Longitudinal Pulmonary Function Losses in Vermont Granite Workers*

A Reevaluation

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Previous studies have suggested that excessive losses of FVC and FEV_1 were occurring in Vermont granite workers despite the fact that mean quartz levels existing in the industry were below the current OSHA standard of 100 μg/m³. We reexamined these losses in granite workers over an 8-year period, testing the workforce biennially from 1979 to 1987. All workers, including stone shed, quarry, and office, were offered forced spirometry using a 10-L water-sealed spirometer (Collins). In the peak year of participation (1983), 887 workers out of a total of approximately 1,400 were tested. Estimates of longitudinal loss were based on 711 workers who participated in at least three of the surveys. The mean age of this group was 42.9 years, and the mean years employed was 19.3 years; 21.4 percent were nonsmokers (NS), 34.2 percent were ex-smokers (ES), and 44.4 percent were current smokers (CS). Average annual losses of FVC were 0.018 (SD=0.056) L (CS, 0.025 L; NS, 0.006 L: and ES, 0.016 L). Average annual losses of FEV_1 were 0.030 (SD=0.041) L (CS, 0.038 L; NS, 0.020 L; and ES, 0.027 L). Analysis of covariance indicated that losses were related to the initial values for FVC or FEV_1, height, age, and smoking status. After adjusting for these variables, the losses of both FVC and FEV_1 were not correlated with years employed in the granite industry. No significant differences existed in the loss of FVC or FEV_1 in categories of workers exposed to different levels of granite dust, *eg*, office, quarry, and stone shed workers. The annual losses of pulmonary function were significantly smaller than those estimated previously, which were 0.070 to .080 L in FVC, and 0.050-0.070 L in FEV_1. We conclude that dust levels in the Vermont granite industry, which have been in conformance with OSHA permissible exposure limits, do not accelerate pulmonary function loss.

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OSHA=Occupational Safety and Health Administration

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Concern about the health effects of quartz dust exposure has led to many studies of the Vermont granite industry, several of which have been influential in setting federal standards for safe levels of exposure to quartz dust. The earliest studies dealt with the prevalence of radiographic silicosis and the presence of tuberculosis.[1-4] Questions regarding pulmonary function were not addressed until 1974, when one[5] of a series of three articles[5-7] that were influential in the National Institute for Occupational Safety and Health (NIOSH) criteria document[8] suggested that quartz dust exposure was producing an excessive loss of pulmonary function, independent of aging or smoking history. A statistical analysis of a single annual pulmonary function survey of the granite workforce, using cross-sectional techniques, suggested that a 2-ml loss in forced vital capacity (FVC) was occurring annually in relation to an average year of dust exposure (estimated to be 526 μg/cm³ and 9 percent quartz). This 2-ml loss was in contrast to a 9-ml loss per year due to smoking, and a 30-ml loss per year due to aging. Although the 2-ml loss attributed to dust exposure was described in one commentary as trivial in terms of clinical importance,[9] a subsequent article detailing longitudinal losses[10] suggested that far greater losses were in fact occurring. The authors described a 50- to 70-ml annual loss for FEV_1 and a 70- to 80-ml loss for FVC. This conclusion bolstered the authors' previous contention that the permissible exposure limit for quartz dust should be lowered from 100 μg/m³ to 50 μg/m³. However, the authors could not demonstrate a relationship between dust exposure and pulmonary function loss. This lack of a relationship was attributed to difficulties in accurately measuring dust exposure. The recommendation for a 50-μg/m³ meter permissible exposure limit had already been incorporated in the NIOSH criteria document concerning crystalline silica.[8]

In 1981, we published an article[11] which concluded that the losses of pulmonary function in the same individual granite workers who had been tested longitudinally had not occurred as predicted. In 1979, when we retested 487 workers who had been tested in 1974, FVC values had increased by 530 ml and FEV_1 values had remained essentially the same. The previous authors agreed that their estimate of

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FVC losses was invalid because of short expiratory times.[12] The extent of changes in FEV_1 has been the subject of continued discussion, suggesting that the issue has not been resolved.[12-14]

This study presents further longitudinal data on pulmonary function losses in the Vermont granite industry working force. The initial survey, done in 1979, was the basis for our 1981 publication.[11] Follow-up industry-wide surveys were carried out biennially to 1987, giving an 8-year period of observation. The purpose of the study was to characterize the rate of pulmonary function change and to determine whether exposure to the relatively low levels of granite dust prevailing in the industry significantly affect pulmonary function loss. Estimates of average quartz exposure have been below the current permissible exposure limit, but above the recommended exposure limit. Since we tested all workers, including stone shed, quarry, and office workers, we can compare pulmonary function losses in different exposure categories.

Methods

All employees in the Vermont granite industry, which includes approximately 70 individually owned and operated stone sheds and 6 quarries in 5 different communities, were offered spirometry biennially from 1979 to 1987. In 1983, spirometric testing was carried out in conjunction with a chest radiographic survey and the administration of a standardized symptom questionnaire[15] that included information on smoking and work histories. Job categories included the various stone shed jobs (polisher, cutter, lumper, sawyer, sandblaster, *etc*) as well as those of outdoor quarry workers (driller, jet burner operator, *etc*) and office workers (draftsmen, accountants, secretaries). Work histories were either updated or started, including the date of first employment, the number of years spent in each job category, and in which shed or quarry the worker was employed.

Spirometry during the years 1979 to 1983 was performed on the same 10-L water-sealed spirometer (Collins) used in previous surveys. This spirometer was replaced in the 1985 and 1987 surveys by a similar machine. However, the replacement consistently gave calibration readings that were 1 percent lower (30 ml in 3 L) than the older machine, using the same calibration syringe. Values for FVC and FEV_1 in the 1985 and 1987 surveys have been accordingly adjusted. Frequent recordings of ambient temperature, daily calibrations, and checks for detection of leaks were conducted. All FVC and FEV_1 values were measured manually by a single reader using the same plastic overlay. We observed standards for acceptable tracings, such as duration of expiratory time, repeatability of efforts, *etc*, as set out by the Epidemiology Standardization Project.[15] These performance standards for spirometry were current at the time of the study, and in all essential ways conform to later recommendations.[16] The best FEV_1 and FVC values were used, whether or not they were from the same effort and were corrected to BTPS.

Measurements of ambient dust levels in the stone sheds were carried out during the years 1983 to 1984 using personal breathing zone samplers that collected only respirable size particles on polyvinyl choride filters. The samplers were run at a flow rate of 2 L/min for an entire workshift and were calibrated before and after each sampling period. Sampler use was monitored by a technician. Estimates of quartz concentration were made using our measurements of total dust concentration, and previous estimates of quartz dust percentage of 10 percent.[17]

Table 1—*Number of Workers With Data Available by Years Tested*

1979	1981	1983	1985	1987	3×	4×	5×	3 or more
426	613	864	806	661	272	272	167	711

All data were double blind entered and screened for logical and range inconsistencies as well as completeness. Statistical packages (SAS and SPSS) residing on a computer (University of Vermont VAX 8600) were used for analysis. Yearly decrements in FEV_1, FVC, and FEV_1/FVC were estimated for each worker as the slope of the fitted least squares linear regression for each individual.[18] Analyses of variance and covariance were used to compare means of these slopes for various subject groups and examine relationships.

Results

The number of workers tested in the biennial surveys who also had background information available (age, height, smoking status, years in granite) is given in Table 1. The numbers listed for 1979 are artifactually low, since 150 workers had spirometry performed in 1978 before the current study was initiated, and they were not retested when we began this study in early 1979. Their spirometric values are not included in the study because the apparatus used (Vitalograph) had not been carefully calibrated. In addition, approximately 100 tracings from the 1979 survey have been lost and are not available for analysis. Only 173 workers were tested on all five occasions over the 8-year period, reflecting the fact that new workers were coming into the work force, others had retired or were unavailable for testing because of vacation, sick leave, or unwillingness to be tested. We believe that the high participation rate in 1983 was partially due to the fact that chest radiographs were offered in a mobile van at the workplace for the first time since 1976, when the annual chest radiograph surveys carried out by the Vermont State Health Department were abandoned.

Seven hundred eleven workers were tested three times or more and had relevant background information available; our conclusions regarding longitudinal loss of pulmonary function are based on this sample. Since there were only two women working in the stone sheds, and the participation of women who worked in offices was low, we have analyzed

Table 2—*Average (±SD) Data of Workers With Three or More Tests (All Subjects=711)*

Characteristics	Data
Age in 1983	42.90±11.96
Height, cm	68.3±2.65
Years in granite	19.34±11.4
Mean FEV_1, L.	3.687±0.722
Mean FVC, L	4.804±0.795
Mean FEV_1/FVC	0.766±0.072

Table 3—*Mean Annual Longitudinal Change in Pulmonary Function Parameters in 711 Workers Tested three or More Times**

	Smokers n=316	Ex-smokers n=243	Nonsmokers n=152	All N=711
FVC, L	−0.025±0.056	−0.016±0.053	−0.006±0.059	−0.018±0.056
FEV_1, L	−0.038±0.044	−0.027±0.036	−0.020±0.037	−0.030±0.041
FEV_1/FVC	−0.44±0.78	−0.32±0.70	−0.31±0.76	−0.37±0.75

*Average values unadjusted for covariates (initial value, height, age).

only the male workers. The basic cross-sectional data describing these workers, such as age, height, and years worked in the granite industry, are presented in Table 2. This demographic information was used in the analysis of covariance. Their average age was 42.9 years, and the number of years worked averaged 19.3. Nearly 80 percent of the workers were either ex-smokers or current smokers; only 21.4 percent had never smoked.

Longitudinal pulmonary function changes are depicted in Table 3. The R^2 values on average suggest that changes in pulmonary function variables were adequately described by a linear relationship. These slopes were approximately normally distributed within smoking categories. Overall annual losses were 0.018 L for FVC, 0.030 L for FEV_1, and 0.37 percent for FEV_1/FVC. Nonsmokers had the lowest losses, ex-smokers intermediate, and current smokers the highest losses. These data are presented by smoking and job status in Tables 4 through 6. Decrements in lung function appear to be similar to those reported in other blue-collar working populations not exposed to dust in the occupational environment. More importantly, they are far lower than the estimates of longitudinal loss reported previously among Vermont granite workers.[10]

To separate out the effects on lung function of variables such as age, smoking history, and granite working history, we carried out an analysis of covariance (Table 7). For the FVC and FEV_1, the variables of initial FVC or FEV_1, height, age, and smoking all individually had a significant effect on pulmonary function changes ($p<0.002$ or less, except height for FEV_1, where $p=0.074$). "Years in granite" (*ie*, years employed in the granite industry), used as an index of granite exposure, had no significant effect ($p=0.210$ for FVC, $p=0.231$ for FEV_1). Moreover,

Table 4—*Average Annual Change in Forced Vital Capacity (Mean±SD) Related to Smoking and Exposure Status**

	Office	Quarry	Shed	All
Smokers	−0.030±0.051 (n=16)	−0.019±0.041 (n=41)	−0.025±0.059 (n=259)	−0.025±0.056 (n=316)
Ex-smokers	+0.002±0.046 (n=19)	−0.022±0.049 (n=18)	−0.022±0.054 (n=206)	−0.016±0.053 (n=243)
Nonsmokers	−0.012±0.053 (n=24)	−0.021±0.058 (n=14)	−0.002±0.061 (n=114)	−0.006±0.059 (n=152)
All	−0.012±0.051 (n=59)	−0.020±0.046 (n=73)	−0.018±0.058 (n=579)	−0.018±0.056 (n=711)

*Average values unadjusted for covariates (initial value, height, age).

Table 5—*Average Annual Change in FEV_1 (Mean±SD) Related to Smoking and Exposure Status**

	Office	Quarry	Shed	All
Smokers	−0.023±0.038	−0.037±0.040	−0.039±0.045	−0.038±0.044
Ex-smokers	−0.017±0.021	−0.039±0.040	−0.026±0.037	−0.027±0.036
Nonsmokers	−0.029±0.034	−0.017±0.030	−0.019±0.038	−0.020±0.037
All	−0.023±0.032	−0.033±0.039	−0.031±0.042	−0.030±0.041

*Average values unadjusted for covariates (initial value, height, age).

Table 6—*Average Annual Loss in FEV_1/FVC (mean±SD) Related to Smoking and Exposure Status**

	Office	Quarry	Shed	All
Smokers	+0.02±0.83	−0.45±0.80	−0.46±0.77	−0.44±0.78
Ex-smokers	−0.36±0.61	−0.44±0.76	−0.30±0.71	−0.32±0.70
Nonsmokers	−0.38±0.65	−0.05±0.57	−0.33±0.80	−0.31±0.76
All	−0.26±0.70	−0.37±0.76	−0.38±0.76	−0.37±0.75

*Average values unadjusted for covariates (initial value, height, age).

Table 7—*Results of Analysis of Covariance*

Effect	FVC		FEV_1		$FEV_1/FVC \times 100$	
	Coefficient	p Value	Coefficient	p Value	Coefficient	p Value
Initial value	−0.02087	<0.001	−0.00947	0.002	−0.01480	<0.001
Height	0.00423	<0.001	0.00115	0.074	−0.00689	0.532
Age	−0.00224	<0.001	−0.00128	<0.001	0.00065	0.896
Granite years	0.00044	0.210	0.00032	0.231	−0.00242	0.635
Smoke		<0.001		<0.001		0.041
Smoker*	−0.01360	0.009	−0.01547	<0.001	−0.15529	0.041
Ex-smoker*	0.00205	0.712	−0.00025	0.953	−0.01494	0.851
Job		0.523		0.348		0.410
Shed†	−0.00630	0.386	−0.00709	0.197	−0.13901	0.186
Quarry†	−0.01064	0.256	−0.00984	0.163	−0.11028	0.414
	R^2=15.48%		R^2=9.16%		R^2=2.59%	

*Compared with nonsmoker.
†Compared with office smoker.

office, shed, and quarry workers did not have significantly different lung function decrements (p=0.523 for FVC, and p=0.348 for FEV_1). Pairwise comparisons of the three groups of workers also were not significant.

While "years in granite" may be a reasonable index of granite dust exposure for stone shed workers, it is not an appropriate index for office and quarry workers, who are generally thought to be exposed to less or no quartz dust. The analysis of covariance for the stone shed workers alone did not indicate that "years in granite" had a significant effect on pulmonary function loss.

Four hundred thirteen dust measurements were made in the stone sheds during 1983 to 1984. Samples were collected using personal breathing zone samplers. To assure that the resulting dust samples were representative of the prevailing environment, the sampling design used a stratification process that included shed size, occupational category, and season as stratification variables. The mean (±SD) concentration was 601 (±368) $\mu g/m^3$, which is quite similar to the results reported previously.[7,17] The previous workers' estimates of percentage quartz present in granite dust were 10 percent, derived from analysis using infrared spectroscopy.[7,17] Using this percentage, we estimate the average quartz dust level as 60 $\mu g/m^3$. Our own estimate of quartz percentage using x-ray diffraction techniques is 10.81 percent, which agrees closely with previous findings. Our analysis of this material is not complete since we found some variation in the estimates related to using different sized x-ray diffraction filter holders.

Our measurements also indicate that approximately 10.5 percent of the dust samples were in excess of the current Occupational Safety and Health Administration (OSHA) standard of 100 $\mu g/m^3$. If our sampling is representative of dust exposures, and dust levels have been relatively constant for the past several decades, this finding implies that a portion of the stone shed workers have been exposed to excessive quartz as defined by the current OSHA standard of 100 $\mu g/m^3$.

Discussion

The purpose of the current study was to reevaluate the issue whether the current exposures to granite dust led to a precocious or accelerated loss of pulmonary function, as stated in several previous articles.[5,10,14] We had raised serious questions concerning the validity of these estimates of loss. The previous workers have agreed that the FVC estimates of loss were invalid because of short expiratory times;[12] however, there has been continued discussion of the losses in FEV_1 values.[12-14] In 1983, Eisen et al[14] discussed the "effects of selection" in Vermont granite workers, using the data from pulmonary function surveys performed from 1970 to 1975. Granite shed workers were divided into four categories based on the 1975 survey: (1) the "survivors," who were still working and performed spirometry acceptably; (2) those who declined to participate; (3) "terminees," those who had left the industry; and (4) those who failed to meet the repeatability criteria for spirometry, defined as variation in best values less than 200 ml. This group, labeled "PFT-failures," had losses of FEV_1 averaging 101 ml/yr. When the "terminees" were combined with "PFT failure" group, the decrements in FEV_1 were 167 ml/yr. Why these groups (the "PFT failures" and the "terminees") had as good lung function in the initial year (1970) of the study as the other groups, after working in the industry for an average of 15 years, smoking similarly, and being exposed to the same granite dust levels is not clear. In fact, the "PFT failures" had perfectly normal lung function with an observed/expected ratio of 1.0 for the FEV_1, the best ratio of all the subgroups. The expected values were derived from a healthy nonsmoking population.[19] The conclusions of these authors that excessive lung function losses in the "PFT failure" group were due to "temporary sickness, or a function of poor health" are probably speculative. The FEV_1 values used for their analysis were derived from the same tracings that have been criticized previously on the basis of possible technical inadequacies.[11] Despite the implication that accelerated pulmonary function loss in some groups is related to adverse health effects from work exposure to dust, the effect of granite exposures on decrements of FEV_1 for the "PFT failure" group when compared with the "survivor" group did not reach statistical significance.

Aside from attempting to clarify whether previous estimates of loss were accurate, our major goal was to determine whether the occupational exposure to granite dust leads to a loss of pulmonary function in excess of losses expected from smoking and aging. Two approaches to this issue are possible: comparing the average losses in pulmonary function to decrements reported in the literature for working populations not exposed to work environments recognized as containing noxious substances such as particles or fumes; or comparing losses of pulmonary function within the Vermont granite industry between workers who have differing exposures to dust.

Comparison of pulmonary function losses in granite workers with those of healthy or nonexposed workers reported in the literature suggests that the granite workers are not experiencing excessive losses. Musk et al[10] summarized annual FEV_1 losses from six published studies that varied from 13 ml (in a study with only 35 subjects) to 34 ml; losses in $FEV_{0.75}$ were from 21 ml to 49 ml. Losses of FVC ranged from 1 ml to 38 ml; these extremes were reported on the same population by the same author.[20,21] Musk et al[10] concluded that expected losses in FEV_1 and FVC were normally less than 40 ml in healthy working blue collar class workers. However, several of the studies cited were cross-sectional rather than longitudinal.

Becklake[22] detailed longitudinal loss of ventilatory function in both exposed and nonexposed workers derived from five studies. The range of losses for nonexposed workers is complex to summarize, since losses were expressed in several different terms (*eg*, milliliter per year; percent initial FEV per year; percent predicted per year; FEV/FVC percent per year) The range, however, goes from 0.1 percent predicted/yr to 53 ml/yr loss in FEV_1. The study with the lowest loss in nonexposed workers (0.1 percent predicted per year) showed losses in exposed workers of 1.5 percent of predicted per year, a 15-fold difference, which would seem to be an unusually large spread. In the other four studies cited, losses of lung function in nonexposed workers are larger than those of the Vermont granite workforce.

When Russell et al[1] studied the effects of different dust exposures on the prevalence of radiographic silicosis and the incidence of silicotuberculosis, clear differences existed within the industry. These ranged from jobs with very high dust levels such as cutters, who were exposed to average levels of 60 million particles per cubic feet of air (mpplf), to washstand operators exposed to less than 10 mppcf. Average stone shed air was 20 mppcf. Using these different exposure levels and relating them to how quickly silicosis developed, Russell et al[1] recommended a safe dust exposure level of less than 10 mppcf. This level is approximately equivalent to the current OSHA level of 1 mg total dust containing 10 percent quartz. That is, 1,000 $\mu g/m^3$ of total dust containing 10 percent quartz is the current OSHA standard for crystalline silica of 100 $\mu g/m^3$. After dust reduction in the late 1930s, however, the clear separation of jobs according to differing dust levels became more difficult. Although Eisen et al[17] could account for about 40 percent of the variability in dust measurements by season of the year, job category, and different stone shed, none of the previous studies of Vermont granite workers has been able to relate pulmonary function loss to dust exposure. This lack of relationship was attributed to difficulty in measuring total dust exposure accurately. An alternative explanation, as suggested by our data, is that there is no relationship.

Our dust measurements in the stone shed workers showed that when analyses of variance methods were used to compare exposures in seven job categories, no pairs differed. On the other hand, we can compare the shed workers with two other categories of workers in relation to pulmonary function loss, the office workers and quarry workers. Although no dust exposure estimates have ever been made in the quarry or office workers, a reasonable supposition is that their exposures are considerably lower than the stone sheds workers or negligible. Within these different occupational categories, mean changes in pulmonary function that occurred are illustrated in Table 4. Losses of FVC and FEV_1 over the duration of the study did not differ among exposure groups, suggesting that granite dust exposure did not play a detectable role in inducing pulmonary function loss.

Finally, results of analysis of covariance suggest that granite dust exposure, defined as years working in granite, did not have an independent effect on pulmonary function loss for any of the three pulmonary function variables we examined. As noted above, "years in granite" as an exposure index would be reasonable for men employed in the stone sheds, but it is not appropriate for office workers or quarry workers. Despite differences in exposure to dust, spirometric losses within each of these three groups are not statistically different, providing additional support for the conclusion that granite dust exposure at current levels which are in conformance with current OSHA standards does not appear to accelerate pulmonary function loss. The confounding effect of years in granite and age was addressed by inclusion of both in the statistical covariance model. Furthermore, the analysis of stone shed workers alone detected no "years in granite" effect on losses. This supports the conclusions of Musk and Eisen that no relationship could be established between granite dust exposure and rate of pulmonary function loss.

In summary, we find that annual average pulmonary function losses in Vermont granite workers are much less than previously reported, and that the rate of decrement is essentially that reported in non-dust-exposed blue collar workers. While the mean granite dust exposure was below the current OSHA standard, approximately 10 percent of the dust samples exceeded this standard. We conclude that the standard proposed by Russell et al[1] in 1929, which is the basis of the current OSHA standard, is adequate to protect workers exposed to silica from abnormal lung function losses. Reports of excessive losses of pulmonary function based on studies performed in the early 1970s, which were influential in the proposed NIOSH standard of 50 $\mu g/m^3$, appear to have overestimated pulmonary function losses. Further, the suggestion that granite dust has an independent effect on inducing lung function loss at current levels of exposure has not been confirmed. The gradients in pulmonary function loss among never-smokers, ex-smokers, and current smokers suggest that cigarettes are the major cause of accelerated loss. If exposure to quartz dust is maintained below the current OSHA limits, we believe that detriment to lung function will not occur.

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