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A Large-Scale Cross-Sectional Study On Respiratory Health, Lung Function Impairment, And Radiological Assessment Of Stone Crushing Workers In Pakistan

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Abstract
Occupational exposure to respirable silica dust generated during stone crushing operations has been associated to the development of silicosis; an irreversible, and untreatable fibrotic lung disease that continues to progress even after cessation of work.Therefore, primary prevention through exposure control is extremely important. In Pakistan, most stone crushing industries operate without any dust control or containment systems. Therefore, the present investigation was carried out to assess the association and extent of silicosis with the inhalation of silica dust among the stone crusher workers in the hub district of Baluchistan which is the biggest province of Pakistan. The cross-sectional study was conducted among the workers of six different stone crushing industries who voluntarily participated in the study. Demographic data included age, gender, service duration, education, smoking and different departments of the industry. Estimation of pulmonary function tests (PFTs) was performed using spirometer. Radiography was carried out in workers with disturbed PFTs to observe the appearance of micro nodules in lungs. Data was analyzed by SPSS ® version 16.0 software. The PFTs were significantly reduced in workers with service duration of 15-20 years. A significantly reduced level of Forced Vital Capacity (FVC) and Vital Capacity (VC) was detected in workers of screening department, while reduced Peak Expiratory Flow (PEF) in loading and decreased Maximal Voluntary Ventilation (MVV) in drilling, crushing and screening divisions of industries was observed. No safety measures were acquired by 68% of the population in industries. The nodule appearance detected by radiography suggested the presence of silicosis in 4.3% of the population of stone crushing workers. Finding of this study suggests a cause-and-effect relationship between dust exposure and disturbed PFTs with lack of awareness and implementation of safety measures by the workers of stone crushing industries in Pakistan.

Keywords: Dust exposure, Nodules, Radiography, Stone crushing workers, Silicosis

Introduction

Silicosis is one of the leading occupational disorders globally [1]. World Health Organization (WHO) fact sheet, no. 238 reported that there are approximately 500,000 cases of silicosis with an incidence of 6,000 new cases per year [2].Itis defined as arespiratory disorder denoted by nodular pulmonary fibrosis and develops due to the inhalation of crystalline silicon dioxide or silica particles into the lungs [3]. It is considered a major health problem throughout the world and has been reported from all the regions, with higher prevalence in low to middle income countries due to poor surveillance and lack of provision of safety measures.The factories and industries working with materials of rocks and stones possess high chances of occupational exposure of aerodynamic diameter of less than 10 μm particles of crystalline silica [4].

It is seen that silicosis develops gradually due to the deposition of tiny respirable crystalline silica quartz particles into the alveoli of lungs which later occupies significant volume[5]. Commonly observed symptoms of silicosis include persistent cough, shortness of breath, loss of appetite, fatigue, fever and chest pain[6].

In industries, stone crushing procedure comprised of various divisions which majorly includes mining operations such as drilling, hauling, blasting, loading and plant processing operations which includesstone crushing, material handling and transportation. They are further processed through primary, secondary, tertiary, and quaternary stagesbeforereachingtheir final form[7].The mechanical breakdown of stones forms dust which contains respirable minute size fine particles of silica. The health of the workers is usually compromised after the prolonged exposure of silica dust particleswithoutstringent implementation of safe acquaintance recommendations in stone crushing departments of these industries [8].

Stone crushing is considered a growing significant industrial sector in Pakistan which provides employment to a huge mass on daily basis [9, 10]. Prolonged exposure of silica particles often increases the susceptibility of silicosisandother occupational disorders in local workers [11]. The major contributing factors are high rate of illiteracy and insufficient training practices which leads to develop pathologies such as breathing congestion injuries, noise respiratory dysfunction, eye irritation, hearing loss, carcinoma, skin allergy, chest tightness and silicosis [12]. It is estimated that there are approximately eight hundred stone crushing plants currently active in all over the Pakistan [13]. However, the mortality rate of silicosis is only 28in 10,000 population for the highest exposurereported by pooled cohort studyannually[14].
The Hub is a vast industrial district ofPakistan. It is localized in the region of Baluchistan province which is in proximity of metropolitan cityKarachi, Pakistan.The industries in Hub district accommodate several stone crushing plants to overcome the need ofmining and construction industries.In Pakistan, as studies related to silicosis is very rare and localized [15], therefore, aim of this study was to investigate the rate of exposure, its effect on lungs capacity and correlation with silicosis disorder in the workers of six major stone crushing Hub industriesof Pakistan.In the previous cross-sectional studies conducted in Faisalabad [15] and Peshawar [16] city of Pakistan, frequency of silicosis was calculatedin 80 and 204 workers respectively. This cross-sectional study was conducted among 502 stone crushing workers to assess the pulmonary function and occurrence of silicosis. The research findings will have important implications for the development of further prevention strategies to protect mine workers from silicosis in Pakistan.

Experiment

Study design and locations

Thiscross-sectional epidemiological study was performed at Hub district, Pakistan.Total six stone crushing industries were selected namelyKhan crushing stone plants, Sehar stone crushing plant, Azam crushing stone plant, Rohri stone crushing plan, Karam ceramics and Madina crushing plant. These industries majorly carry out operations in two departments:quarrying and mining. Quarrying includes crushing, conveying, screening, handling and transfer operations, while mining includes blasting, loading, drilling, and hauling processing.

Ethical approval and data collection

The study was ethically approved from the Institutional Ethical Committee ofFaculty of Pharmacy, Federal Urdu University for Arts Science and Technology, Karachi, Pakistan(Ethical approval no. 063-A dated 11-02-22).Study population consisted of 502 workers and demographic data collected in questionnaireform included age, gender, sign andsymptoms of silicosis and the service duration at targeted study sites.All the procedures and data were kept confidential andfollowed the ethical standardsof the Helsinki Declaration.

Estimation of pulmonary function tests (PFTs)

Lungs working capability was checked by Vitalograph Portable Digital Spirometer (Model # SN AL 24516/6000/ALPHA Ireland). The instrument comprised of a pump and display screen which was ISO certified for the measurement of PFTs. All the datawasdocumented during peak time of the day (10am – 14:00pm). The instrument was originally calibrated by biomedical instrument technology limited and a certification for calibration was also taken as a part of their yearly services. Spirometer calibration was also made on daily basis during the study period before the operation and the temperature of 20-25^{o}C was maintained for optimum efficacy. The standard protocol was followed for recording the PFT readings in accordance with manual guideline of spirometer with the reference to American Thoracic Society of Standardization of Spirometry. Readings were observed in three replicates and the mean was used for statistical analysis. Four parameters of PFTs were recorded in all the study subjects which included force vital capacity (FVC), peak expiratory flow (PEF), maximum voluntary ventilation (MVV) and vital capacity (VC).

Radiography imaging

The decline in PFTs suggested pulmonary pathological disturbance which was validated by pulmonary radiography to check the appearance of micronodules for the evaluation of silicosis risk. Digital radiography was performed by portable x-ray machine (Fujifilm FDR XairPortable Radiology). The analyzed reports wereobtained from the laboratory of Hamdard Shifa-Ul-Mulk Hospital, Gadap Town, Karachi, Sindh, Pakistan.

Statistical analysis

The data was statistically analyzed using software IBM SPSS ® version 16.0. Mean and standard deviation were used in descriptive analysis for continuous variables. While absolute and relative distribution of frequencies were estimated for the analysis of categorical variables. The univariate analysis was conducted for demographicfactorswhich included age groups, gender, service duration, education, smoking history, and departments by descriptive statistics. PFT parameters were categorized into six categories from normal to reduced. The variations in PFTs with various demographic trends were analyzed by bivariate analysis.The Kolmogorov-Smirnov test and Mann-Whitney U tests were used to assess the normal distributionof continuous and categorical variables. Bar graph was used to depict the frequency of workers wearingprotective measures during the work timings.

Results and discission

Demographic analysis

The demographic trends in studied population of stone crushing workers are shown in Table 1. Among them, males (98.8%) were predominant in comparison to females (1.2%). The age was divided into nine groups of workers. The highest number of individualsbelonged to the age group of 26-30 years (24.3%). Maximum service duration was 5-10 years spent by 40.6% individuals. Among all the workers, 25.7%of workers acquired schooling till primary level, 16.7% till secondary level, and only 19.3% were university graduate. While 38.3% of the workers were illiterate with no schooling. The education levels were only evaluated to pursue the understanding of workers for the usage of personal protective equipment (PPE) during exposure. Smoking history showed that 65.9% workers were non-smokers, 23.5% were regular smokers and 10.6% were ex-smokers. Stone crushing industries under study, broadly comprised of total seven departments. The frequency of individuals serving in crushing departments was 28.0% with highest risk of dust exposure, followed by 18% in screening, 16% in loading, 12% in hauling, 10% in drilling and 8.1% belonged to security and office staff.

Pulmonary function tests (PFTs) analysis

The lung volume, capacity, rate of flowand gas exchange were measured which wasgroupedinto six categories showed in Table 2. Among total population (n=502), highest frequency of workers fell in the category of normal rangefor all four measures, including forced vital capacity (FVC), peak expiratory flow (PEF), maximum voluntary volume (MVV) and vital capacity (VC) levels which was found to be mildly reduced in 13.1%, 21.5%, 12.2% and 9.6% workers respectively.

Association of demographic trends with PFTs

The pulmonary function tests (PFTs) were analyzed with demographic factors among the workers of stone crushing mills described in Table 3. Higher levels of FVC was observed in 20-25 years, PEF and MVV in 46-55 years, and VC in 61-65 years of age groups. Moreover, reduced FVC and PEF levels were recorded after the service duration of 32 years, Therefore, it is suggested that increasing duration compromised the FVC and PEF levels. No significant difference was observed in trends of education levels and smoking history. Among various departments, a significantly reduced level of FVC and VC was detected in screening, PEF in loading, and MVV in drilling, crushing and screening divisions of workers. Data revealed that drilling, crushing, loading and screening are the prone departments for the exposure of silicon dust which thereby affected the PFTs levels of their workers.

Association of silicosis symptoms with PFTs

The PFT parameters were also analyzed,and the symptoms associated with silicosis disorder in stone crushing workers arerepresented in Table 4. Among seven signs and symptoms, high FVC value was detected in workers with fever (91.05). Furthermore, high PEF was associated with fatigue (78.07), MVVwith dyspnea and VCwas observed with cough and loss of appetite symptoms respectively. Despite standard deviations in PFT levels, no significant difference was observed in all four parameters observed among various signs and symptoms of silicosis.

Frequency of safety measures

The use of personal protective equipment (PPE) among the studied population of workers is illustrated in Fig. 1. Among all, 13% of subjects used dust mask, 7% used helmets, 4% wore boots and googles, 3% used ear plugs for voice reduction, and only 1% wore dust coats. However, the remaining 68% workersdid not adopt any safety measures during the work which could increase their chances of high dust exposure and the pathogenesis of silicosis and associated lung disorders.

Radiography of lungs

The formation of micronodules and fibrosis in radiography of stone crushing workers who showed abnormal PFT levels is illustrated in Fig. 2. Alveolar macrophages ingest tiny silica particles which dissociate and release enzyme that led to generate fibrogenic response in lungs suggesting the presence of silicosis. Four X-ray images showed the nodule formation in workers with service duration of 10-20 years. Small, rounded opacities shown in radiography ranged from 1 to 10 mm in size. These opacities hada glassy appearance and approximately 20% were centrally calcified. It was also observed that the large opacities were developedfrom the conglomerations of small opacities which occurred due to the enlargement of lymph nodes. The micronodules formation in lungs of patients having disturbed PFTs level suggested the development of silicosis evident by x-ray imaging. Primarily, large service duration, high amount of illiteracy, lack of awareness,not using safety procedures, smoking habits in people with late ages are considered as the contributing factors in the development of silicosis (Table 1). Various symptoms of silicosis were observed which includes fever, fatigue, cough, dyspnea, chest pain, gastro dysfunction, and loss of appetite. Among them, disturbed levels of PFTs were detected in subjects with fever, fatigue, dyspnea and cough (Table 4) as reported in previous studies [17].

Our study revealed 4.3% prevalence of silicosis among the stone crushing workers of six industries in Pakistan. Contrastingly, it is lower than the 8.9% prevalence reported by a recent cross-sectional study conductedin Hamadan province of Iran [18], 18-19% prevalence of silicosis in workers of gold mining plants in South Africa [19] and 17.9% prevalence estimated in ex-workers of quartz crushing units in Gujrat India. From this study, it is also predicted that silicosis is a progressive disorder even despite the cessation of dust exposure [20]. Association of PFT parameters with demographics of studied population showed significant reduction of FVC and PEF levels with the service duration greater than 32 years as compared to less than 5 years ($p<0.01$). Results indicated gradual progression of lung pathologies as an impact of dust exposure with increasing service duration (Table 3) [21-24]. The reduced PFTs indicated the formation of silicosis in lungs, which was verified by the presence of micronodules in chest x-ray of the stone crushing workers in Pakistan (Fig

2).Clinicalsymptoms of silicosis werealso diagnosed by the formation of lesions in asymptomatic patients using chest x-ray [25]. Nodular formations in pulmonary region suggested the late features of silicosis that could be detected earlier by active health screening of the workers.

Table 1. Demographic trends in stone crushing workers

Characteristics	Workers	Frequency
Gender		
Males	n=496	98.8%
Females	n=6	1.2%
Age Groups		
20-25	n=56	11.2%
26-30	n=122	24.3%
31-35	n=115	22.9%
36-40	n=79	15.7%
41-45	n=58	11.5%
46-50	n=41	8.2%
51-55	n=14	2.8%
56-60	n=16	3.2%
61-65	n=1	0.2%
Service Duration		
< 5 years	n=105	20.9%
5-10 years	n=204	40.6%
10-15 years	n=125	24.9%
15-20 years	n=67	13.4%
32 years	n=1	0.2%
Education		
Illiterate	n=192	38.3%
Primary	n=129	25.7%
Secondary	n=84	16.7%
Graduates	n=97	19.3%
Smoking History		
Regular smokers	n=118	23.5%
Ex-smokers	n=53	10.6%
Non smokers	n=331	65.9%
Departments		
Office Staff	n=40	8.1%
Security Guard	n=40	8.1%
Loading	n=80	16.0%
Hauling	n=60	12.0%
Drilling	n=50	10.0%
Crushing	n=142	28.0%
Screening	n=90	18.0%
Total	n=502	100%

includes fever, fatigue, cough, dyspnea, chest pain, gastro dysfunction, and loss of appetite. Among them, disturbed levels of PFTs were detected in subjects with fever, fatigue, dyspnea and cough (Table 4) as reported in previous studies [17].

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Use of personal protective equipment (PPE) plays a crucial role in the aspect ofavoidinghigh dust exposure. Data suggested that 68% workers did not acquire any safety measures during the work which put them on high risk for the pathogenesis of silicosis and other hazardous health disorders in Pakistan (Fig 1). Similar to our data, research in Spain revealed that only 32.6% workers reported to wore PPE including gloves, helmet, footwear and glasses in artificial stone workers [26].AnAustralian study reported that only a limited frequency of workers had access to PPE during work [27].Both cases of unavailability of PPE or avoiding their use ultimately enhanced the risk of developing silicosis [28].

Major strength of this research was relatively higher number of subjects participated from six large stone crushing industries of Pakistan with respect to other similar studies from different populations to date. However, being a cross-sectional study, it lacks the follow-up of workers and routine analysis of their health and safety measures for a certain period of timecontributed as a limitation of this study.

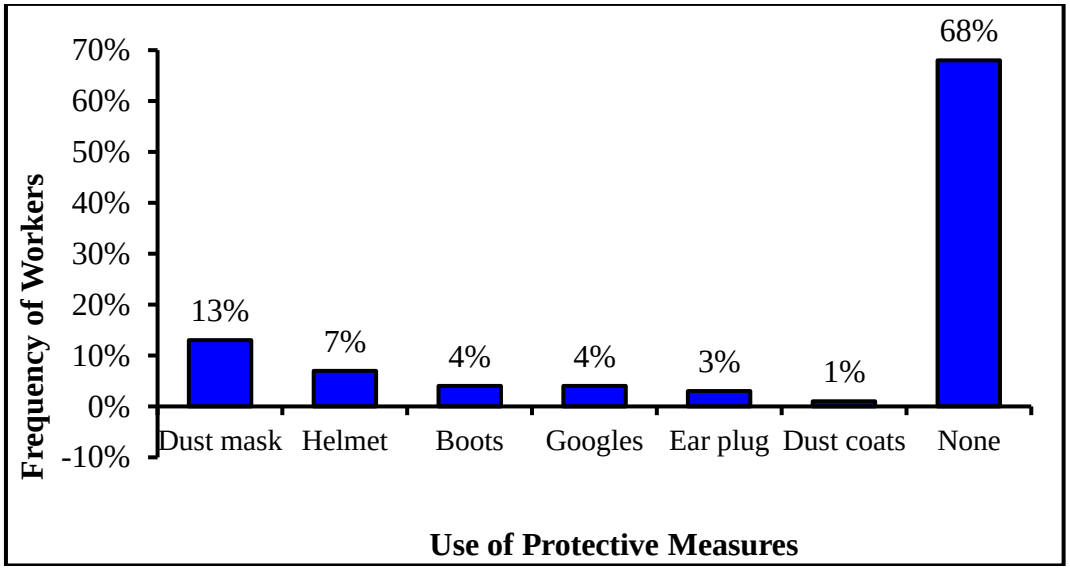

Fig. 1Use of protective measures in workers ofstone crushing industries

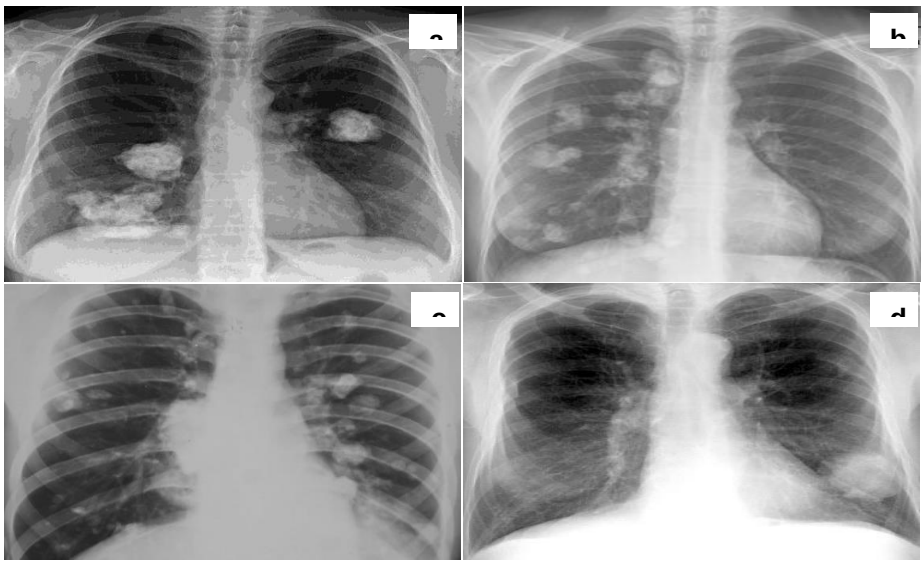

Fig. 2Multiple bilateral pulmonary calcified micronodules are evident in radiography images. Predominantly in lower left lobe (a), superior to inferior left lobe (b), lower right lobe (c) and right posterior zone (d). Conglomerate soft-tissue densities in both lobes (a). The tendency towards coalescence of the nodules is also seen in pulmonary superior left lobe (d)

Table 2. Categories of pulmonary function test (PFT) levels among stone crushing workers

Categories	FVC n (%)	PEF n (%)	MVV n (%)	VC n (%)
Normal	375 (74.7%)	167 (33.3%)	375 (74.7%)	395 (78.7%)
Elevated	2 (0.4%)	9 (1.8%)	6 (1.2%)	2 (0.4%)
Mildly Reduced	66 (13.1%)	108 (21.5%)	61 (12.2%)	48 (9.6%)
Moderately Reduced	34 (6.8%)	2 (0.4%)	37 (7.4%)	23 (4.6%)
Severely Reduced	3 (0.6%)	141 (27.3%)	6 (0.4%)	5 (0.2%)
Reduced	3 (0.6%)	75 (12.9%)	14 (0.8%)	29 (3.8%)

Forced Vital capacity (FVC); Peak Expiratory Flow (PEF); Maximum Voluntary Volume (MVV); Vital Capacity (VC)

Table 3.Association of PFTs parameters with demographics in stone crushing workers

Parameters	FVC	PEF	MVV	VC
Age Groups				
20-25	80.35 ± 1.1	81.05 ± 1.2	32.05 ± 1.3	87.08 ± 3.7
26-30	75.77 ± 2.4	81.92 ± 1.4	81.92 ± 1.4	82.62 ± 2.1
31-35	74.58 ± 2.9	79.58 ± 1.3	79.58 ± 1.3	80.42 ± 2.0
36-40	61.76 ± 2.8	80.81 ± 1.6	80.81 ± 1.6	82.32 ± 1.6
41-45	63.98 ± 2.5	77.71 ± 1.5	77.71 ± 1.6	78.29 ± 1.7
46-50	60.39 ± 2.1	83.21 ± 1.5	83.21 ± 1.5	77.42 ± 2.1
51-55	60.50 ± 1.8	83.03 ± 1.6	83.01 ± 1.6	85.55 ± 7.0
56-60	58.00 ± 2.5	79.45 ± 2.0	79.45 ± 2.0	82.90 ± 1.7
61-65	65.90 ± 0.0	79.70 ± 0.0	79.70 ± 0.0	90.30 ± 0.0
Service Duration				
< 5 years	85.4 ± 21.8	61.9 ± 27.6	75.56 ± 18.9	80.10 ± 18.4
5-10 years	80.92 ± 22.2	64.4 ± 27.1	81.97 ± 13.2	78.90 ±19.1
10-15 years	82.09 ± 17.6	60.33 ± 26.5	77.88 ± 16.6	77.42 ±18.9
15-20 years	78.18 ± 18.9	60.94 ± 25.1	83.00 ± 17.3	82.75 ± 16.6
32 years	72.80 ± 0.0	38.50 ± 0.0	75.80 ± 0.0	74.80 ± 0.0
Education				
Illiterate	81.67 ± 1.5	62.74 ± 2.6	82.46 ± 1.3	79.54 ± 1.7
Primary	80.35 ± 1.8	62.50 ± 2.5	81.80 ± 1.4	79.74 ± 1.9
Secondary	83.08 ± 1.7	64.47 ± 1.4	79.36 ± 1.6	81.12 ± 1.6
Graduates	83.07 ± 1.0	79.49 ± 0.7	84.48 ± 1.0	86.79 ± 1.6
Smoking History				
Regular smokers	80.39 ± 1.7	63.27 ± 2.7	79.71 ± 1.6	77.18 ± 2.3
Ex-smokers	79.17 ± 2.3	58.92 ± 2.6	79.82 ± 1.6	75.88 ± 2.0
Non smokers	82.51 ± 2.1	62.57 ± 2.6	79.94 ± 1.5	80.63 ± 1.6
Departments				
Office Staff	83.18 ± 1.1	88.99 ± 3.1	84.57 ± 1.5	84.96 ± 1.1
Security Guard	82.60 ± 1.8	60.78 ± 2.7	82.16 ± 1.1	89.61 ± 7.4
Loading	86.33 ± 7.9	58.54 ± 2.3	82.16 ± 1.3	87.08 ± 6.8
Hauling	84.69 ± 1.0	62.89 ± 3.0	82.62 ± 1.4	83.62 ± 1.4
Drilling	85.44 ± 8.6	60.63 ± 2.6	81.25 ± 1.3	82.21 ± 1.4
Crushing	73.49 ± 2.4	62.18 ± 2.4	81.83 ± 1.5	73.09 ± 2.4

Screening	72.46 ± 1.7	69.06 ± 2.3	81.66 ± 1.3	72.85 ± 2.1
Total	81.80 ± 2.1	62.36 ± 2.6	78.67 ± 1.7	78.65 ± 1.9

Table 4.Association of pulmonary function test (PFTs) with signs and symptoms of silicosis.

Types	Frequency	FVC	PEF	MVV	VC
No symptoms	n=187 (37.2%)	80.84 ± 13.2	78.70 ± 18.2	81.28 ± 27.2	85.70 ± 18.2
Cough	n=43 (8.6%)	81.84 ± 28.8	70.85 ± 13.9	59.93 ± 25.5	83.85 ± 13.9
Dyspnea	n=99 (19.7%)	81.20 ± 15.7	77.87 ± 20.6	63.51 ± 28.0	77.87 ± 20.6
Fatigue	n=90 (17.9%)	82.25 ± 15.82	78.07 ± 21.5	60.95 ± 25.6	78.07 ± 21.5
Fever	n=14 (2.8%)	91.05 ± 5.72	72.62 ± 16.5	59.21 ± 22.4	82.62 ± 16.5
Chest pain	n=22 (4.4%)	82.51 ± 18.8	73.64 ± 26.3	61.60 ± 27.9	73.64 ± 26.3
Loss-of-appetite	n=17 (3.4%)	85.16 ± 11.1	71.20 ± 16.2	51.81 ± 23.9	83.20 ± 16.2
Gastro dysfunction	n=30 (6%)	81.82 ± 15.1	75.33 ± 17.2	71.24 ± 27.5	75.33 ± 17.4

Conclusions

This study concluded 4.3% prevalence of silicosis in stone crushing workers of six industries in Pakistan. It also revealed itscorrelation with later age groups, higher service duration, illiteracy, and exposure of workers in crushing and screening departments. Radiography of n=22 workers confirmed the presence of micronodules in lungs from various departments of stone crushing industries. The formation of micro nodules is attributed to the degree of silica dust exposure. Symptoms of silicosis are ignored by the workers as they consider them as a part of their daily job. Interestingly, this study also highlighted the fact that 68% of workers did not perform work with safety measures.Proper surveillance, strict acquisition of safety measures and development of further prevention strategiesare needed for protecting the health of local workers in these stone crushing industries. The Ministry should frame and implement strict policies and practices for industrialists to makethe working environment safefor the workers. Awareness programs should be conductedas much as possible for industrial workers about the use of precautionary measures thatkeep them safe from exposure to silica dust. Civil society and media should promote and take part in spreading awareness among the public about silicosis and its negative health effects.

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Conflict of Interest

None to declare

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