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Pulmonary function among stone quarry workers in India: The effect of duration of exposure, smoking status and job profile on pulmonary function tests

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Abstract

Introduction: Despite advances in technology, in India workers of stone processing industry continue to be at high risk for lung function deterioration. This study was designed to analyse the effect of duration of exposure, job profile and smoking on lung function of stone quarry workers from Jammu city, Jammu and Kashmir State, India.
Methods: A cross-sectional study was carried out among 100 male stone crusher workers, selected through multi-stage random sampling technique. Effect of risk factors on the pulmonary function tests of the workers was analysed by 'Students independent t-test', one-way ANOVA and simple linear regression. The significance threshold was set up at $P < 0.05$.
Results: We observed a significant reduction in lung function in subjects having duration of exposure above 10 years (Group III) with respect of stone crushers with duration of exposure up to 5 years (Group I) and 6 to 10 years of exposure (Group II). Lung function tests revealed a statistically significant ($P < 0.05$) reduction in lung function test parameters among manual workers compared to non-manual group of workers and among smokers compared to non-smokers. However, simple linear regression analysis revealed that only increase in duration of silica dust exposure was significantly associated with a reduction in pulmonary function tests, specifically in FVC ($P = 0.019$), FEV_3 needs to be as subscript ($P = 0.016$), FEF_{25} ($P = 0.016$), $FEF_{0.2\text{-}1.2}$ ($P = 0.048$), PEFR ($P = 0.019$) and MVV ($P = 0.001$) values.
Conclusion: Duration of silica dust exposure is the most important determinant of pulmonary function deterioration. Therefore, limiting cumulative silica dust exposure can effectively reduce damage to airways in silica-exposed workers.

KEY WORDS: Duration of exposure; job profile; occupational medicine; respiratory function tests; quarry workers; silicosis; smoking.

Riassunto

Introduzione: Nonostante gli avanzamenti tecnologici, in India i lavoratori delle cave di pietra continuano ad essere ad alto rischio di deterioramento della funzionalità polmonare. Questo studio è stato realizzato per analizzare l'effetto della durata di esposizione, del profilo lavorativo e del fumo di sigaretta sulla funzionalità polmonare dei lavoratori delle cave di pietra nella città di Jammu, stato di Jammu e Kashmir, India.
Metodi: Prove di funzionalità respiratoria sono state eseguite su 100 operai di sesso maschile delle cave di pietra selezionati attraverso un campionamento casuale a più stadi. L'effetto dei fattori di rischio sulla funzionalità respiratoria dei lavoratori è stato studiato attraverso il t-test di Student a campioni indipendenti, l'ANOVA ad una via e la regressione lineare semplice. Il limite di significatività statistica è stato fissato a $P < 0.05$.
Risultati: Abbiamo osservato una riduzione significativa nella funzionalità respiratoria degli operai delle cave di pietra con più di 10 anni di esposizione rispetto ai gruppi di lavoratori con durata di esposizione fino a 5 anni e tra 6 e 10 anni. Fumatori ed operai hanno evidenziato una riduzione dei test di funzionalità respiratoria rispetto ai non fumatori ed ai lavoratori che non svolgevano attività manuale. Tuttavia, l'analisi di regressione lineare semplice ha rivelato che solo l'incremento nella durata di esposizione alle polveri di silice era associata in modo significativo ad una riduzione dei test di funzionalità respiratoria, specialmente nei valori di FVC ($P = 0.019$), FEV_3 ($P = 0.016$), FEF_{25} ($P = 0.016$), $FEF_{0.2\text{-}1.2}$ ($P = 0.048$), PEFR ($P = 0.019$) ed MVV ($P = 0.001$).
Conclusioni: La durata di esposizione alle polveri di silice è il fattore più importante nel deterioramento della funzionalità polmonare. Pertanto, limitare l'esposizione cumulativa alle polveri di silice può efficacemente ridurre il danno alle vie aeree nei lavoratori esposti alle polveri di silice.

TAKE-HOME MESSAGE

In our India-based study, duration of silica dust exposure was the most important determinant of lung function decline in silica-exposed workers.

Competing interests - none declared.

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INTRODUCTION

Occupationally related lung diseases have been a burden on mankind over the centuries and silica dust continues to be one of the most notorious respiratory toxins [1]. Strict and effective dust control measures employed by developed countries in the previous century have resulted in substantial decrease in morbidity and mortality from silica-associated airway diseases, whereas such a reduction has not been satisfactory in developing countries like India.

Silica dust exposure is inherent in many industrial operations worldwide [1]. Silica is present in many materials used at construction sites, including soil, sand, concrete, rock, granite, etc. Stones are rich in free silica and the stone crushing process releases a high level of fine silica dust in the working environment [2]. In India, due to lack of resources and awareness at stone-crushing sites, the preventive measures against inhalation of dust particle are generally poor. Therefore, workers exposed to silica dust over a long time can develop a considerable lung function impairment that cannot be reversed [3, 4].

Deposition of silica dust in the lung is one of the key events involved in_occupationally related lung diseases. Many factors like dust type, exposure duration, concentration and the size of the dust particles in the breathing zone influence silica deposition in airways [5]. For instance, the crystalline form of silica, particularly quartz and cristobalite is associated with an increased risk for various silica-related lung diseases compared to amorphous type [6]. Furthermore, dust particles within the size range of 0.5 to 3 microns are retained in the lungs and continue to exert their effect even after cessation of exposure. However, the main factors involved in significant damage to airways are the exposure duration and, secondly, the exposure concentrations [7]. Indeed, even low dust level exposure for longer duration can result in lung function deterioration [8]. Most often, pathological changes in the lungs as a result of silica exposure lead to pulmonary fibrosis mostly after many years of exposure based on the dose-response pattern [9].

Many previous studies have reported a progressive deterioration of lung function associated with an increased duration of exposure to silica dust [8, 10–17]. Also, manual or blu-collar workers are at higher risk of lung function deterioration than non-manual or white-collar workers employed at this sector, as the first are exposed to high concentration of silica dust for a prolonged period of time. In literature, there is no convincing conclusion about the effect of smoking on lung function in silica dust exposure. Some studies have reported a significant reduction in lung function [8, 11], whereas others have found better lung function test parameters in workers exposed to silica dust who were smokers compared to non-smokers [18, 19]. Thus, the present study was carried out to analyse the effect of duration of exposure, job profile and smoking on lung function among stone crusher workers employed at Jammu city, Jammu and Kashmir State, India.

METHODS

Pulmonary function tests were performed on 100 male stone quarry workers from Jammu city, Jammu and Kashmir State of India, during the period January-December 2016. Subjects were divided into 3 study groups according to the duration of dust exposure (length of service) – Group I (up to 5 years), Group II (5-10 years) and Group III (above 10 years). A minimum sample size of 30 for each group was calculated on the basis of a study by Rathod et al. [11] (Mean and SD values of $FEF_{25-75\%}$ at 95% confidence level and 80% power). Therefore, 100 subjects were enrolled in the study with 34 stone crusher workers in Group I (up to 5 years), 36 in Group II (5-10 years) and 30 in Group III (above 10 years). Subjects were selected by multistage random sampling technique. A list of all the crusher units in the vicinity of the Jammu city was obtained and 10 crusher units were randomly selected; afterly, from each of them, 10 subjects were randomly chosen. These 10 subjects comprised at least 3 subjects for each of the 3 study groups (based on the duration

of exposure). Study subjects comprised only male workers aged 18 to 55 years and exposed to dust for at least one year. Subjects with cardiac, respiratory and neuromuscular diseases or with gross anatomical abnormalities in the thoracic cage and vertebral column were excluded from the study.

A computerized spirometer, DTSpiro (Maestro Medline System Ltd, Himachal Pradesh) was used to perform pulmonary function tests. The lung function test parameters recorded were forced vital capacity (FVC), forced expiratory volumes ($FEV_{0.5}$, FEV_1, FEV_3, $FEV_{0.5\%}$, $FEV_{1\%}$, $FEV_{3\%}$), flow rates (including PEFR and FEF_{25}, FEF_{50}, FEF_{25-75}, $FEF_{0.2-1.2}$) and Maximum voluntary ventilation (MVV). Three readings were recorded and a maximum of three was taken for the evaluation. Information regarding individual factors such as age, smoking status, body surface area (BSA), and occupational factors such as duration of exposure to silica dust, and job profile regarding the study participants was collected. On the basis of job profile, subjects were divided into manual and non-manual workers. Non-manual or white-collar workers comprised professional jobs like office workers, drivers and other staff who were not directly involved in manual handling of the materials. Manual or blu-collar workers comprised of quarry employees working in the quarries, where the activities of mining, milling, blasting, breaking, bagging and loading of stones take place.

The data collected was analyzed by SPSS version 20 statistical software and tested for normality distribution by Shapiro Wilk test that revealed data to be normally distributed. 'Students independent t-test' and one-way ANOVA were applied to determine the significance of the difference in the lung function test parameters between the groups. Many physiological factors including age, gender, height, and body surface area (BSA) can influence lung function [20]. Thus, simple linear regression was performed to analyze the effect of duration of exposure, smoking status and job profile on pulmonary function in stone crushers after controlling for the effect of age and body surface area. The significance threshold was set up at $P < 0.05$.

Ethical approval from the Institutional Ethics Committee was obtained and data was collected after acquiring written consent from all the participants, assuring them about the confidentiality of the data.

RESULTS

Mean age of our sample population was 34.19 ± 9.73 years. Among 100 participants, nearly half (n = 44, 44%) of the subjects were in the age group of 31- 40 years. Moreover, about the half of them were blu-collar workers (n = 56, 56%) and smokers (n = 52, 52%) (see Table 1).

Our data showed a significant reduction in all of the pulmonary function test parameters associated with an increase in the duration of exposure (see Table 2). Tukey's post hoc analysis revealed that only reduction in the Mean ± SD of pulmonary function test parameters in subjects having duration of exposure above 10 years (Group III) was statistically significant compared to that we showed in stone crushers with duration of exposure up to 5 years (Group I) and 6 to 10 years of exposure (Group II). Comparison of pulmonary function tests between Group I and Group II was statistically non-significant.

Effect of job profile on lung function tests revealed a statistically significant ($P < 0.05$) reduction in lung function test parameters among manual workers compared to non-manual group of workers, except in $FEV_{0.5}$/FVC ($t = 0.706$, $P = 0.483$) and MVV ($t = 1.363$, $P = 0.176$) values (Table 3). Similarly, all the lung function test parameters were significantly ($P < 0.05$) reduced among smokers compared to non-smokers, except in FEF_{75} ($t = 1.891$, $P = 0.062$) values (Table 3).

Simple linear regression analysis revealed that an increased duration of dust exposure, in terms of length of service, was significantly associated with a reduced pulmonary function among stone crushers. This statistically significant reduction was observed in FVC ($P = 0.019$), FEV_3 ($P = 0.016$), FEF_{25} ($P = 0.016$), $FEF_{0.2-1.2}$ ($P = 0.048$), PEFR ($P = 0.019$) and

MVV (P = 0.001) values. However, none of the lung function test parameters depicted any significant association with smoking status and job profile among the quarry workers (Table 4).

Table 1. Distribution of study subjects according to various characteristics.

	No. (n = 100)
Age Group (in years)	
≤ 20	8
21-30	20
31-40	44
41-50	22
>50	6
Duration of exposure (in years)	
Up to 5	34
5 - 10	36
Above 10	30
Job profile	
Blu-collar workers	56
White-collar workers	44
Smoking Status	
Smoker	52
Non-smoker	48

Table 2. Pulmonary function test according to duration of exposure to silica dust.

	Duration of Exposure (Mean ± SD)			***P* value**
	Group I, Up to 5 years (n = 34)	**Group II, 6 -10 years (n = 36)**	**Group III, Above 10 years (n = 30)**	
FVC (Liters)	3.53 ± 0.78	3.18 ± 0.68	**2.74 ± 0.54**	<0.001
$FEV_{0.5}$ (Liters)	1.47 ± 0.72	1.21 ± 0.63	**0.73 ± 0.46**	<0.001
FEV_1 (Liters)	2.85 ± 0.77	2.54 ± 0.72	**1.89 ± 0.6**	<0.001
FEV_3 (Liters)	3.47 ± 0.79	3.08 ± 0.69	**2.61 ± 0.51**	<0.001
$FEV_{0.5}$/FVC (%)	41.26 ± 18.69	38.3 ± 19.24	**26.33 ± 15.97**	0.004
FEV_1/FVC (%)	79.51 ± 11.36	78.66 ± 16.16	**68.37 ± 17.31**	0.006
FEV_3/FVC (%)	96.89 ± 3.48	95.27 ± 4.06	**93.94 ± 4.69**	0.018
FEF_{25} (Liters/sec)	5.51 ± 2.04	5.02 ± 1.59	**3.69 ± 1.24**	<0.001
FEF_{50} (Liters/sec)	4.33 ± 1.43	4.12 ± 1.8	**2.96 ± 1.13**	0.001
FEF_{75} (Liters/sec)	2.42 ± 0.87	2.2 ± 1.15	**1.75 ± 0.65**	0.018
FEF_{25-75} (Liters/sec)	3.89 ± 1.28	3.57 ± 1.54	**2.67 ± 1**	0.001
$FEF_{0.2-1.2}$ (Liters/sec)	2.87 ± 0.8	2.56 ± 0.82	**2.09 ± 0.58**	<0.001
PEFR (Liters/sec)	5.95 ± 1.92	5.61 ± 1.5	**4.16 ± 1.37**	<0.001
MVV (Liters/min)	96.86 ± 10.07	91.61 ± 10.43	**82.6 ± 15.11**	<0.001

P < 0.05, Statistically significant (ANOVA test).

Table 3. Pulmonary function test according to job profile and smoking status of stone crushers.

	White-collar (*n* = 56)	**Blu-collar (*n* = 44)**	***P* value**	**Smoker (*n* = 52)**	**Non-Smoker (*n* = 48)**	***P* value**
FVC (Liters)	2.84 ± 0.57	3.58 ± 0.73	<0.001	2.93 ± 0.62	3.4 ± 0.79	0.001
$FEV_{0.5}$ (Liters)	1.00 ± 0.66	1.34 ± 0.68	0.014	0.88 ± 0.58	1.42 ± 0.68	<0.001
FEV_1 (Liters)	2.04 ± 0.68	2.98 ± 0.61	<0.001	2.13 ± 0.73	2.77 ± 0.74	<0.001
FEV_3 (Liters)	2.71 ± 0.57	3.53 ± 0.72	<0.001	2.82 ± 0.63	3.32 ± 0.79	0.001
$FEV_{0.5}$/FVC (%)	34.52 ± 20.3	37.23 ± 17.36	0.483	29.84 ± 18.37	41.59 ± 17.96	0.002
FEV_1/FVC (%)	70.57 ± 17.71	82.6 ± 9.27	<0.001	71.17 ± 17.61	80.55 ± 12.05	0.002
FEV_3/FVC (%)	93.83 ± 4.65	97.44 ± 2.40	<0.001	94.29 ± 4.57	96.55 ± 3.51	0.006
FEF_{25} (Liters/sec)	4.03 ± 1.57	5.75 ± 1.66	<0.001	4.31 ± 1.37	5.27 ± 2.08	0.008
FEF_{50} (Liters/sec)	3.03 ± 1.43	4.87 ± 1.14	<0.001	3.46 ± 1.42	4.23 ± 1.68	0.016
FEF_{75} (Liters/sec)	1.74 ± 0.96	2.65 ± 0.68	<0.001	1.96 ± 0.97	2.32 ± 0.93	0.062
FEF_{25-75} (Liters/sec)	2.69 ± 1.29	4.32 ± 0.87	<0.001	3.07 ± 1.26	3.75 ± 1.43	0.013
$FEF_{0.2-1.2}$ (Liters/sec)	2.06 ± 0.65	3.11 ± 0.56	<0.001	2.27 ± 0.76	2.78 ± 0.78	0.002
PEFR (Liters/sec)	4.67 ± 1.67	6.09 ± 1.59	<0.001	4.87 ± 1.42	5.72 ± 1.99	0.016
MVV (Liters/min)	89.11 ± 13.47	92.7 ± 12.54	0.176	85.89 ± 14.63	95.49 ± 9.34	<0.001

P < 0.05, Statistically significant (Independent sample t test).

Table 4. Linear regression analysis of factors affecting lung function test parameters.

	Age		**Body Surface Area**		**Exposure duration**		**Smoker**		**Blu-Collar Worker**	
	Beta	***P***	**Beta**	***P***	**Beta**	***P***	**Beta**	***P***	**Beta**	***P***
FVC (Liters)	0.321	**0.006***	-0.112	0.256	0.270	**0.019***	-0.072	0.447	0.002	0.986
$FEV_{0.5}$ (Liters)	0.216	0.091	-0.173	0.115	0.159	0.208	-0.009	0.930	0.046	0.651
FEV_1 (Liters)	0.369	**0.002***	-0.139	0.166	0.202	0.083	-0.057	0.547	-0.032	0.727
FEV_3 (Liters)	0.311	**0.008***	-0.109	0.272	0.279	**0.016***	-0.060	0.522	-0.006	0.950
$FEV_{0.5}$/FVC (%)	0.141	0.287	-0.155	0.172	0.045	0.730	0.051	0.637	0.024	0.823
FEV_1/FVC (%)	0.254	0.054	-0.128	0.255	-0.025	0.845	0.011	0.917	-0.059	0.572
FEV_3/FVC (%)	0.009	0.948	-0.153	0.176	0.125	0.339	0.066	0.538	-0.013	0.899
FEF_{25} (Liters/sec)	0.195	0.114	-0.063	0.547	0.295	**0.016***	0.017	0.864	0.054	0.577
FEF_{50} (Liters/sec)	0.257	**0.046***	-0.098	0.370	0.116	0.359	-0.006	0.953	0.006	0.957
FEF_{75} (Liters/sec)	0.099	0.456	-0.034	0.763	0.042	0.749	-0.059	0.590	-0.058	0.584
FEF_{25-75} (Liters/sec)	0.232	0.074	-0.073	0.510	0.098	0.442	-0.022	0.832	-0.028	0.787
$FEF_{0.2-1.2}$ (Liters/sec)	0.251	**0.040***	-0.077	0.456	0.239	**0.048***	-0.037	0.710	-0.079	0.413
PEFR (Liters/sec)	0.345	**0.003***	-0.139	0.160	0.271	**0.019***	-0.011	0.905	0.023	0.801
MVV (Liters/min)	0.302	**0.007***	-0.166	0.081	0.388	**0.001***	0.052	0.563	0.030	0.729

* (P < 0.05, statistically significant by Linear Regression analysis).

DISCUSSION

In the present study, we observed a significant reduction in the lung function test parameters associated with the increase in the duration of exposure to silica dust. Also, stone crushers who were tobacco smokers and those who worked as manual workers in crusher plants had a significantly reduced lung function compared to non-smokers and non-manual workers, respectively. However, by applying simple linear regression analysis, we observed that only duration of exposure to silica dust was associated with a significant reduction in pulmonary function among stone crushers.

In our study, a significant progressive reduction in the lung function associated with an increase in the duration of exposure to silica dust is in accordance with findings by Rathod et al [10], who also reported a statistically highly significant ($P < 0.001$) reduction in the FVC, FEV_1, FEV_1%, PEFR, FEF_{25-75} and MVV associated with an increase in the duration of exposure to silica dust. Many previous studies have also reported a progressive decline in pulmonary function test parameters among silica-exposed workers by increasing duration- implies that authors increased the exposure duration [8, 11–17]. In our study, we observed a maximum reduction in lung function volumes among stone crusher subjects with dust exposure of more than 10 years. Indeed, comparison of pulmonary function tests between workers with exposure duration of up to 5 years and 6 to 10 years was statistically non-significant, whereas a comparison of these two groups with above 10 years exposure group was statistically significant. This finding shows that significant changes in the lung function occur after chronic exposure to silica dust. In agreement with our research, Shaik et al. [21] also found a reduction in FVC, FEV_1, FEV_3 and PEFR values related to an increase in duration of exposure, particularly in subjects with an exposure of more than 10 years.

Simple linear regression analysis carried out in our research revealed that besides age, duration of silica dust exposure is an independent determinant of reduced lung function among stone crushers. In a study carried out in Thailand, linear regression analyses revealed a decreased lung function in workers with longer work durations ($P < 0.05$), regardless of age, sex and height [22]. Gupta et al. [18] reported a significant negative association between lung function and both age and duration of work among quarry workers.

The comparison of lung function in stone crushers on the basis of job profile revealed that manual laborers had a reduced lung function compared to that of non-manual workers. These findings are also in accordance with those by Shaik et al. [21], who reported reduced FVC, FEV_1, FEV_3, PEFR and FEV_1% values among workers involved in crushing operations compared to those of workers employed in manual handling of loads. Isara et al. [23] in a study on ventilatory functions among quarry workers in Nigeria also reported significantly lower mean values of FEV_1 and FVC among site workers than among office workers. Differences in the pulmonary function tests among manual workers subgroup compared to the other one might be attributed to the fact that the manual class of workers is exposed directly to a high concentration of dust particles in the air. Indeed, they also spend more time at the crushing site compared to supervisors, drivers and office workers.

We observed a significant reduction in the pulmonary function test parameters among stone crushers who were smokers compared to non-smokers, which is supported by findings of some researchers [8, 11, 24]. However, on simple linear regression analysis, we observed a non-significant effect of smoking on the pulmonary function, which is in contrast to findings by Hertzberg et al. [24], who found a significant reduction in FEV_1, FVC and FEV_1/FVC due to smoking by a linear regression analysis. This might be due to non-inclusion of duration of smoking among smokers and dust concentration estimation in the working environment that could influence lung function in these workers, as well. Further, there are conflicting reports about the effect of smoking on the pulmonary fun-

ction among silica-exposed workers. Gupta et al. [18] reported higher FVC and FEV_1 values, though non-significant, in smoker compared to non-smoker stone quarry workers. Recent evidence suggests that smoking might have a protective effect on pulmonary function in workers exposed to silica dust [19]. Ophir et al. [19] reported a significantly lower decrease in the pulmonary function with increase in the duration of exposure in the smokers group compared to non-smoker group. They also observed a protective effect of smoking on pulmonary function test parameters among the workers diagnosed with silicosis who were also current smokers.

Study limitations

Non-inclusion of factors such as the effect of gender, silica dust concentration in the environment at the working site, and not taking into account the duration of smoking among smokers were some of the limitations of our study. Moreover, radiological assessment of the workers would have helped in better understanding of the lung involvement and effect of silica and smoking on lung function.

Recommendations

Policies framed to control the overall lifetime duration of exposure to silica dust among silica-exposed workers can be a potential intervention to reduce the morbidity and mortality among silica-exposed workers. Regular health surveillance of manual workers exposed to silica dust is important to identify individuals with compromised lung function as they are at higher risk for lung function deterioration in case of chronic silica exposure. Health surveillance should include occupational exposure history, clinical examination, lung function testing and chest radiography, in order to detect abnormalities in the airways at early stages. However, it is essential to pursue a strict monitoring of dust control measures for collective prevention, and provision of occupational health & safety services to these workers.

CONCLUSION

Duration of exposure to silica is the most strong and well-documented predictor of reduced lung function in workers exposed to silica dust. Workers involved in directly handling of silica material and working in close proximity to dust generating sites, such as manual workers are at high risk of lung function deterioration due to exposure to high dust concentrations for a prolonged time period. Although we found a non-significant effect of smoking on lung function of silica-exposed workers after controlling for various factors that could affect it, in literature there are contrasting results about the effect of smoking on lung function of silica-exposed workers.

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