometry was performed before and after the work shifts on both days. On Mondays, a 5% or greater decrease in the forced expiratory volume in 1-second (FEV_1), regarded as an "FEV_1-response," occurred in 23.6% of the machinists and in only 9.5% of the assembly workers (relative risk = 2.5, $p < .05$). After adjusting statistically for a history of childhood asthma, for smoking prior to lung function testing, and for race, odds ratios for an FEV_1-response of 4.4 among workers exposed to aerosols of straight mineral oils, 5.8 for oil emulsions, and 6.9 for synthetic fluids were found. The FEV_1-responses on Fridays were similar to those on Mondays. There was no progressive decline in FEV_1 over the work week. Personal air samples, collected with a two-stage impactor, allowed aerosol masses to be measured in three size fractions: <3.5 μm, 3.5–9.8 μm, and >9.8 μm aerodynamic diameter. Exposure levels to each type of machining fluid were remarkably similar within each size fraction and for total aerosol levels. Total aerosol concentrations for assembly workers ranged from 0.07 to 0.44 mg/M^3, and for machinists from 0.16 to 2.03 mg/m^3. Inhalable particle (≤9.8 μm) levels were derived from the sum of the air concentrations in the two smallest-size fractions, and significant cross-shift decrements in FEV_1 on Mondays and Fridays were associated with inhalable aerosol levels >0.20 mg/m^3. These findings show that acute airflow obstruction is associated with exposures to aerosols of various machining fluids and that airway responses occur well below current recommended exposure limits.

Key words: cutting oils, coolants, machining operations, aerosol levels, spirometry, exposure-response models

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INTRODUCTION

Metalworking operations (such as drilling, milling, turning, grinding, boring, and broaching) are very common in industry. Essential requirements for efficient machining or grinding operations are lubrication and cooling of the tool and the metal part, and various "machining fluids" are used for these purposes.

Several broad categories of machining fluids have been used in industry. The oldest type are petroleum-based mineral oils, referred to as "straight cutting oils," which are still used for their high lubricating qualities. Emulsions of mineral oils in water, termed "soluble mineral oils," have been used extensively since the 1940s and are still used widely; they provide reasonable lubrication (by virtue of the oil component) and excellent cooling properties (resulting from the high water content). More recently, machining fluids have been introduced that contain synthetic chemicals instead of mineral oils; these "synthetic fluids" are water-soluble and thus are used largely for their cooling properties, and they have acceptable lubricating qualities.

All of these machining fluids contain numerous chemical additives, usually in small amounts, that improve their physical characteristics and prolong their usable life; these additives include biocides, surfactants, corrosion inhibitors, extreme-pressure agents, water conditioners, antifoaming agents, glycols, ethanolamines, and occasionally fluorescein and petroleum azo dyes. Several of these agents have been shown to cause acute pulmonary inflammation [Jarvholm, 1982; Lushbaugh et al., 1950] or airway sensitization [Hendy et al., 1985; Robertson et al., 1988].

Studies of the effects of inhaling aerosols of machining fluids have been few and largely confined to mineral oils and oil emulsions [Cullen et al., 1981; Goldstein et al., 1970; Hendy et al., 1985; Jarvholm, 1982; Jarvholm et al., 1982; Lushbaugh et al., 1950; Robertson et al., 1988]. The possible acute respiratory effects of these agents have not been addressed systematically, although a recent case report cited occupational asthma that was thought to be caused by a pine resin "reodorant" in an oil emulsion fluid [Hendy et al., 1985]. Further case studies from the United Kingdom [Robertson et al., 1988] have shown that some workers have asthmatic responses to unused fluids while others respond only to used fluids, suggesting that different agents in these fluids may be responsible for asthma in different workers. A number of case reports have also implicated ethanolamines, agents found commonly in synthetic fluids, as a cause of asthma in other occupational settings [Pepys and Pickering, 1972; Vallières et al., 1977].

The present study addresses workers' acute changes in lung function relative to the levels of machining fluid aerosols (mineral oils, oil emulsions, synthetic fluids) generated during common machining operations.

MATERIALS AND METHODS

Study Population

Subjects were recruited from 1,850 participants in a cross-sectional survey which investigated chronic pulmonary effects in relation to machining fluid exposures. The overall participation rate for this study was 86%. Eligibility requirements for inclusion in the large cohort included employment in designated factories, areas, and job types. We restricted the study to males because fewer than 5% of the eligible

TABLE I. Demographic Characteristics of Automobile Workers Exposed to Aerosols of Machining Fluids

	Factory A			Factory B	
	Assemblers	Oil emulsions	Mineral oils	Assemblers	Synthetic fluids
No.	23	34	24	19	31
Age, yr	48.3 ± 7.1	46.6 ± 8.5	49.4 ± 7.1	34.4 ± 8.7	36.5 ± 9.9
Height, cm	174 ± 6	173 ± 7	178 ± 6	176 ± 6	174 ± 6
Race, % black	82.6	61.8	79.2	21.0	19.4
Exsmokers, %	21.7	23.5	41.7	31.6	22.6
Current smokers, %	65.2	52.9	37.5	36.8	48.4
History of asthma, %	13.0	5.9	0	10.5	9.7

exposed workers were females. In addition, the structure of this work force was such that all hourly employees in the areas and jobs of interest had worked for the company for at least 5 years.

Workers were selected from two factories: one manufactured steering gears and axles (factory A) and the other produced automatic transmission parts (factory B). "Unexposed" subjects were selected from among assembly workers who performed no machining operations (and were not exposed to other airborne toxic agents), and "exposed" individuals were selected from machining operations that were known to use a single type of machining fluid and which afforded a range of air exposure levels. For the present study, we further restricted selection of "unexposed" and "exposed" subjects to those who had performed the same job in the same area for at least 6 months. A total of 131 out of 177 eligible men were tested (Table I).

Pulmonary Function Tests

Spirometry was performed on four occasions for each subject: on a Monday, before and after the work shift, and similarly on the following Friday. Because of variable work schedules, the testing times varied from 5:00 A.M. to 9:15 A.M. before shifts and from 11:10 A.M. to 3:20 P.M. after shifts. Although start and finish times varied between workers, each worker had a stable work period for at least 4 weeks prior to testing and we took care to include exposed and nonexposed workers at the same times. Subsequent analysis showed that the time of starting and finishing had no association with cross-shift change in lung function.

All spirometry was performed in the production areas by trained respiratory technicians using computerized Eagle IIS Spirometry Systems (Warren E. Collins, MA). Forced expiratory volume in 1 second (FEV_1), forced vital capacity (FVC), peak expiratory flow (PEF), and maximum midexpiratory flow (MMEF) were obtained from the computer output [Black et al., 1980]. Particular care was taken to ensure that all spirograms were at least 6 seconds in duration, and that at least three (and usually five) acceptable efforts were obtained [American Thoracic Society, 1979]. The spirometers were calibrated with a 3-liter syringe before and after each testing session. All spirogram tracings were checked for completeness and accuracy before the results were entered into a computer data base. All acceptable spirograph results were entered, and for each test the largest FEV_1, FVC, and PEF were

identified for subsequent analysis; MMEF was taken from the spirogram that had the largest sum of FEV_1 + FVC.

Each subject's age, height, and race were recorded, as well as information regarding smoking status, history of asthma, hay fever, and any recent upper respiratory infection. Although subjects were specifically asked not to smoke for at least 1 hour before the tests, many did smoke during this period, and this information was recorded for later analysis.

Subjects were asked also to scale their sensation of breathing difficulty by marking a line of 100 mm length at one end labeled, "I cannot breathe at all," and at the other "My breathing is perfectly normal." No consistent pattern of breathing abnormality emerged in relation to time of day or exposures. Further symptom evaluation was not performed because of time constraints.

Exposure Monitoring

Each worker wore an individual air-sampling device on his collar for the duration of the working period (6–8 hours) on both testing days. The collecting device was a two-stage Marple impactor [Rubrow et al., 1987], operating at an airflow of 2.0 liters per minute. The aerosol concentrations in each of three particle size ranges—<3.5 μm, 3.5–9.8 μm, and >9.8 μm mass median diameter for 50% collection efficiency—were determined by gravimetric analysis and expressed in units of mg/m^3. We used the size-specific particle masses as indicators of the relative levels of exposure among workers to the various contaminants in the machining fluids. Total aerosol concentration was the sum of the three size fractions (uncorrected for collection efficiency). This measure of total aerosol mass is not equivalent, however, to that obtained with the usual closed-face filter cassette [NIOSH, 1977a]; the latter will collect more material, depending on the aerosol size distribution, because it has fewer entrance losses.

The individual size fractions represent approximately deposition in alveoli (<3.5 μm), in airways (3.5–9.8 μm), and in the upper respiratory tract (>9.8 μm). For the purposes of the present study, we were particularly interested in the "inhalable aerosol" fraction, consisting of particles ≤9.8 μm. Thus, the inhalable aerosol concentrations were obtained from the sum of the two smallest particle fractions measured with the impactor.

Statistical Analysis

Measurements of FEV_1, FVC, PEF, and MMEF were categorized into a cross-shift "response" or "nonresponse" by examining the percentage decrease in the measurement across the work period (see below).

Logistic regression analyses were performed separately for each dichotomous measure of lung function. Each variable was tested individually and in combination with other variables expected a priori to be related to the outcome. In addition, a step-down procedure was used which involved eliminating variables (one at a time) for which the regression coefficient did not differ significantly from zero ($p > .2$). Covariates that were obviously collinear (such as exposure group and exposure level category; smoking status and smoking a cigarette shortly before a test) were not included together in the models.

Prediction formulae for FEV_1 and FVC were derived from Dockery and co-workers [1985] based on general population data from six U.S. cities, and the

TABLE II. Participating Automobile Workers Compared With Eligible Nonparticipants

	Assemblers		Machinists	
	Participants	Non-participants	Participants	Non-participants
No.	42	13	89	33
Age, yr	41.2	39.8	42.9	45.4
Race, % black	54.8	33.3	50.6	48.5
Exsmokers, %	26.2	30.8	27.0	18.8
Current smokers, %	52.4	30.8	48.3	65.6
FEV_1, % predicted	98.7	99.1	99.0	90.2[a]
FVC, % predicted	100.0	98.4	100.3	92.4[a]

[a]Differ significantly from participant machinists: $p < .01$.

correction factors for blacks reported by these authors were applied to the respective predicted values for whites.

RESULTS

Demographic characteristics of the study group (Table I) showed differences between workers at the two factories: workers in factory A were older, a greater proportion smoked currently, and a much greater proportion were black. These findings reflected overall differences between the two sites that were apparent in the cross-sectional survey.

Comparisons are shown also (Table II) between the 131 men studied and the 46 men who were eligible but either refused (n = 17), or failed to attend for scheduled testing (n = 19), or were absent on long-term sick leave (n = 10). No significant differences were found between participants and nonparticipants regarding age, race, and smoking status. Spirometry measurements obtained during the earlier cross-sectional survey showed that participants had average FEV_1 and FVC values similar to the general population and that the nonparticipants among the machinists had substantially worse lung function, with significantly lower values of FEV_1 and FVC than for the participating machinists (Table II). Thus, the machinists included in this study of acute respiratory effects were significantly healthier than the sizable fraction (approximately 27%) of those who were eligible and not tested.

Exposure Assessment

Complete and acceptable exposure assessment data were available for 114 men on Mondays and 103 on Fridays; missing data resulted from insufficient sampling equipment to measure all subjects on some days and were confined almost exclusively to the "unexposed" assembly workers. Those workers who had missing exposure data were assigned the mean exposure levels for other workers performing similar jobs in the same work areas.

The measured exposure levels for each size fraction are shown for workers at the two factories in relation to exposure categories (Table III). Exposures in all size fractions were considerably lower for assembly workers compared with machinists. Monday exposure levels were similar to the Friday levels ($r^2 = .64$ comparing particle sizes ≤ 9.8 μm). Total aerosol concentrations ranged from 0.07 to 0.44 mg/m^3 for assemblers and from 0.16 to 2.03 mg/m^3 for machine operators. For each

TABLE III. Monday Exposure Levels (mg/m^3) Obtained From Personal Air Samples of Automobile Assemblers and Machinists

	No. of personal air samples taken	Particle size fraction, median (range)		
		<3.5 μm	3.5–9.8 μm	>9.8 μm
Nonexposed				
Factory A	19	0.07 (0.04–0.17)	0.05 (0.02–0.15)	0.07 (0.01–0.21)
Factory B	11	0.06 (0.03–0.21)	0.03 (0.01–0.08)	0.05 (0.02–0.17)
Exposed				
Oil emulsions	32	0.28 (0.12–0.73)	0.27 (0.07–0.86)	0.20 (0.05–0.81)
Mineral oils	24	0.31 (0.13–0.58)	0.28 (0.10–0.59)	0.11 (0.06–0.17)
Synthetic fluids	28	0.16 (0.07–0.26)	0.23 (0.07–0.44)	0.15 (0.06–0.61)
Total samples	114			

particle size fraction, the distribution of exposures for each machining fluid type was log-normal.

Within each exposure type, the range of individuals' exposures was relatively small (generally less than an order of magnitude), and exposure levels were very similar across different machining fluid types (Table III). High degrees of correlation were seen among the various size fractions; a high correlation was also noted between total and inhalable aerosol concentrations ($r^2 = .93$).

For the purposes of exposure-response modeling, inhalable aerosol exposure level was expressed either as a continuous variable or as categories of exposure (low, medium, high) that were created separately for Mondays and Fridays. The categories were obtained by using the first and third quartiles for exposure levels; this meant that half of the workers ($n = 65$) were assigned to the "medium" exposure category (0.20–0.55 mg/m^3 inhalable aerosol), and a quarter ($n = 33$) each to the "low" (< 0.20 mg/m^3 inhalable aerosol) and "high" (> .55 mg/m^3 inhalable aerosol) categories. From this classification of exposure levels, four assemblers were assigned to the "medium" exposure category and the rest to the "low" category; three machinists were assigned to the "low" category and the rest to the "medium" and "high" categories.

Cross-Shift Changes in Lung Function

Mean changes in FEV_1 measurements across the work shift on Mondays, Fridays, and from Monday morning to Friday morning, were -70 ± 140 ml (mean $\pm$ SD), -10 ± 170 ml, and -30 ± 150 ml, respectively. Given the substantial between-individual variation in cross-shift changes, any difference in the mean values for given exposure groups would need to be large in order to demonstrate a significant difference. To examine the cross-shift changes in spirometry more comparably between subjects, and to identify individuals who had greater-than-expected decreases across a work shift, we calculated the percentage changes for individuals.

$$\text{Percentage change (\%)} = 100 \times (\text{Postshift} - \text{Preshift}) / (\text{Preshift})$$

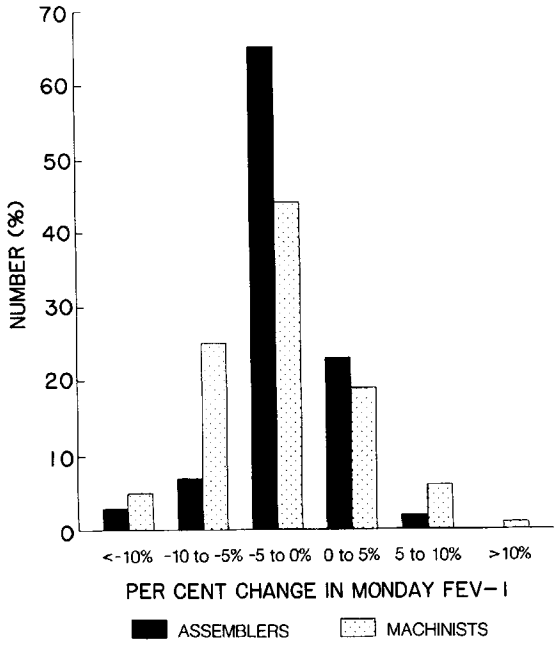

Fig. 1. Distribution of cross-shift changes in FEV_1 on Mondays for assemblers (solid bars) vs. machinists exposed to aerosols of machining fluids (stippled bars).

The criteria used to identify a subject with a "response" were a decrease of 5% or greater in FEV_1 or in FVC or a 10% or greater decrease in PEF or MMEF. The value of 5% for FEV_1 or FVC has been recommended in the Cotton Dust Standard published by the U.S. Occupational Safety and Health Administration [1978]. The value of 10% for PEF or MMEF is arbitrary but consistent with PEF and MMEF being more inherently variable than FEV_1 or FVC.

The distributions of percentage changes in FEV_1 on Mondays for assemblers and machinists (Fig. 1) show a clear shift in the negative tail of the distribution for machinists who, relative to assemblers, had a greater proportion of subjects with 5% or greater cross-shift decrements in FEV_1.

The crude prevalence rates for Monday FEV_1-responses in relation to particular machining fluid exposures showed that each fluid type was associated with a greater proportion of workers with a 5% or greater decrease in FEV_1 relative to the assemblers (Fig. 2).

Logistic regression models were analyzed to determine the contributions of other factors to the likelihood of having an FEV_1-response on Mondays as well as to assess whether confounding might have contributed to the observed exposure relationship (Table IV). Age, race, smoking status (current vs. ex- and nonsmokers), location (factory A or B), lung function measured previously in the cross-sectional survey (expressed as percent predicted), a recent upper respiratory infection, a history of asthma or hay fever, and having smoked a cigarette within an hour before testing were examined. Because of the small number of assemblers who showed an FEV_1-response, the coefficients (that is, the odds ratios) from the logistic models

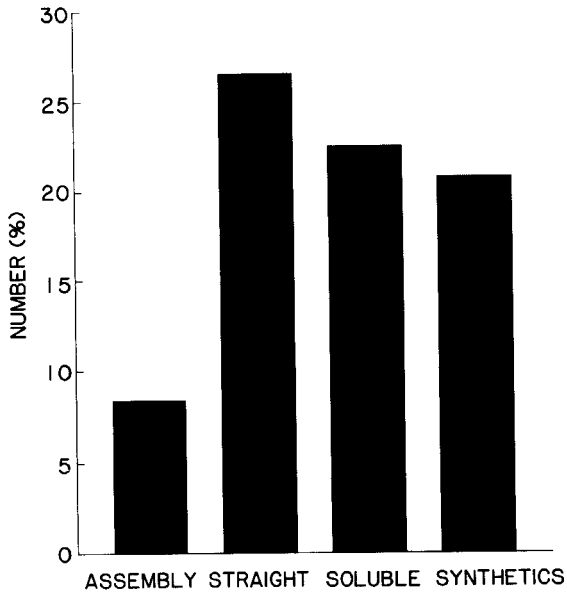

Fig. 2. Prevalence (in percent) of Monday FEV_1-responses according to exposure group. The three groups of exposed machinists had significantly increased rates of FEV_1-responses ($p < .05$) relative to the unexposed assembly workers. An FEV_1-response was defined as a cross-shift decrement in FEV_1 of 5% or greater.

TABLE IV. Logistic Regression Model for Monday FEV_1-Response Among Automobile Workers Exposed to Aerosols of Machining Fluids*

Independent variables	Coefficient (β)	SE	Odds ratios	95% CI[a]
Intercept	−3.84			
Race (black)	0.98	0.58	2.7	0.9–8.3
Childhood asthma	2.21	1.01	9.1	1.3–66
Smoking before morning test	1.16	0.53	3.2	1.1–9.0
Exposure to oil emulsions	1.49	0.77	4.4	1.0–20
Exposure to mineral oils	1.75	0.83	5.8	1.1–29
Exposure to synthetic fluids	1.93	0.83	6.9	1.4–35

*Logistic model: Dependent variable = Monday drop in FEV_1 (0,1) $\ln[p/(1-p)] = \beta_0 + \beta_1$ [Race] + β_2 [Asthma] + β_3 [Smoke] + β_4 [Oil emulsion] + β_5 [Mineral oil] + β_6 [Synthetic fluid].
[a]95% confidence interval.

were rather unstable. Nevertheless, despite the large confidence intervals, the odds ratios were significantly greater than 1.00 for a history of childhood asthma, smoking in the morning, and exposure to each of the machining fluid types, while race (blacks relative to whites) was marginally significant (Table IV).

Similar analyses were conducted for FEV_1-responses on Fridays and from Monday through Friday. The FEV_1 changes between Monday and Friday mornings showed no relationship to exposures, nor to the other factors related to FEV_1-responses on Mondays. Cross-shift FEV_1-responses on Fridays showed relationships qualitatively similar to those on Mondays for a history of childhood asthma,

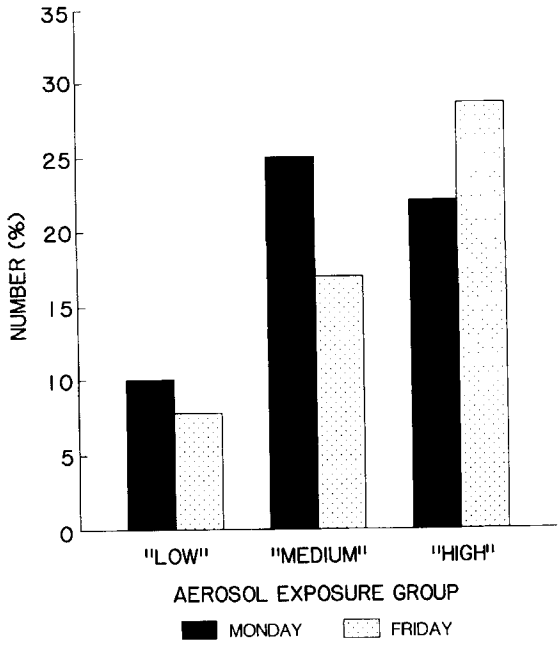

Fig. 3. Relationships between the prevalence of FEV_1-responses and air levels of machining fluid aerosols on Mondays (solid bars) and Fridays (stippled bars). The exposure levels to inhaled particles ($\leq$9.8 μm) have been classified as "low" (<0.20 mg/m^3), "medium" (0.20–0.55 mg/m^3), and "high" (>0.55 mg/m^3). An FEV_1-response was defined as a cross-shift decrement in FEV_1 of 5% or greater.

smoking in the morning, type of machining fluid exposure, and race, but none of these relationships achieved conventional levels of statistical significance, largely because a greater proportion of assemblers had FEV_1-responses on Fridays (16% vs. 10% on Mondays) and fewer machinists had responses on Fridays (19% vs. 24% on Mondays). Other features of the Friday FEV_1-responses among machinists did indicate an exposure-response relationship, however, and these are discussed further below.

No other pulmonary function parameters (FVC, PEF, MMEF) demonstrated significant cross-shift or cross-week changes related to exposure types. Both the PEF and MMEF measurements showed weak cross-shift trends with exposure types, similar to those for FEV_1, but the variability in these measurements was much greater than for FEV_1.

Exposure-Response Analyses

When each worker was assigned an exposure category (low, medium, high) based on individual measurements of inhalable aerosol ($\leq$9.8 μm) levels, significant relationships were found with cross-shift FEV_1-responses on Mondays and Fridays (Fig. 3).

The exposure-response relationships on Mondays and Fridays were examined also with logistic regression models that regressed FEV_1-response on the covariates found previously to be significant predictors (asthma, race, smoking) and an inhalable aerosol exposure variable (low, medium, high, as defined above). The coefficients

for the trichotomous exposure level term (low = 0, medium = 1, high = 2) yielded incremental odds ratios of 1.8 for Mondays (95% CI 0.9, 3.3) and 2.0 for Fridays (95% CI 1.0, 3.8). A significant linear trend ($p < .05$) between FEV_1-response and exposure level was thus present for Fridays, but a similar trend for Mondays was not significant ($p > .05$) even though the incremental odds ratios for the exposure term were essentially identical for both days. From these findings, it is unclear whether the relationship between FEV_1-response and quantitative exposure level is linear (as suggested by the findings for Fridays) or a "step" function (as for Mondays). Comparison of the logistic models for each day does not distinguish between these two possibilities.

When the inhalable aerosol level was expressed as a continuous variable in similar logistic regression models, the coefficient for exposure on Mondays did not achieve statistical significance but was significant for exposure on Fridays. Again, this discrepancy is explicable by the shape of the exposure-response curves on each day (Fig. 3). The use of a continuous exposure term in these models again implied a linear relationship between exposure and effect, which was observed on Fridays but not on Mondays.

The practical importance of these exposure-response models lies not in their shape but in the FEV_1-responses relative to the least exposed group of workers (<0.20 mg/M^3 inhalable aerosol). On both Mondays and Fridays, the medium exposure group (0.20–0.55 mg/m^3 inhalable aerosol) had significantly increased rates for FEV_1-responses relative to the low exposure group ($p < .01$). Thus, the concentration of inhalable particles at which no FEV_1-response would be seen is less than 0.20 mg/m^3 of inhalable aerosol.

Repeatability of Spirometry in Relation to FEV_1-Responses

Previous work has shown that application of the recommended repeatability criteria for accepting lung function measurements as valid may lead to exclusion of data from subjects who have worse-than-average lung function or who may be losing lung function at an unusually rapid rate [Eisen et al., 1984, 1985]. In a recent update on the performance of spirometry, the American Thoracic Society [1987] recommended against excluding subjects with poorly repeatable measurements. Thus, we decided before performing the above analyses that we would not exclude anyone with poorly repeatable spirometry but would analyze data from all subjects by using the maximum value achieved at each testing occasion.

When we applied our usual repeatability criteria—that is, the difference between the largest and next largest FEV_1 and FVC values should agree within 5% or 200 ml (whichever is greater)—112 of the 134 workers had repeatable data on the four occasions that they were tested. We repeated the logistic exposure-response modeling by using data only from these 112 workers (34 assemblers, 68 machinists), and the results did not differ in any significant respect from those for all 134 workers, except that the relationships were strengthened between FEV_1-responses and exposure types for Mondays and Fridays. Among those excluded with poorly repeatable data were three of the four assemblers who had shown an FEV_1-response on Mondays, leaving a prevalence among assemblers of only 2.9%. The corresponding prevalence among machinists remained significantly increased at 20.6% (relative risk = 7.10 $p < .01$, exposed vs. unexposed).

Another feature among those with repeatable data was that machinists had a

significantly greater mean decrease in FEV_1 on a Monday than did assemblers ($-2.01 \pm 3.8\%$, mean $\pm$ SD, vs. $0.44 \pm 2.7\%$, respectively; $p < .02$). Also, the previously apparent, marginally significant, association between race and FEV_1-response was not seen among the subset of workers with repeatable tests, nor was the previous relationship with smoking before the morning test. This suggests that race and smoking were associated with a measured FEV_1-response by virtue of a greater variability in individuals' spirometry.

Finally, in the subset of workers with repeatable tests, statistically significant exposure-response relationships were seen with respect to exposure levels (low, medium, high) for both Mondays and Fridays (chi-square test for trend, $p < .05$ for FEV_1-response in relation to exposure level category on each day).

DISCUSSION

The present findings show that machine operators exposed to aerosols of various cutting oils and coolant fluids are significantly more likely to have an acute drop in FEV_1 over a workshift than are comparable unexposed workers. The data further indicate that the likelihood of a cross-shift decrease in FEV_1 increases with increasing exposure levels above approximately 0.20 mg/m^3 of inhalable aerosol.

Exposure-response relationships were similar on Mondays and Fridays with no significant exposure-related effects being found over the course of a working week. Furthermore, the average values of lung function for exposed and nonexposed workers were similar to those for healthy subjects in the general population. The exposure-related changes in FEV_1 among these workers thus appeared completely reversible.

Exposure status, that is, machinist vs. assembler, was the main exposure determinant for having a cross-shift FEV_1-response. A relationship with air concentration of inhalable aerosol was present despite the low total aerosol exposure levels (0.07–2.03 mg/m^3) relative to levels measured by others [Goldstein et al., 1970; Jarvholm, 1982; Jarvholm et al., 1982] and the rather narrow range of exposures available for the assessment of health effects.

A decrease in FEV_1 across a Monday shift after a weekend absence from work has been suggested as a diagnostic feature of occupational asthma. Burge [1982; Burge et al., 1981], in reporting on a group of electronics workers, suggested that a cross-shift decrease in lung function is a feature of occupational asthma in some cases. We have no clear evidence for an occupational cause of asthma among the workers at either of these factories. No worker was tested who demonstrated work-related acute airflow obstruction that was sufficiently severe to diagnose clinical asthma. The fact that this study population was necessarily made up of workers with at least 5 years tenure with the company meant that we could not test anyone with a short exposure history, and it also meant that workers who may have been affected adversely by these exposures might have left the company. If machining fluid aerosols caused serious health effects in some people within only a few years of exposure, then we may have been studying an essentially healthy "survivor" population. Venables and co-workers [1985] have found such a selection effect among workers exposed to isocyanates in a steel coating plant.

Another source of selection bias is suggested by the findings for workers who failed to participate in the cross-shift assessment of lung function. Among the

exposed workers who were nonparticipants, lung function was significantly worse than for those who participated (Table II). It is conceivable that these nonparticipants included workers who had substantial decrements in lung function resulting from exposures to machining fluids, and thus their absence may have led to an underestimation of the respiratory effects attributable to machining fluid aerosols.

Examples of occupational asthma have been reported for machinists using oil emulsion fluids [Hendy et al., 1985; Robertson et al., 1987]. Specific sensitivity to colophony (a pine resin product) in an oil emulsion was demonstrated for one worker [Hendy et al., 1985]. We have examined material safety data sheets, the only source of information provided by various suppliers, and found no evidence of colophony or other pine resins having been added to the machining fluids that were used in this study. Because components that make up less than 1% by weight of the total composition are not necessarily declared on material safety data sheets, small amounts of colophony might have been present.

In a study of 25 workers exposed to various oil mists, Robertson and co-workers [1987] found highly variable PEF responses to oil mists in 13 of their subjects. Challenge testing of six workers in the laboratory showed that some responded to unused fluids and one responded only to a used fluid. From their findings, Robertson and colleagues [1987] concluded that "occupational asthma due to oil mists is common, the peak flow response is heterogeneous, and the provoking agent within the oil may vary from worker to worker." Our observation that 25–30% of workers exposed to straight mineral oils or oil emulsions had an FEV_1-response (Fig. 2) also suggests that mild airway narrowing is a common response to such exposures. Whether the high proportion of mild responses that we observed represented a nonspecific "irritant" airway effect or airway sensitization to a component of oil mists could not be determined.

An oil component would not explain, however, the similar high rate of FEV_1-responses among workers exposed to synthetic fluids which contained no mineral oils, and it would appear that additional agents or contaminants may be acting as airway irritants or sensitizers. Ethanolamines are a prominent component of many synthetic machining fluids. In other occupational settings, airway sensitization has been reported in workers exposed to various ethanolamine compounds [Pepys and Pickering, 1972; Vallières et al., 1977] but sensitization among machinists has not been studied.

Several authors have suggested, in relation to other types of exposures, that a cross-shift decrease in FEV_1 on a Monday can be a useful predictor of not only occupational asthma but also of subsequent respiratory impairment and disability. Among grain handlers studied by Tabona and co-workers [1984], a Monday cross-shift decrease in FEV_1 was found in a significant proportion of workers who had no specific sensitivity to grain dust; the FEV_1 decrease on a Monday was related, however, to increased rates of longitudinal FEV_1 decline observed at a follow-up study. Cross-shift decreases in FEV_1 have been observed also in cotton textile workers. Berry and co-workers [1973] found a relationship between Monday decreases in FEV_1 and cotton dust levels for workers without the symptoms of byssinosis. Unlike grain workers, the decrease in FEV_1 on a Monday was not associated with an accelerated longitudinal decline in FEV_1. Nevertheless, cotton mill workers who subsequently developed byssinosis did have greater initial cross-shift decreases in FEV_1 than those who did not develop byssinosis.

The practical implications of these exposure-related changes in lung function cannot be determined from this study alone. An intriguing result of the present study is that each of the machining fluids (mineral oils, oil emulsions, synthetic fluids) gave rise to similar exposure levels and similar potencies with respect to FEV_1-responses. It is very unlikely that a single agent would account for the similar biologic effects of these diverse fluid types. Our findings indicate, therefore, a need for further research to determine which of the various components in different machining fluids may be responsible for acute airway effects. Colophony and ethanolamines are two agents worthy of further investigation in these fluids.

Microbial contamination of water-based machining fluids (oil emulsions, synthetic fluids) is an important practical problem encountered in industry and may be sufficiently severe to turn the fluids rancid and foul-smelling. For these reasons, large quantities of biocides are added to suppress microbial growth. An important agent to consider, in the water-based fluids particularly, is endotoxin from Gram-negative bacteria; to date levels of endotoxin have not been measured in these fluids. Endotoxin is believed to be responsible for much of the acute lung responses seen among textile workers exposed to aerosols of cotton dust [Castellan et al., 1984]. Endotoxin could be having a similar effect in machinists and is also worthy of further investigation as a possible causative agent.

In considering the possible toxic agents in machining and grinding fluids, it must be remembered that these fluids are highly variable and complex mixtures of metals and chemicals that are subjected to heat (at the interface of the tool and workpiece), constant mixing during recirculation of the fluids, and microbial contamination. The identification of specific agents in these fluids that cause irritant or sensitizing airway effects is therefore likely to be complex and time consuming.

Allowable exposures in the workplace to these aerosols is cause for concern. The current threshold limit value (TLV) for exposure to aerosols of oil mists is 5 mg/m^3, and for ethanolamines the TLV is 8 mg/m^3 [ACGIH, 1987]. If the lung function changes demonstrated here in relation to machining fluid exposures are indeed relevant to asthma or long-term respiratory impairment, then they suggest that the allowable exposure levels in industry are now too high.

Worldwide, many millions of workers are employed in machining operations and are exposed regularly to aerosols of machining fluids. In the U.S. alone, it is estimated that upwards of 10 million workers may be exposed to these agents [NIOSH, 1977b]. If the present findings, in conjunction with case studies of asthma, are indicative of serious respiratory problems in machinists and others exposed to aerosols of these fluids, then there may be substantial risk of occupational airway disease to many thousands of workers who have been thought previously to work with relatively innocuous agents. The public health implications of exposure to machining fluid aerosols are thus potentially great.

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