

Assessment of Respiratory Function and Exercise Capacity Among Persons Having Occupational Exposure to Silica Dust

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Abstract

Background: Silica inhalation at the workplace remains a major public health concern, particularly in developing countries where large numbers of workers are engaged in mining, stone crushing, stone cutting, and drilling activities. Prolonged inhalation of silica dust can result in progressive pulmonary fibrosis, leading to deterioration in lung function and a decline in exercise capacity. While radiological assessment plays an important role in disease evaluation, measurements of pulmonary function and functional exercise capacity provide additional insight into the physiological impact and severity of silica-related lung disease.

Methods: Workers exposed to silica dust were selected as study subjects over the time period of two years. Clinical history and examination in detail, along with chest radiography, spirometry, and six-minute walk test (6MWT), etc were done and results were correlated with chest x-ray findings.

Results: The mean age of participants was 47.19 ± 11.18 years, and 78.08% were male. The mean duration of silica exposure was 14.64 ± 6.76 years, with 68.49% exposed for more than 10 years. Dyspnoea (98.63%) and cough (93.15%) were the predominant symptoms. Mean pre-bronchodilator FEV₁ and FVC were $46.32 \pm 17.35\%$ and $52.15 \pm 16.54\%$, respectively, indicating severe ventilatory impairment. The mean six-minute walk distance was 263.41 ± 94.88 meters, with significant exercise-induced oxygen desaturation from $95.11 \pm 1.66\%$ to $92.34 \pm 2.61\%$. Chest radiographic severity showed significant correlations with spirometric impairment ($p < 0.001$), and reduced exercise capacity ($p < 0.001$).

Conclusion: Workers exposed to silica dust demonstrate significant impairment of respiratory function and exercise capacity. Pulmonary function testing and six-minute walk testing are valuable tools for assessing disease burden and should be incorporated into routine occupational health surveillance programs.

Keywords: Silica dust, Silicosis, Spirometry, Exercise capacity, Six-minute walk test, Occupational lung disease, Respiratory function.

INTRODUCTION

Lung diseases arising from occupational dust exposure continue to affect millions of workers across the world and remain a major challenge for occupational health services. Workers engaged in stone processing, mining, quarrying, and construction activities are routinely exposed to airborne silica particles that can penetrate deep into the respiratory tract and produce chronic lung injury.¹ Silicosis is a long-standing fibrotic lung disease resulting from prolonged inhalation of respirable crystalline silica particles and remains one of the oldest yet most prevalent occupational respiratory diseases worldwide.^{1,2} Despite advances in industrial safety,

silica exposure continues to pose a major health hazard in mining, quarrying, construction, stone cutting, ceramic manufacturing, and related industries.¹

Continuous exposure to silica dust may result in structural and functional alterations within the lungs, leading to respiratory symptoms, reduced physical performance, and long-term disability.² As many affected individuals remain asymptomatic during the initial stages of disease, objective

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evaluation of respiratory health is essential for timely recognition of occupational lung impairment.³

The effect of silica inhalation on lung function can be assessed through spirometry, which remains a cornerstone of respiratory evaluation in exposed workers. Spirometry allows quantification of airflow limitation and lung volume reduction by measuring parameters such as FEV₁, FVC, and the FEV₁/FVC ratio.⁴ Studies have shown that occupational silica exposure may be associated with restrictive, obstructive, or mixed ventilatory abnormalities, depending on the duration and intensity of exposure.⁵ Functional deterioration may occur even in individuals without advanced radiographic manifestations, highlighting the importance of routine respiratory assessment in high-risk occupational groups⁶. As silicosis is associated with fibrotic and emphysematous changes in lung parenchyma, investigations like the diffusing capacity of the lung for carbon monoxide (DLCO) can also assess the extent of the disease. Studies have shown that there is a significant reduction in DLCO as the degree of radiological profusion increases.^{7,8}

Assessment of lung function alone may not adequately capture the impact of respiratory impairment on everyday activities. Exercise capacity reflects the integrated performance of the pulmonary, cardiovascular, and muscular systems and serves as an important marker of functional status.⁹ The Six-Minute Walk Test (6MWT) is widely used to evaluate submaximal exercise performance and provides clinically relevant information regarding exercise tolerance and oxygen desaturation.¹⁰ Reduced walking distance has been positively associated with greater respiratory dysfunction and radiological involvement of the disease. Therefore, simultaneous evaluation of respiratory function and exercise capacity can provide a clear picture of the health effects of occupational silica exposure and may facilitate earlier intervention aimed at preserving functional ability and quality of life.¹¹

Even though radiological evaluation remains the cornerstone of silicosis diagnosis, physiological impairment may not always correlate directly with imaging findings. Therefore, assessment of respiratory function and exercise capacity may provide additional insights into disease burden. The present study was undertaken to evaluate pulmonary function and exercise capacity among workers exposed to silica dust and explore their relationship with exposure duration and radiological severity.

METHODS

Study Design and Population

This hospital-based observational cross-sectional study was undertaken after obtaining Ethical approval from the

Institutional Ethics Committee before commencement of the study, and participation was voluntary following written informed consent.

The study enrolled 73 individuals with documented occupational exposure to respirable silica dust. Participants were recruited from occupations known to generate significant silica exposure, including stone drilling, stone cutting, stone crushing, mining, stone loading, and well-digging activities, etc. Adults aged 18 years and above with a history of occupational silica exposure were considered eligible. Individuals with acute respiratory illnesses, unstable cardiac conditions, severe locomotor disabilities interfering with exercise testing, or inability to perform pulmonary function assessment were excluded to ensure reliable physiological measurements.

Clinical Evaluation and Functional Assessment

A detailed evaluation was performed for each participant using a structured study schedule. Information regarding demographic characteristics, occupational history, smoking status, duration of silica exposure, respiratory symptoms, and relevant medical history was systematically recorded. Physical examination was conducted in all participants, and the severity of breathlessness was graded using the Modified Medical Research Council (mMRC) dyspnoea scale.

Radiological evaluation consisted of posteroanterior chest radiography interpreted according to the International Labor Organization (ILO) classification system for pneumoconiosis. Radiographs were assessed for the presence and profusion of small opacities, large opacities, progressive massive fibrosis, pleural abnormalities, and hilar or mediastinal lymph node enlargement.

Respiratory functions were evaluated using spirometry performed in accordance with internationally accepted ATS/ERS recommendations. Measurements included forced vital capacity (FVC), forced expiratory volume in one second (FEV₁), and the FEV₁/FVC ratio. Both pre-bronchodilator and post-bronchodilator values were recorded, and ventilatory abnormalities were categorized as restrictive, obstructive, mixed, or normal patterns using standard interpretative criteria.

Functional exercise capacity was assessed through the Six-Minute Walk Test (6MWT) conducted on a standardized walking course following American Thoracic Society guidelines. The total distance covered during the six-minute period was documented. Physiological parameters, including oxygen saturation, pulse rate, respiratory rate, and perceived breathlessness, were measured immediately before and after exercise. The magnitude of exercise-induced oxygen desaturation was calculated from the difference between pre-test and post-test oxygen saturation values.

Statistical Analysis

Data were compiled and validated before statistical processing.

Quantitative variables were summarized as mean values with corresponding standard deviations, while categorical variables were expressed as frequencies and percentages. Group comparisons involving continuous variables were performed using Student's t-test or one-way analysis of variance, depending on the number of comparison groups. Associations between categorical variables were examined using the Chi-square test or Fisher's exact test whenever appropriate. Correlation analyses were undertaken to explore relationships between duration of exposure, radiological severity, pulmonary function indices, and exercise capacity parameters. Statistical significance was defined as a two-tailed p-value below 0.05.

RESULTS

A total of 73 silica-exposed workers were included. The mean age was 47.19 ± 11.18 years. Males constituted 78.08% of the cohort, while females accounted for 21.92%. The mean duration of silica exposure was 14.64 ± 6.76 years, and 68.49% of workers reported exposure exceeding 10 years (Table 1). More than half of subject had history of smoking. Around 47.95% (n=35) subjects were non- smokers, whereas 39.73% (n=29) were ex- smokers and 12.33% (n=9) were current smokers. Shortness of breath was the most frequent symptom, reported in 98.63% of participants, followed by cough (93.15%), chest pain (69.86%), and fatigue (60.27%). Nearly 81% of participants had moderate-to-severe breathlessness (mMRC grades 2–3).

Spirometry showed both restrictive and mixed ventilatory defects, with minimum post-bronchodilator improvement, that suggesting predominantly irreversible structural lung damage secondary to silica exposure (Table 2). The mean six-minute walk distance was 263.41 ± 94.88 m. Exercise resulted in a decline in oxygen saturation from $95.11 \pm 1.66\%$ to $92.34 \pm 2.61\%$. Pulse rate increased from 79.55 ± 9.51 to 88.19 ± 10.44 beats/minute, while respiratory rate increased from 18.33 ± 3.97 to 23.34 ± 4.99 breaths/minute (Table 3). ILO Category 3 small opacities were the most frequent radiographic finding, observed in 41 participants, with type C lesions being the most common large-opacity pattern in 13 patients (Figure 1).

On correlating chest X-ray finding with spirometric parameters, there was a decline in pulmonary function

Table 1: Baseline demography and exposure characteristics of study subjects

Demographic and occupational variables	Value
Sample size, n	73
Mean age (years)	47.19 ± 11.18
Male sex, n (%)	57 (78.08)
Mean BMI (kg/m ²)	20.73 ± 4.09
Mean duration of silica exposure (years)	14.64 ± 6.76
Exposure duration >10 years, n (%)	50 (68.49)

Table 2: The spirometric parameters of the study participants

Parameter	Range (% predicted)	Mean $\pm$ SD
FEV ₁ Pre-bronchodilator (%)	15-86	46.32 ± 17.35
FVC Pre-bronchodilator (%)	20-84	52.15 ± 16.54
FEV ₁ /FVC Pre-bronchodilator (%)	42-90	69.68 ± 12.32
FEV ₁ Post-bronchodilator (%)	15-90	49.94 ± 17.48
FVC Post-bronchodilator (%)	20-87	55.84 ± 16.33
FEV ₁ /FVC Post-bronchodilator (%)	45-91	73.70 ± 12.34

parameters with increasing radiological severity of silicosis as assessed by ILO chest X-ray grading. Mean FEV₁ progressively decreased from $55.03 \pm 20.69\%$ predicted in Grade 1 to $36.38 \pm 12.27\%$ predicted in large opacity C, indicating worsening airflow limitation with advancing radiological involvement ($p < 0.001$). Similarly, mean FVC values showed a marked reduction across increasing ILO grades, declining from $63.21 \pm 12.43\%$ predicted in Grade 1 to $44.38 \pm 13.78\%$ predicted in Category C, suggesting progressive loss of lung volume associated with increasing pulmonary fibrosis ($p < 0.001$). There was a significant reduction in the FEV₁/FVC ratio, observed with increasing radiological severity, which had a strong statistical significance. The mean FEV₁/FVC ratio decreased from $73.77 \pm 9.70\%$ in Grade 1 to $63.45 \pm 12.62\%$ in Category C disease ($p = 0.012$), indicating that airflow obstruction became more pronounced in advanced stages of silicosis. Although the decline in FEV₁/FVC ratio was less marked than that observed for FEV₁ and FVC, the significant association suggests the coexistence of obstructive airway involvement in addition to restrictive impairment.

These findings indicate that worsening chest radiographic abnormalities are associated with progressive deterioration in lung function. The strongest associations were observed for FEV₁ and FVC, highlighting the substantial impact of increasing fibrotic burden on ventilatory capacity. The results support the utility of spirometry as an important adjunct to radiological assessment in evaluating disease severity and functional impairment among silica-exposed workers (Table 4). There was a progressive decline in exercise capacity with increasing radiological severity of silicosis as assessed by Chest X-ray ILO grading. The mean distance covered during the Six-Minute Walk Test (6MWT)

Table 3: Six-Minute Walk Test Findings among study subjects

Parameter	Range	Mean $\pm$ SD
Distance covered (meters)	126-588	263.41 ± 94.88
Pre-test SpO ₂ (%)	93-98	95.11 ± 1.66
Post-test SpO ₂ (%)	85-96	92.34 ± 2.61
Pre-test Pulse Rate/min	58-112	79.55 ± 9.51
Post-test Pulse Rate/min	75-120	88.19 ± 10.44

Table 4: Correlation of radiological severity with spirometric parameters

Parameters	Chest X-ray ILO Grading					p-value
	0	1	2	3	C	
FEV ₁ (%PREDICTED)	-	55.03 ± 20.69	50.21 ± 18.43	43.88 ± 14.70	36.38 ± 12.27	< 0.001
FVC (%PREDICTED)	-	63.21 ± 12.43	54.79 ± 18.28	48.88 ± 15.46	44.38 ± 13.78	< 0.001
FEV ₁ /FVC (%PREDICTED)	-	73.77 ± 9.70	72.80 ± 12.56	68.76 ± 12.16	63.45 ± 12.62	0.012

Table 5: showing association of radiological severity with exercise capacity

Parameters	Chest X-ray ILO Grading					p value
	0	1	2	3	C	
Distance Covered (meter)	-	344.50 ± 112.59	298.36 ± 93.28	232.07 ± 67.76	211.08 ± 120.12	< 0.001 (S)
O ₂ desaturation (%)	-	1.86 ± 1.17	2.36 ± 1.91	2.80 ± 2.04	3.62 ± 3.18	0.05 (S)

decreased significantly from 344.50 ± 112.59 meters in Grade 1 to 211.08 ± 120.12 meters in Category C disease ($p < 0.001$). This finding indicates that advancing radiological abnormalities are associated with marked deterioration in functional exercise performance, likely reflecting worsening pulmonary impairment and reduced cardiopulmonary reserve. Oxygen desaturation during exercise increased with higher ILO grades. The mean oxygen desaturation rose from 1.86 ± 1.17% in Grade 1 to 3.62 ± 3.18% in Category C disease, demonstrating a significant association between radiological progression and impaired oxygenation during physical activity ($p = 0.05$). Greater desaturation in advanced disease may be attributed to increasing pulmonary fibrosis, ventilation-perfusion mismatch, and reduced gas exchange efficiency (Table 5).

Overall, the findings suggest that worsening radiological severity is associated with reduced exercise tolerance and

increased exertional oxygen desaturation. The significant decline in six-minute walk distance and the rise in oxygen desaturation with increasing ILO grades highlight the adverse impact of progressive silicosis on functional exercise capacity and reinforce the value of the Six-Minute Walk Test as a useful tool for assessing disease severity and functional limitation in silica-exposed workers.

DISCUSSION

There is a substantial physiological burden experienced by workers with prolonged occupational exposure to silica dust. Our cohort mainly included middle-aged individuals with an average exposure duration exceeding fourteen years, emphasizing the chronic nature of silica-related respiratory injury. The long latency period observed before clinical presentation suggests that significant pulmonary damage may accumulate silently before becoming symptomatic.²

Respiratory complaints were almost universal among the study participants, with breathlessness and cough being the predominant manifestations. The high prevalence of dyspnea observed in the present study reflects the progressive reduction in pulmonary reserve associated with silica-induced parenchymal damage. Persistent inhalation of respirable crystalline silica initiates a cascade of inflammatory and fibrotic processes that gradually compromise lung mechanics and gas exchange capacity.¹

There was a statistically significant association with a proportionate fall in FEV₁ and FVC with an increase in ILO profusion. The markedly reduced FEV₁ and FVC values indicate advanced physiological involvement in a large proportion of workers with substantial impairment in pulmonary function. These findings suggest that silica exposure not only affects lung parenchyma but may also contribute to airway dysfunction, resulting in complex ventilatory abnormalities. The limited bronchodilator response further supports the predominance of fixed structural changes rather than reversible airflow limitation. Jalutharia *et al.*¹¹ reported that there is a statistically significant

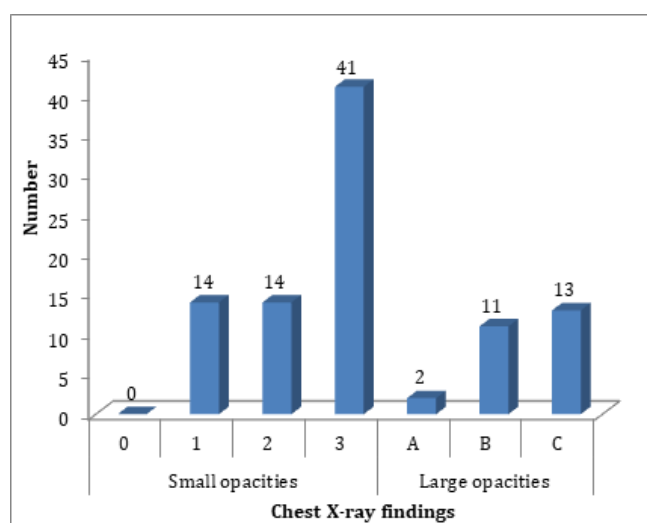


Figure 1: Distribution of chest X-ray findings according to ILO classification among study subjects

fall in spirometric parameters with an increase in chest X-ray ILO grading, and comprised of both restrictive and mixed ventilatory defects. Yang *et al.*⁶ reported that lower FVC was observed in advanced radiological profusion and fibrosis with significant statistical association

Assessment of exercise capacity provided additional insight into the functional consequences of silica-related lung disease. The mean six-minute walk distance recorded in the present study was considerably lower than expected values for healthy adults of comparable age. Reduced walking performance, coupled with exercise-induced oxygen desaturation, indicates impaired cardiopulmonary adaptation to physical exertion. Such findings suggest that physiological impairment extends beyond resting pulmonary function measurements and becomes more evident during activities that increase metabolic demand.¹² Jalutharia *et al.*¹¹ documented a substantial fall in distance and exercise-induced oxygen desaturation with an increase in the extent of profusion in radiographs. The reduction in lung function was found to be associated with the severity of nodular profusion observed on radiological evaluation, including both chest radiography and high-resolution computed tomography (HRCT). 6MWT is an effective and inexpensive method for assessing functional status in patients with silicosis. Izabela Cozza *et al.*¹³ showed a better correlation with pulmonary function and the 6-minute walk test, supporting its role as a practical clinical assessment tool.

Blanco Perez *et al.*¹⁴ showed that 6-minute walk distance was reduced with advanced radiological grading from large opacities A to C, and the correlated distance walked was a prognostic factor for mortality and hospitalization. In our cohort, radiological evaluation demonstrated that a large proportion of workers had advanced disease, with Category 3 small opacities representing the most frequent abnormality. The presence of large opacities in a substantial number of participants further indicates progression to complicated silicosis. Advanced radiographic abnormalities are likely to reflect extensive fibrosis and destruction of functional lung tissue, thereby contributing to the observed reductions in pulmonary function and exercise performance.¹⁵

Longer duration of silica exposure was associated with greater functional impairment, as evidenced by a higher prevalence of abnormal spirometric findings and post-6MWT oxygen desaturation. Which highlight the importance of early surveillance and regular functional assessment of silica-exposed workers to facilitate timely intervention and reduce disease progression.¹⁶ An important observation from this study is the coexistence of severe radiological abnormalities and marked functional impairment. This relationship emphasizes that structural changes visible on imaging are accompanied by clinically meaningful reductions in respiratory capacity and physical performance. Consequently, reliance solely on radiographic findings may underestimate the overall disease burden experienced by affected workers.

The findings also draw attention to the continued occupational health challenges associated with silica exposure. Insufficient regulatory frameworks and a lack of occupational safety awareness among stone processing, drilling, and mining workers expose them to hazardous dust levels¹⁷. Consequently, these individuals are at a high risk of developing irreversible physiological abnormalities and long-term disabilities.¹⁸

CONCLUSION

This study highlights that prolonged occupational exposure to silica dust is associated with significant deterioration in respiratory function and exercise capacity. Workers exhibited substantial reductions in spirometric indices, impaired exercise performance, and advanced radiological abnormalities, indicating considerable disease burden.

The findings suggest that physiological impairment progresses alongside radiological severity and may have a profound impact on daily functional status. Pulmonary function testing and six-minute walk testing provide valuable complementary information regarding disease severity and should form an integral component of occupational health surveillance. Strengthening dust-control measures, improving workplace safety practices, promoting the consistent use of personal protective equipment, and implementing periodic health assessments are essential strategies for reducing the burden of silica-related respiratory disease. Early recognition of functional impairment may improve clinical outcomes and help prevent progression to advanced and disabling forms of silicosis.

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