Results of Spirometry Among Individuals in a Silicosis Registry

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Objective: To determine whether individuals with simple silicosis have obstructive and restrictive decrements. **Methods:** The prevalence of spirometric abnormalities by radiograph profusion, smoking, duration, and latency from first silica exposure was evaluated among confirmed silicotics. **Results:** Among 526 silicotics, 17.3% who had never smoked and 26.5% of smokers had obstruction, 30.1% and 28.1% had restriction, and 22.4% and 25.7% had a mixed obstructive and restrictive pattern. Individuals with category 3 profusion or progressive massive fibrosis were more likely to have abnormalities. **Conclusion:** Both obstructive and restrictive patterns were observed regardless of smoking status with a low profusion category of simple silicosis. There was an increased prevalence of restrictive changes with increased profusion. After controlling for age, smoking, and duration of exposure to silica, there was a statistically significant increased risk of obstructive and mixed changes with progressive massive fibrosis.

Simple silicosis, particularly of low-profusion category according to the International Labor Organization (ILO), has been described as a benign condition that usually is not associated with significant measures of respiratory impairment. A recent occupational medicine text book discussed simple silicosis as follows: "In general when the radiographs show only small rounded opacities of low profusion, significant impairment in ventilatory capacity is unlikely to be present."[1] In addition, silicosis historically has been described as a condition limited to restrictive changes in lung function. However, research over the last 20 years has shown that the pulmonary function abnormalities associated with silicosis include obstructive and restrictive changes.[2]

To address the question of the nature and magnitude of spirometry changes associated with individuals with both simple silicosis and progressive massive fibrosis (PMF), we analyzed spirometry test and radiographic findings among a large cohort of individuals confirmed to have silicosis and who had been reported to the State of Michigan Silicosis Registry.

METHODS

Details of the Michigan Silicosis Registry have previously been published.[3] Michigan has had a silicosis registry since 1987, collecting cases back to 1985. Cases are reported to the registry from hospitals, individual physicians, or a review of death certificates and workers' compensation records. Approximately 80% of reports are received from hospitals. All individuals identified are confirmed to have silicosis before being entered in the registry. This confirmation process includes the telephone administration of a standardized health and work history questionnaire with the individual or next of kin if deceased, review of the most recent chest radiograph by a National Institute for Occupational Safety and Health certified "B" reader, and review of any pathology reports of lung tissue if a biopsy was performed. The same "B" reader has interpreted all radiographs from all cases since the registry began. An individual is considered to have confirmed silicosis if they meet the criteria for exposure and demonstrate either radiographic or pathological changes, as outlined by National Institute for Occupational Safety and Health as part of its Sentinel Event Notification System for Occupational Risks program.[4] Confirmed cases, in the absence of a lung biopsy, must exhibit an ILO profusion of 1/0 or greater for rounded opacities, involving at least the upper lung zones on standardized ILO classification. The physician who performed the ILO classification was unaware of the individual's spirometry test results when the ILO classification was performed.

The standardized interview of the individual or next of kin obtains lifetime cigarette-smoking and work history. If the next of kin or individual was not interviewed or the next of kin was not familiar with the smoking history of the deceased, this information was obtained from medical records. Duration and latency from first silica exposures was determined from the complete occupational history obtained in the standardized interview.

As part of the process of obtaining medical records for confirmation, pulmonary function test results were also requested. The pulmonary function test results came from a large number of different hospital-based pulmonary laboratories and individual practitioners' offices, which used different referent-predictive equations, handled race correction differently, and had varying levels of quality control. Because a large percentage of the pulmonary test results received only included spirometry, only spirometry results were used for the analysis. The pulmonary function test results were not evaluated to determine whether they met American Thoracic Society criteria for reproducibility or validity. To standardize the results, the actual values for FEV_1, FVC, height, age, gender and race were obtained for each individual to calculate the percent predicted using the National Health and Nutrition Examination Survey (NHANES) prediction equations.

Each individual's most recent radiograph and spirometry test results were used for analysis. All radiographs with large opacities A, B, or C (minimum size for opacity A is 10 mm) were considered to be PMF regardless of their overall profusion score. Pulmonary function tests were categorized into four groups on the basis of the percentage predicted of the forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1), and the FEV_1/FVC ratio, as shown in Table 1.

These criteria are more conservative for defining obstruction than the Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria that require only the FEV_1/FEV ratio to be less than 70% and do not require a decrease in the FEV_1.[5] Our criteria are also more conservative than the British Thoracic Society criteria that require the FEV_1 to be less than 80%.[6] We used the more stringent criteria since our population of silicotics is elderly and there is evidence that use of the GOLD criteria overdiagnose obstruction, particularly among the elderly.[7,8]

Tests for trend were based on chi-squared analysis looking just at the three levels of simple silicosis and excluding the biopsy-only and PMF categories. Logistic regression analysis was performed for each spirometry test with ILO radiographic profusion categorized into five levels (0 [positive biopsy for silicosis], 1, 2, 3, and PMF) and duration of exposure to silica categorized into four levels (<10, 10–20, 20–30, and ≥ 30 years) as the primary factors of interest. Cigarette-smoking status (ever vs never) was a control variable.

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Odds ratios (OR) and 95% confidence intervals (CI) were calculated from analyses using binary logistic regression or multinomial logistic regression models. Age, when reported to the surveillance system was also included in the logistic model. All analyses were carried out using SAS software, version 9 (SAS Institute Inc, Cary, North Carolina).

The silicosis registry and activity associated with it has been approved annually since 1988 by the Michigan State University Human Subjects institutional review board.

RESULTS

Among the 886 individuals with confirmed silicosis for the years 1985 to 2002, spirometry results and smoking status were available on 526 individuals. One individual was missing a "B" reading and 11 were missing duration of silica exposure or latency from first silica exposure. The average age of the 526 cases that was included in the analysis was 69.3 years, 98.3% were men and 40.9% were African American (Table 2).

A similar effort to obtain data on the other 360 confirmed cases had been made; there were no differences in mean age or mean radiograph profusion category between the 526 who had sufficient data to be included in this analysis and the 360 who were excluded because of missing data. Six individuals who had an FEV_1/FVC% less than 70 but whose FEV_1% predicted was greater or equal to 70 were excluded from the analyses in Tables 3–6 and 9. The 11 individuals who were missing duration of silica exposure were excluded from Tables 4, 6, and 9.

There were 20 (3.8%) cases with category 0 radiographic evidence (positive biopsy for silicosis), 198 (37.6%) with a category 1, 121 (23.0%) with category 2, 51(9.7%) with category 3, and 136 (25.9%) with PMF. Of the biopsy-only group (category 0), 17 were ever smokers and 3 were never smokers. Within the category 1 group, 152 were ever smokers and 46 were never smokers. In the category 2 group, 81 were ever smokers and 40 were never smokers. Within category 3, 33 were ever smokers and 18 were never smokers. Within PMF, 91 were ever smokers and 45 were never smokers.

Tables 7 and 8 show the percentage predicted of FVC and percentage of FEV_1/FVC by ILO radiographic profusion and cigarette-smoking status. These data show that 43.3% of individuals who ever smoked and 52.0% who never smoked had an FVC less than 70% (Table 7) and that 54.0% of individuals who ever smoked and 39.5% of individuals who never smoked had an FEV_1/FVC less than 70% (Table 8).

Table 3 shows the number and percentage of silicosis cases with restrictive, obstructive, mixed, or normal results on their spirometry tests categorized by ILO radiographic profusion and cigarette smoking status (ever vs never). Table 4 shows the spirometry results by duration of silica exposure and Table 5 shows the spirometry results by latency from first exposure to silica. Overall, 17.8% of never smokers and 28.7% of ever smokers had obstructive changes, 21.7% of never smokers and 25.5% of ever smokers had mixed changes, while 30.3% of never smokers and 18.0% of ever smokers had restrictive changes.

Never smokers had a slight but nonsignificant increase in normal spirometry test results compared with smokers (30.3% vs 27.9%, OR = 1.18 [95% CI = 0.73–1.91], $P = 0.50$), a nonsignificant increase in restrictive changes compared with smokers (30.3% vs 18.0%, OR = 1.45 [95% CI = 0.80–2.60], $P = 0.22$), a nonsignificant decrease in mixed changes (21.7% vs 25.5%, OR = 0.85 [95% CI = 0.45–1.61], $P = 0.63$), but a significant decrease in obstructive changes compared with smokers (17.8% vs 28.7%, OR = 0.43 [95% CI = 0.21–0.85], $P = 0.016$). Overall, among never smokers there was a statistically significant decrease in the prevalence of normal spirometry tests by increasing ILO radiographic profusion category from 1 to 3 ($\chi^2 = 5.40$, $P = 0.025$). Both never smokers and ever smokers had a statistically significant increased prevalence of restrictive but not obstructive changes with increased ILO profusion category ($\chi^2 = 9.75$, $P = 0.002$ and $\chi^2 = 5.74$, $P = 0.021$, respectively) (Table 3). There was no statistically significant trend of increasing prevalence of abnormal spirometry tests with longer duration of exposure (Table 4), but there was statistically significant trend of increasing prevalence of abnormal spirometry tests with increasing latency from first exposure (Table 5). A logistic model including ILO radiographic profusion (five categories), duration of silica exposure (four categories), cigarette-smoking status (ever vs never), and age is shown in Table 6. There was an increased risk of restrictive spirometry test results in the model for radiographs with category 3 profusion and mixed changes or any abnormality with PMF. Similar results were found when latency from first exposure to silica was used in the logistic model instead of duration of exposure to silica (data not shown). Table 9 shows a lack of an association between changes in spirometry tests and duration of silica exposure after adjustment for ILO radiograph profusion, age, and smoking status. There was a similar lack of an association between changes in spirometry tests and latency from first exposure to silica after adjustment for ILO radiograph profusion, age, and smoking status (data not shown).

TABLE 1. Criteria for Categorization of Spirometry Results

Pulmonary Function Category	FEV_1/FVC%	FVC% Predicted	FEV_1% Predicted
Normal	≥70	≥70	≥70
Restrictive	≥70	<70	–
Obstructive	<70	–	<70
Mixed	<70	<70	<70

FEV_1, forced expiratory volume in one second; FVC, forced vital capacity.

TABLE 2. Select Characteristics of Individuals Confirmed With Silicosis: 1985 to 2002

Characteristic	Mean	SD
Age, yrs	69.5	11.2
Duration, yrs	26.8	11.3
% Predicted FEV_1	64.5	23.4
% Predicted FVC	71.8	20.3
FEV_1/FVC%	67.2	16.6
	N	**%**
Gender, male	526	98.1
Race		
White	303	57.6
African American	223	42.4

FEV_1, forced expiratory volume in one second; FVC, forced vital capacity.

DISCUSSION

The occurrence of reduced spirometry test results consistent with restrictive and obstructive changes was common in our cohort of silicotics, including those with simple silicosis. For silicotics with category 1 simple silicosis, 15.1% of those who had ever smoked cigarettes and 19.6% of those who had never smoked cigarettes had changes consistent with restriction; 32.9% of ever smokers and 10.9% of never smokers had changes consistent with obstruction; and 18.4% of ever smokers and 26.1% of never smokers had changes consistent with both obstruction and restriction. The decrease in FVC and FEV_1/FVC were to levels that would be expected to be of

TABLE 3. Spirometry Test Results by ILO X-Ray Film Results and Cigarette-Smoking Status for Individuals Confirmed With Silicosis: 1985 to 2002

	Restrictive				Obstructive				Mixed				Normal			
	Ever Smoked		Never Smoked		Ever Smoked		Never Smoked		Ever Smoked		Never Smoked		Ever Smoked		Never Smoked	
ILO X-Ray Film Results	*N*	%*	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Category 0 (biopsy evidence)	5	29.4	0	–	5	29.4	2	66.7	4	23.5	0	–	3	17.6	1	33.3
Category 1	23	15.1	9	19.6	50	32.9	5	10.9	28	18.4	12	26.1	51	33.6	20	43.5
Category 2	15	18.8	13	32.5	20	25.0	6	15.0	24	30.0	7	17.5	21	26.3	14	35.0
Category 3	14	42.4	11	61.1	5	15.2	3	16.7	4	12.1	2	11.1	10	30.3	2	11.1
PMF	10	11.0	13	28.9	27	29.7	11	24.4	35	38.5	12	26.7	19	20.9	9	20.0
Total	67	18.0†	46	30.3	107	28.7‡	27	17.8	95	25.5§	33	21.7	104	27.9‖	46	30.3
Trend¶	($\chi^2 = 5.74$, $p = 0.021$)		($\chi^2 = 9.75$, $p = 0.002$)		($\chi^2 = 0.893$, $p = 0.40$)		($\chi^2 = 2.92$, $p = 0.10$)		($\chi^2 = 0.38$, $p = .61$)		($\chi^2 = 0.02$, $p = 0.99$)		($\chi^2 = 0.62$, $p = 0.45$)		($\chi^2 = 5.40$, $p = 0.025$)	

ILO, International Labor Organization; PMF, progressive massive fibrosis.
*Percentage calculated by row separately among ever smoked and never smoked.
†Restrictive abnormal: never smoked vs ever smoked OR = 1.45 (95% CI = 0.80 to 2.60), $P = 0.22$.
‡Obstructive abnormal: never smoked vs ever smoked OR = 0.43 (95% CI = 0.21 to 0.85), $P = 0.016$.
§Mixed abnormal: never smoked vs ever smoked OR = 0.85 (95% CI = 0.45 to 1.61), $P = 0.63$.
‖Normal: never smoked vs ever smoked OR = 1.18 (95% CI = 0.73 to 1.91), $P = 0.50$.
¶Using categories 1–3 of x-ray film results within smoking status: restrictive vs normal; obstructive vs normal; mixed vs normal; abnormal vs normal.

TABLE 4. Spirometry Test Results by Duration of Years Exposed to Silica and Cigarette-Smoking Status for Individuals Confirmed With Silicosis: 1985 to 2002

	Restrictive				Obstructive				Mixed				Normal			
	Ever Smoked		Never Smoked		Ever Smoked		Never Smoked		Ever Smoked		Never Smoked		Ever Smoked		Never Smoked	
Duration of Years Exposed to Silica	*N*	%*	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
<10	4	14.8	6	46.2	12	44.4	1	7.7	3	11.1	2	15.4	8	29.6	4	30.8
10–20	9	13.2	6	22.2	16	23.5	5	18.5	25	36.8	5	18.5	18	26.5	11	40.7
20–30	25	21.4	12	32.4	31	26.5	4	10.8	30	25.6	11	29.7	31	26.5	10	27.0
30	26	17.0	22	30.6	45	29.4	16	22.2	37	24.2	15	20.8	45	29.4	19	26.4
Total†	64	17.5	46	30.9	104	28.5	26	17.4	95	26.0	33	22.1	102	27.9	44	29.5
	($\chi^2 = 0.05$, $p = 0.87$)		($\chi^2 = 0.16$, $p = 0.76$)		($\chi^2 = 0.19$, $p = 0.68$)		($\chi^2 = 1.96$, $p = 0.18$)		($\chi^2 = 0.12$, $p = 0.76$)		($\chi^2 = 0.65$, $p = 0.48$		($\chi^2 = 0.08$, $p = 0.81$)		($\chi^2 = 1.02$, $p = 0.33$	

*Percentage calculated by row separately among ever smoked and never smoked.
†Duration was missing on 13 individuals, so this table has 551 subjects.

clinical significance (Tables 7 and 8). Three previous studies have also reported spirometric abnormalities in individuals with simple silicosis.[9–11]

The prevalence of a restrictive abnormal pattern on spirometric test results increased with increasing profusion abnormalities on the chest radiographs and latency from first exposure to silica but not with duration of exposure to silica (Tables 3–5). The association of increasing spirometric abnormalities with ILO radiographic profusion has been reported in a number of silicosis cohorts.[12–17] Controlling for age, duration of silica exposure, and cigarette-smoking status, restrictive changes were significantly increased in individuals with profusion category 3, and obstructive and mixed changes in individuals with PMF compared with individuals with profusion category 1 (Table 6). *Silicosis* is a chronic disease, which may progress after silica exposure ceases. This is consistent with our results of an association between latency from first exposure to silica and a decrease in normal spirometric values. Nevertheless, this association with latency dropped out in the multiple logistic model.

Overall, the prevalence of obstructive changes was greater than the prevalence of a pattern of restrictive changes in smokers (28.5% vs 17.5%, OR = 1.60 [95% CI = 1.09–2.33], $P = 0.011$), but a pattern of restrictive changes was greater, although not statistically greater, than obstructive changes in nonsmokers (30.3% vs 17.8%, OR = 1.70 [95% CI = 0.93–3.13], $P = 0.064$). Individuals who had ever smoked cigarettes had a significant increase in obstructive changes compared with those who had never smoked cigarettes (28.7% vs 17.8%, $P = 0.016$) (Table 3), but clearly obstructive changes were common in individuals with silicosis who had never smoked cigarettes (Tables 3 and 8). Using the British Thoracic Society criteria, only about 3% to 9% of asymptomatic lifetime nonsmokers of similar age, as our study group would be expected to be, categorized as having obstruction.[8] Thus, the even more conservative criteria we used were unlikely to pick up false-positive results.

Our findings are consistent with the previous reports of obstructive changes in individuals exposed to silica and the increased prevalence in individuals with both silica exposure and cigarette smoking versus silica exposure alone.[17–30] We found obstructive

TABLE 5. Spirometry Test Results by Latency of Years From First Exposure to Silica and Cigarette-Smoking Status for Individuals Confirmed With Silicosis: 1985 to 2002

	Restrictive				Obstructive				Mixed				Normal			
	Ever Smoked		Never Smoked		Ever Smoked		Never Smoked		Ever Smoked		Never Smoked		Ever Smoked		Never Smoked	
Latency of Years From First Exposure to Silica	*N*	%*	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
<25	3	7.3	4	25.0	10	24.4	1	6.3	9	22.0	5	31.3	19	46.3	6	37.5
25–35	9	14.8	7	28.0	17	27.9	5	20.0	15	24.6	4	16.0	20	32.8	9	36.0
35–45	21	19.3	10	32.3	38	34.9	4	12.9	24	22.0	4	12.9	26	23.9	13	41.9
45	31	20.1	25	32.5	39	25.3	16	20.8	47	30.5	20	26.0	37	24.0	16	20.8
Total†	64	17.5	46	30.9	104	28.5	26	17.4	95	26.0	33	22.1	102	27.9	44	29.5
	($\chi^2 = 7.89$, $p = 0.005$)		($\chi^2 = 2.05$, $p = 0.15$)		($\chi^2 = 2.83$, $p = 0.09$)		($\chi^2 = 3.29$, $p = 0.08$)		($\chi^2 = 5.28$, $p = 0.02$)		($\chi^2 = 0.87$, $p = 0.36$		($\chi^2 = 8.4$, $p = 0.004$)		($\chi^2 = 3.01$, $p = 0.08$	

*Percentage calculated by row separately among ever smoked and never smoked.
†Latency was missing on 13 individuals, so this table has 551 subjects.

TABLE 6. Adjusted Odds Ratio for Restrictive, Obstructive, or Abnormal (Mixed, Restrictive, and Obstructive Combined) Spirometry by Radiograph Profusion

ILO Profusion Category	Restrictive OR (95% CI)	Obstructive OR (95% CI)	Mixed OR (95% CI)	Abnormal OR (95% CI)
0	2.95 (0.72–12.04)	2.14 (0.58–7.85)	1.68 (0.39–7.22)	2.18 (0.69–6.93)
1	Reference	Reference	Reference	Reference
2	1.70 (0.85–3.37)	0.99 (0.52–1.91)	1.70 (0.90–3.23)	1.40 (0.83–2.35)
3	4.45* (1.91–10.38)	0.89 (0.33–2.41)	0.89 (0.30–2.62)	1.82 (0.86–3.85)
PMF	1.66 (0.81–3.39)	1.73 (0.93–3.21)	2.89† (1.55–5.39)	2.07‡ (1.22–3.49)

ILO, International Labor Organization; CI, confidence interval; OR, odds ratio.
*$p = 0.0005$.
†$p = 0.0008$.
‡$p = 0.007$.
Control variables, age, and duration of exposure are continuous; smoking is dichotomous (ever, never). Model for abnormal vs normal is estimated by binary logistic regression. Model of restrictive, obstructive, and mixed vs normal is estimated by multinomial logistic regression.

TABLE 7. Percentage-Predicted Forced Vital Capacity by X-Ray Film Results and Cigarette-Smoking Status for Individuals Confirmed With Silicosis: 1985 to 2002

	Percentage-Predicted FVC											
	≤60%				60%–69%				≥70%			
	Ever Smoked		Never Smoked		Ever Smoked		Never Smoked		Ever Smoked		Never Smoked	
ILO X-Ray Film Results	*N*	%*	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Category 0 (biopsy evidence)	4	23.5	0	–	5	29.4	0	–	8	47.1	3	100.0
Category 1	35	23.0	13	28.3	16	10.5	8	17.4	101	66.4	25	54.3
Category 2	27	33.3	16	40.0	12	14.8	4	10.0	42	51.9	20	50.0
Category 3	6	18.2	12	66.7	12	36.4	1	5.6	15	45.5	5	27.8
PMF	29	31.9	16	35.6	16	17.6	9	20.0	46	50.5	20	44.4
Total	101	27.0	57	37.5	61	16.3	22	14.5	212	56.7	73	48.0

FVC, forced vital capacity; ILO, International Labor Organization; PMF, progressive massive fibrosis.
*Percentage calculated by row separately among ever smoked and never smoked.

changes in silicotics who had never smoked cigarettes and did not have advanced silicosis. This is in contrast to the results of some studies[19,24,28] while in agreement with others.[20,23] We did find that individuals with category 3 profusion had more restrictive changes and those with PMF had more obstructive and mixed changes than individuals with lower ILO radiographic profusion levels (Table 3).

The increased prevalence of spirometric abnormalities in individuals with radiographic changes, including ILO category 1, suggests that these spirometric changes may be present even before the radiographic changes of silicosis. If this is so, it would support the inclusion of spirometry in the medical-screening programs of individuals with ongoing silica exposure to identify adverse effects at an early stage. Since all but 22 individuals in our cohort had radio-

TABLE 8. Ratio of Forced Expiratory Volume in One Second Divided by Forced Vital Capacity by X-Ray Film Results and Cigarette-Smoking Status for Individuals Confirmed With Silicosis for the Years 1985 to 2002 FEV_1/FVC%

	≤40%				41%–59%				60%–69%				≥70%			
	Ever Smoked		Never Smoked		Ever Smoked		Never Smoked		Ever Smoked		Never Smoked		Ever Smoked		Never Smoked	
ILO X-Ray Film Results	*N*	%*	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Category 0 (biopsy evidence)	2	11.8	1	33.3	3	17.6	0	–	4	23.5	1	33.3	8	47.1	1	33.3
Category 1	16	10.5	0	–	38	25.0	4	8.7	24	15.8	13	28.3	74	48.7	29	63.0
Category 2	2	2.5	1	2.5	19	23.5	6	15.0	23	28.4	6	15.0	37	45.7	27	67.5
Category 3	1	3.0	0	–	5	15.2	0	–	3	9.1	5	27.8	24	72.7	13	72.2
PMF	13	14.3	3	6.7	29	31.9	12	26.7	20	22.0	8	17.8	29	31.9	22	48.9
Total	34	9.1	5	3.3	94	25.1	22	14.5	74	19.8	33	21.7	172	46.0	92	60.5

FEV_1, forced expiratory volume in one second; FVC, forced vital capacity; ILO, International Labor Organization; PMF, progressive massive fibrosis.
*Percentage calculated by row separately among ever smoked and never smoked.

TABLE 9. Adjusted Odds Ratio for Restrictive, Obstructive, or Abnormal (Mixed, Restrictive, and Obstructive Combined) Spirometry by Duration

Duration, Years	Restrictive OR (95% CI)	Obstructive OR (95% CI)	Mixed OR (95% CI)	Abnormal OR (95% CI)
<10	Reference	Reference	Reference	Reference
10–20	0.63 (0.20–1.93)	0.63 (0.23–1.72)	2.24 (0.68–7.41)	0.91 (0.39–2.14)
20–30	0.96 (0.34–2.70)	0.64 (0.25–1.65)	1.89 (0.59–6.05)	0.96 (0.43–2.16)
>30	0.56 (0.20–1.56)	0.60 (0.24–1.49)	1.24 (0.39–3.93)	0.69 (0.31–1.53)

CI, confidence interval; OR, odds ratio.
Control variable age is continuous; smoking is dichotomous (ever, never); profusion category is categorical (4 categories). Model for abnormal vs normal is estimated by binary logistic regression. Model of restrictive, obstructive, and mixed vs normal is estimated by multinomial logistic regression. Duration was missing on 13 individuals, so this table has 551 subjects.

graphic evidence of silicosis, our data cannot directly address the utility of spirometry for early identification of the adverse effects of silica exposure.

There are two potential mechanistic pathways for silica to cause spirometric decrements. In pathway 1, pulmonary function decrements are a consequence of the interstitial changes responsible for the radiographic changes of silicosis. In pathway 2, pulmonary function decrements are a consequence of silica-induced pathology that causes chronic bronchitis and/or emphysema or interstitial changes that are insufficient to be seen on chest radiograph.

Ninety-six percent of our population had radiographic changes of silicosis, so we are unable to address the effect of silica on spirometric test results in the absence of radiographic changes. A direct effect of silica on spirometry has been previously reported by us in another cohort and by other investigators.[11,17,31] Since we found no association between duration of work in this current study, our surrogate measure of duration of silica exposure, and spirometric results, our current data suggest that the direct effect of silica on spirometric decrements is outweighed by the pathological changes associated with the radiological abnormalities of silicosis. On the other hand, since all but a handful of individuals in this cohort had radiographic changes of silicosis, individuals who developed radiographic changes of silicosis in a relatively short period of time (ie, <10 years) presumably had a greater average silica exposure than those with longer duration of exposure, and this may contribute to the lack of association between duration and spirometric results. We had insufficient data to construct a silica-exposure matrix. Duration would also be a surrogate for the other particulates found in foundries where 80% of these individuals with silicosis had worked. Nevertheless, the absence of an association of spirometric abnormalities with duration of work and our previous study of foundry workers showing an exposure response to silica[31] would suggest that these other exposures in a foundry are of secondary importance to silica.

One would expect the duration and concentration of silica exposure to be correlated, although perhaps independently, with both ILO radiographic profusion and spirometry. Therefore, the correlation between the two outcomes, ILO radiographic profusion and spirometry might be weak and studies that compared workers with simple silicosis with silica-exposed workers without silicosis would tend to find no relationship with ILO radiographic findings, while studies that used nonexposed controls would be more likely to find abnormalities with radiographic changes. The presence of a relationship between spirometry and radiographic changes was found in studies in which nonexposed controls were used, but not in the case of silica-exposed controls.[32,33] In addition, a different latency period after silica exposure for the development of spirometry and radiographic changes would cause the results from the studies of current and retired workers to differ.

Because our population is elderly and generally retired, the spirometry abnormalities will differ from those found in a cross-sectional study of workers currently exposed to silica. Our results reflect the respiratory changes seen as silicosis progresses over many years. It should be noted that our study population is not a cohort of individuals receiving workers' compensation, the majority of our subjects had never applied for compensation, but our study population does reflect individuals who have been previously hospitalized (80% of cases were reported by hospitals). Silicosis was one of multiple medical conditions; it is possible that other comorbid medical conditions may contribute to changes in spirometric results and tend to obscure any association with ILO radiographic classification or duration. This may be particularly true for individuals, although

there are only 22, with a zero on the ILO classification who are in this cohort only because of a positive lung biopsy.

The major limitation of the data from our silicosis registry was that spirometry test results were obtained from multiple health care facilities throughout the state of Michigan over a 16-year period. Because of the number of health care facilities and the time period, we cannot present the percentage of individuals with results less than2 SD of predicted value as currently recommended by the American Thoracic Society and we cannot evaluate the quality control procedures of the health care facilities performing the tests. We partially addressed this limitation by recalculating and standardizing the percentage predicted by using the same percentage-predicted equation for all results. Another limitation is that our only measure of lung volume was the FVC derived from simple spirometry. We did not routinely collect the results of lung-volume studies to confirm the restriction suggested by the reduced FVC found on spirometry. We used more stringent criteria for obstruction than the GOLD criteria that have been criticized for overcategorizing individuals, particularly the elderly, as having obstruction. Our use of even more stringent criteria would reduce the percentage of individuals categorized as having obstructive changes, but the trends with ILO radiograph profusion would be unchanged.

The spirometry and chest radiographs reviewed were generally not performed on the same day; 45% were performed the same year and another 45% were performed within 5 years of each other. A difference in the time between the two tests would have reduced the likelihood of finding a correlation between profusion on chest radiograph and spirometry results.

In summary, our data support the occurrence of clinically important restrictive and obstructive changes on spirometric test results at all radiographic profusion levels of silicosis, including simple silicosis with a low profusion of abnormalities in both smokers and nonsmokers. The prevalence of a restrictive abnormal pattern on spirometry was greater in individuals with advanced simple silicosis (ILO category 3), and mixed obstructive and restrictive spirometric test results were most prevalent in individuals with PMF. In this cohort of individuals with radiographic changes of silicosis, spirometric changes were not associated with duration of exposure to silica.

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