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Risk assessment of workers exposed to respirable crystalline silica in silica crushing units in Azandarian industrial zone, Hamadan, Iran

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ABSTRACT

Introduction: Azandarian industrial zone with about 40 active silica crushing units is one of the largest industrial area in Hamadan province, Iran.
Materials and methods: In this study, the personal exposure of workers in the activated silica crushing units was measured. Assessing the risk of mortality due to exposure to Respirable Crystalline Silica (RCS) in the workplace was then estimated through measuring the personnel exposure in accordance with the National Institute for Occupational Safety and Health (NIOSH) 7601 method. Moreover, the mortality rate of lung cancer and risk of mortality due to exposure to RCS were estimated.
Results: Based on the results, the average exposure of employees to RCS in the crushing units was in the range of 1.70 -0.14 mg/m^3. As observed, the lowest and highest exposure was obtained for the admission unit and sandstone, respectively. In general, it can be inferred that in all studied occupation positions, the exposure level was higher than the recommended standard (0.25 mg/m^3). As can be seen, the carcinogenic risk level for the exposed workers was in the range 2-26/1000. The results of risk assessment showed that the highest risk level was related to the stamping machine operator unit and the lowest was related to the administrative unit.
Conclusion: Therefore, the workers working in high-risk units such as stamping machine operator and stone separation operator are more likely to suffer from adverse health complications such as silicosis, lung cancer and other respiratory complications.

Introduction

Silicosis as an occupational respiratory disease is generally caused by inhalation of Respirable Crystalline Silica (RCS) that triggers a fibrotic response in the lung parenchyma [1]. According to the experimental evidence, the toxicity of RCS varies based on its polymorphic forms. In this regard, among different forms of crystalline silica, cristobalite, tridymite and quartz are more reactive and hence pose more cytotoxic effects compared to coesite and stishovite. Based on

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the evidence obtained in animal models and epidemiological studies, there are sufficient evidence, indicating that occupational exposure to RCS can cause cancer in humans [2]. According to the World Health Organization (WHO) report, environmental exposures to RCS can also occur during natural, industrial, and agricultural activities. Mining, stone cutting, employment in abrasive industries such as cement, glass, pottery and stone factories, foundry, silica powder packaging and stone extraction industries, especially granite, are among the industries with high exposure to RCS. Chronic occupational exposure to high levels of RCS dust may have carcinogenic effects [3], and silica has been classified as a carcinogen by the International Agency for Research on Cancer (IARC) [4]. It has been estimated that 3.2 million workers are exposed to RCS in the European Union. The National Institute for Occupational Safety and Health (NIOSH) and American Conference of Government Industrial Hygienist (ACGIH) have recommended an exposure limit of 0.05 mg/m^3 as RCS for all crystalline forms of silica [5].

Synthetic amorphous silica mainly contains measurable levels of RCS and exposure to them causes adverse health effects such as silicosis. The synthetic amorphous silica is widely used in various industrial fields and in chemical and biomedical products such as toner printers, varnishes, cancer treatment, DNA delivery and enzyme immobilization [6]. The widespread industrial applications of silica has raised concerns about the toxicity of silica crystalline particles. Although silica-related diseases are preventable, they still remain a common health problem, especially in developing countries. Different types of clinical and pathological silicosis include acute, progressive, chronic, and conglomerate silicosis (advanced progressive silicosis or complex silicosis). The progression of different types of silicosis depends on the exposure duration and exposure concentration of silica particles [7]. Inhalation of RCS in occupational exposures can also cause pulmonary fibrosis, pulmonary dysfunction, pneumonia, lung cancer, glomerulonephritis, liver disorders, spleen and immune system disorders [8].

In recent decades, a number of environmental and occupational toxins have been identified as causative agents of systemic sclerosis, such as exposure to silica. Several clinical-epidemiological observations have shown that inhalation of silica-containing dust under genetically predisposed conditions may cause various autoimmune disorders, including systemic sclerosis [9]. Studies have also shown that silica nanoparticles increase the concentration of reactive oxygen species, which leads to mitochondrial depolarization, reduced glutathione levels, and inflammation [10]. Smokers are at higher risk because smoking and exposure to RCS have a synergistic effect on chronic obstructive pulmonary disease [11]. In addition, chronic exposure to RCS is associated with other lung diseases such as tuberculosis and lung cancer [12].

Azandarian has been located in Malayer city, Hamadan province, Iran. Azandarain industrial zone as one of the largest industrial clusters in Hamadan province, has about 40 active stone-cutter and silica powder production units. In recent years, with the expansion of the number of silicosis units and the increase in the production of silica for various purposes, the prevalence of silicosis has raised among employees working in this area. Until now, there has been no reliable view available regarding the population exposed to silica inhalation in this industrial zone.

Therefore, the present study aimed at evaluating occupational exposure to RCS among workers of silica stone crushing units in Azandarian Industrial Zone, Hamadan, Iran. Moreover, the relative risk of silicosis mortality and the excess lifetime risk of mortality from lung cancer were also investigated.

Materials and methods

Study sites

Azandarian is a city in Jowkar District, located in Malayer city, Hamadan province, Iran. Azandarian industrial zone as one of the largest industrial clusters in Hamadan province, has about 40 active silica stone crushing units. In this study, the personal exposure of the workers in active silica stone crushing units was measured. The inclusion criteria included having at least one year of continuous work experience in a stone-cutter and silica powder production units and willingness to cooperate. The exclusion criteria were having a history of lung diseases and smoking.

Sampling and analysis

In this regard, a demographic questionnaire was used for collecting and recoding the workers information including age and work experience in the unit exposed to crystalline silica. In order to investigate the level of exposure of the workers, the standard method recommended by the NIOSH (7602) was used [13]. For this purpose, briefly, personal sampling devices including an average-flow personal sampling pump with a flow rate of 1.7 L/min (Gilian- LFS 113DC) along with PVC filter (37-mm, 5-µm) were applied, which have been previously calibrated using a digital calibrator. Before sampling, the PVC filters were placed in a desiccator for 24 h to determine the dry weight of the used filter. Finally, the sampling cyclone containing the PVC filter attached to a personal sampling pump was used in the air breathing zone of the workers. After sampling, the filters were transferred to the laboratory and then prepared for further analysis. In this regard, the PVC filters were placed in a crucible and then heated in an oven at 800 °C. The heated sample was then converted to ashes. In order to prepare the samples for FTIR analysis, a tablet press machine were used to convent the powder ash into a tablet. For this reason, the resulting ash powder obtained from the previous step was mixed in certain amounts with the potassium bromide (KBr) powder. Next, the mixture consisted of ash powder and KBr were converted into tablet using the tablet press machine. The resulting tablets were analyzed using a Fourier Transform Infrared Spectroscope (FTIR, Elmer Perkin/Tow Spectrum device). According to the NIOSH 7602 method, the peak area response of silica was appeared in the wavelength of 800 nm. Therefore, the samples were analyzed in terms of the presence of RCS and its concentration level [14]. In this study, the mortality rate of lung cancer was estimated based on the Rice model [15], which is a linear model and is estimated based on the geometric mean of exposure to silica. The mortality rate of lung cancer was calculated in accordance with the following equation (Eq. 1):

$$A=0.77+373.69\times GM \quad (1)$$

Where, GM is geometric mean and A indicates the mortality rate of lung cancer caused by silicosis. Descriptive statistical tests were used to calculate mean and standard arithmetic and geometric deviation of exposure in various sections of the industry. It is noteworthy that it was not possible to calculate the geometric mean of the real data due to the presence of some workers with non-detectable silica exposure in the studied cases. In this regard, a small value under the limit of the detection of the measuring method was selected instead of zero values (not detected).

In the present study, a previously described model was used to assess the risk of mortality due to exposure to RCS released into the workplace air of Azandrian workshops [16]. For this purpose, first, the personal exposure of the workers was measured in accordance with the standard method NIOSH 7601, and then based on the model defined in previous studies, the risk of death due to silicosis and lung cancer was calculated. This model is based on the cumulative exposure of RCS ranging between 0-99-0 mg/m^3/y. The two main parameters in this model are exposure time and silica concentration that are expressed in mg/m^3 [17].

Results and discussion

Exposure to RCS in different job positions

In this step, we tried to compare the personal exposure of the workers in different job positions of stone-cutter and silica crushing units in Azandarian industrial zone, Hamadan, Iran. As can be seen in Table 1, there are four types of job positions in the stone-cutter of the studied units and all of the units were equipped with bag house ventilation systems and local ventilation system. Table 2 presents the average occupational exposure to RCS dust by the occupational groups.

Table 1. Exposure of workers to RCS in various job positions in silica crushing units in Azandarian industrial zone, Hamadan, Iran

Occupations /Positions	RCS concentration (mg/m^3) Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
Stamping machine operator	5.87±1.8	3.2±2.42	0.82±0.21	1.7±0.99	0.6±0.22	ND*	0.77±0.14	1.2±0.95	1.4±0.67	1.5±1.1
Loader driver	0.2±0.12	0.38±0.32	0.25±0.19	1.11±0.52	ND	0.01±0.02	0.95±0.43	0.01±0.03	1.02±0.79	1.8±0.98
Service	0.72±0.25	0.35±0.18	0.4±0.35	1.18±0.87	1.55±0.15	0.12±0.02	1.8±0.79	0.01±0.02	0.77±0.45	0.46±0.28
Stone separation operator	0.32±0.14	2.37±0.88	0.32±0.23	1.7±1.2	1.2±0.34	ND	3.45±1.9	0.34±0.32	1.05±0.69	4.34±2.8
Administrative unit	-	-	0.12±0.17	-	-	-	-	0.45±0.26	-	0.28±0.55

*ND=Not Detected

Table 2. Average occupational exposure to RCS dust by occupational groups

Occupations/Positions	RCS concentration (mg/m^3) Number of units	Mean ± SD	GM (mg/m^3)	Range
Stamping Machine Operator	10	1.706 ± 1.69	0.705358 ± 5.42	(ND) 0.6-5.87
Loader Driver	10	0.573 ± 0.612	0.143406 ± 1.84	(ND) 0.01-1.8
Service	10	0.73 ± 0.599	0.412038 ± 1.82	0.01 -1.8
Stone separation operator	10	1.50 ± 1.46	0.552415 ± 4.33	(ND) 0.32-4.34
Administrative unit	3	0.14 ± 0.165	0.705358 ± 1.17	(ND) 0.12-0.45
Total		0.95 ± 0.65	1.81	

GM: geometric mean, ND: means not detected (from not detected to the mentioned range)

This study evaluated the level of occupational exposure to RCS among workers of silica stone crushing units in Azandarian industrial zone, Hamadan, Iran. The personal occupational exposure to RCS was measured in various job positions in the stone-cutter and silica crushing units. Based on the job duties in these units, the job potions can be classified into five potions, including stamping machine operator, loader driver, service, stone separation operator and administrator. According to the results, the average exposure of the workers to RCS was in the range of 0.14-1.70 mg/m^3. As observed, the lowest and highest exposure was obtained for the admission unit and sandstone, respectively. In general, it can be concluded that in all studied occupation positions, the silica exposure level was higher than the recommended standard. Therefore, it is necessary to reduce the workers' exposure to RCS dust during activities on different sites through control measures. In a previous study, the total geometric mean of exposure silica dust for workers in various units was reported to be 1.81 mg/m^3, which is higher than mean values obtained in our study [18].

In the present study, the mortality rate caused by silicosis was predicted and estimated based on the Mannetje model and classification of exposures in the range of 6-63/1000 workers. The workplace exposure standard for RCS (silica dust) that must not be exceeded 0.05 mg/m^3 (8 h time weighted average: an 8 h Time-Weighted Average (TWA)). The National Occupational Health and Safety Commission (NOHSC-now Safe Work Australia) has revised the exposure standards for the three forms of crystalline silica, quartz, cristobalite and tridymite. The revised national exposure standards for the three forms are 0.1 mg/m^3 (time weighted average, 8 h). This is half the previous standard value, which was 0.2 mg/m^3. According to the last update, the current Australian standard is now 0.05 mg/m^3, which has now been adopted in most jurisdictions, including Victoria. In fact, Work Safe Victoria is very much in line with the Victorian Trades Hall Council (VTHC) exposure standard in that it "recommends that employers take a precautionary approach and reduce employees' exposure to below 0.02 mg/m^3 as an 8-h TWA to prevent silicosis and minimize the risk of lung cancer. The NIOSH and ACGIH have recommended an exposure limit of 0.05 mg/m^3 as RCS for all crystalline forms of silica [5]. According to Table 4, in this study the relative risk of death due to silicosis based on Mannetije model was estimated to be in the range 2-264/1000 workers, also the risk of death from lung cancer due to exposure to free crystalline silica, for 45 years workers based on the Rice model was determined to be 0.95 mg/m^3, per 1000 workers. Our result compared to Chinese workers exposure to RCS (5.4 mg/m^3) was lower [19]. In a related study reporting the risk of silicosis mortality of workers with cumulative exposure were in the range 0-0.99 mg/m^3/y, a lifetime risk of silicosis in construction workers was > 5% [17]. Another study suggested the risk of mortality in relation to silicosis in workers working in the building and demolition sites to be in the range 3-25/1,000 workers [20]. Finding obtained from a related study showed lifetime risk of mortality from lung cancer in California diatomaceous earth mining workers exposed to silica dust for 45 years was 19/1,000 workers [21]. The lifetime risk of mortality from lung cancer in Vermont granite workers exposed to RCS for 45 years exposure with RCS from age 20 years to 64 years was 27/1000 exposed workers [22]. Table 3 represents the risk assessment of occupational exposure to RCS based on cumulative exposure.

Table 3. Risk assessment of occupational exposure to RCS based on cumulative exposure (mg/m^3-year)

Cumulative exposure to Crystalline	Person years (xl 00000	Number of workers (%)
0-0.99	1	22 (44%)
0.99-1.97	3.4	13 (26%)
1.97-2.87	6.2	1 (2%)
2.87-4.33	9.4	2 (4%)
4.33-7.12	13.7	3 (6%)
7.12-9.58	22.6	0 (0%)
9.58-13.21	24.0	0 (0%)
13.21-15.89	40.2	0 (0%)
15.89-28.10	52.1	0 (0%)
>28.1	63.6	0 (0%)

Table 4. Risk of lung cancer mortality per one thousand exposed workers

Occupations/Positions	Geometric mean of exposure (mg/m^3)	Estimated excess lifetime risks of mortality from lung cancer based on the model presented by Rice et al
Stamping machine operator	0.705358 ± 5.42	264
Loader driver	0.143406 ± 1.84	54
Service	0.705358 ± 5.42	154
Stone separation operator	0.143406 ± 1.84	207
Administrative unit	0.705358 ± 5.42	2

Table 4 represents the risk of lung cancer mortality per one thousand exposed workers. As can be seen, this risk for the exposed population was in the range 2-264/1000 workers.

The results of risk assessment showed that the highest risk of mortality from lung cancer caused by silica exposure was related to the stamping machine operator unit and the lowest one was related to the administrative unit. High risk indicates a higher probability of mortality from lung cancer based on the proposed model [15].

Therefore, people working in the high-risk units, like stamping machine operator and stone separation operator, are more likely to experience various diseases such as silicosis, lung cancer and other respiratory complications [23]. Consistent with our study, in a similar study, it was reported that 79% of workers had unacceptable level of risk of silicosis related-mortality in workers [20]. In another study, it was found that workers did not use proper personal protective equipment such as respiratory protection devices and hence are at a high risk of lung cancer. Although smoking and exposure to RCS has synergistic effects for increasing the mortality risk of lung cancer [17, 18]. According to previous studies, the exposure with RCS in various contaminated industries in addition to lung cancer can increase risk of autoimmune disorders such as rheumatoid arthritis (RA) and cardiovascular disease. So that in our previous studies, it was found that there were a significant association between occupational exposure to RCS and risk of developing RA (OR =2.59, 95% CI=1.73 to 3.45) and cardiovascular disease mortality (SMR: 1.26; 95% CI: 0.88-1.63) among different workers [8, 24].

According to the findings of this study, due to the high level of exposure in the stone crushing units, re-design, optimization and optimal maintenance of general and local ventilation systems, the use of up-to-date equipment and technology for decreasing the concentration of RCS in the workplaces, implementation of respiratory protection programs, training and inspections periodic and annual medicine are necessary for early diagnosis of the disease, periodic evaluation of exposure and quantification of the risk level to monitor the process of exposure and the effectiveness of the control system [25-27]. A limitation of this study is attributed to the relatively small number of samples and the effect of some other factors such as smoking, age and duration of exposure to crystalline silica. Therefore, it is recommended that further research must be undertaken in different work units with a large sample size and the impact of these parameters on risk of lung cancer.

Conclusion

Current study was conducted to evaluate the risk assessment of death and lung cancer caused by silicosis among workers of stone-cutter and silica crushing units in Azandarian industrial zone, Hamadan, Iran. The results of risk assessment analysis on 40 active silica stone crushing units showed that there was a high risk among workers in the stamping machine operator unit for silicosis, lung cancer and death. Our findings implied that the risk for the exposed population was in the range 2-264/1000 workers. The results of risk assessment demonstrated that the highest level of risk was related to the stamping machine operator unit and the lowest risk was related to the administrative unit. Therefore, in the identified high risk workplaces control and protective measures must be implemented such as the use of more powerful particle control systems like bag filters and use of appropriate face masks to decrease the exposure of the workers.

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Competing interests

The authors declare that they have no conflict of interests.

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Ethical consideration

Ethical issues have been completely observed by the authors and this project was approved the Research Ethics Committee of the Hamadan University of Medical Sciences (Code: IR.UMSHA.REC.1400.003).

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