Safety and Health at Work 7 (2016) 251–255

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Original Article

Risk Assessment of Exposure to Silica Dust in Building Demolition Sites

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ARTICLE INFO

Article history:
Received 9 February 2015
Received in revised form
3 December 2015
Accepted 17 December 2015
Available online 2 January 2016

Keywords:
dust
lung cancer
occupational exposure
silica
silicosis

ABSTRACT

Background: Building demolition can lead to emission of dust into the environment. Exposure to silica dust may be considered as an important hazard in these sites. The objectives of this research were to determine the amount of workers' exposure to crystalline silica dust and assess the relative risk of silicosis and the excess lifetime risk of mortality from lung cancer in demolition workers.
Methods: Four sites in the Tehran megacity region were selected. Silica dust was collected using the National Institute for Occupational Safety and Health method 7601 and determined spectrophotometrically. The Mannetje et al and Rice et al models were chosen to examine the rate of silicosis-related mortality and the excess lifetime risk of mortality from lung cancer, respectively.
Results: The amount of demolition workers' exposure was in the range of 0.085–0.185 mg/m^3. The range of relative risk of silicosis related mortality was increased from 1 in the workers with the lowest exposure level to 22.64/1,000 in the employees with high exposure level. The range of the excess lifetime risk of mortality from lung cancer was in the range of 32–60/1,000 exposed workers.
Conclusion: Geometric and arithmetic mean of exposure was higher than threshold limit value for silica dust in all demolition sites. The risk of silicosis mortality for many demolition workers was higher than 1/1,000 (unacceptable level of risk). Estimating the lifetime lung cancer mortality showed a higher risk of mortality from lung cancer in building demolition workers.

1. Introduction

Workers in construction industries are exposed to occupational hazards. According to the Iranian Social Security Organization, construction industries have high rates of occupational injuries and health hazards due to unsafe work environment. The high rates of death and disability were recorded in these industries in Iran [1]. Building demolition can lead to emission of dust into the environment. Construction dust contains several compounds such as crystalline silica, significant levels of lead, and other toxic or carcinogenic agents [2,3]. Exposure to silica dust may be considered an important hazard in the demolition sites and construction activities [2,4]. Silica dust exposure can be important in some demolition activities for instance breaking, cutting, crushing, and grinding. Crystalline silica (SiO_2) is the most abundant component in the earth and is used as the fundamental building blocks of structures [5,6]. Also, building demolition workers may be at increased risk for asbestos-related disease [6,7]. The international Agency for Research on Cancer classified some types of crystalline silica such as quartz and cristobalite as Group 1 (known human lung carcinogen) of carcinogens [8,9]. The current and previous threshold limit values for respirable silica dust are 0.025 mg/m^3 and 0.05 mg/m^3, respectively [8]. Rappaport et al [3] reported that numerous of workers have been overexposed to crystalline silica dust in construction sites and the highest exposure was found in painters (1.28 mg/m^3). The Occupational Safety and Health

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2093-7911/$ — see front matter
http://dx.doi.org/10.1016/j.shaw.2015.12.006

Administration (OSHA) has reported that > 2 million of general, maritime, and construction industry workers are exposed to silica dust in their work environment [10]. Occupational exposure to silica dust is thought to cause silicosis in construction workers [11].

Silicosis is the major industrial lung disease and was defined as nodular lesions that may follow with progressive massive fibrosis in lungs [12]. Between 1987 and 1996, 6,300–7,300 new cases of silicosis were described at each year in the USA [11]. Concentrations of respirable silica dust in breathing-zone air of exposed individuals and duration of exposure are the most potent risk factors for developing of silicosis and a clear effect of cigarette smoking on the etiology of silicosis could not be identified in some studies [8]. Also, the results of some epidemiological studies indicate that silica dust is the leading cause of chronic obstructive pulmonary disease and lung cancer in many workers [13,14]. Toxicological risk assessment allows evaluating the public health conditions [15]. In the new global toxicology, risk assessment has become a central issue for estimating the true risk and hazards of toxic agents [8,16]. The risk of death due to silicosis after 45 years of silica dust exposure (0.05 mg/m^3) in a pooled analysis of six cohorts was 6/1,000. OSHA has determined that acceptable level of risk is 1/1,000 workers [17]. The results of Azari et al's [8] investigation in the construction industry showed that geometric mean of exposure to crystalline silica dust was 0.193 mg/m^3 for workers.

Occupational exposure to silica dust has been shown to increase the risk of mortality from lung cancer in workers. Rice et al's [14] model has been developed and introduced to measure the excess lifetime risks of death from lung cancer based on 45 years of silica exposure with a lag of 10 years of 0.05 mg/m^3 silica exposure. Previous research findings have reported the excess lifetime risk of mortality from lung cancer of 19/1,000 workers [8].

However, little attention has been paid to determine the exposure levels of workers to crystalline silica dust and assessment of mortality and lung cancer risk from exposure to silica dust in building demolition sites in Iran. The objectives of this research were to determine the amount of workers' exposure to crystalline silica dust in building demolition sites and assess the relative risk of silicosis mortality and the excess lifetime risk of mortality from lung cancer in building demolition workers.

2. Materials and methods

Occupational exposure to silica dust in the building demolition workers was determined in this cross-sectional study. Four sites in the Tehran megacity region in Iran were selected. Site 1 was located in the south part of Tehran city. This site consisted of four houses. Three houses in this site were located on the west side of the main street and one house was situated at the other end of street. Buildings demolition operations were from June 10, 2010 to June 29, 2010. Site 2, which was located in the east part of Tehran city, consisted of three houses. House demolition operations were carried out from July 18, 2010 to August 3, 2010. Site 3 was situated in the west part of the city. In this studied site, three houses were demolished from August 23, 2010 to September 9, 2010. Site 4 included three houses in different parts of a narrow street in the center of Tehran. The demolition operations were performed from May 21, 2011 to July 20, 2011. The choice of the right method of demolition work depends on many factors such as project condition, the availability of equipment, and the sensitivity of neighborhoods [7]. In all studied sites, demolition was performed using workers daily operation. Demolition operations did not contain any dust control systems such as water spray. From three to five demolition workers were employed in each operation. Worker demographic features were recorded in a specially designed form, which included personal factors such as worker's age and work experience, smoking habits, working time and condition, and the use of personal protective equipment such as respiratory protection devices among demolition workers. All workers completed the informed consent. Full-time workers with no past history of lung disease were included in the study. The workers with no full corporation and those unwilling to continue the study were excluded.

Based on the results obtained from pilot study (95% confidence interval and 7% error), samples were collected from breathing zone air of 60 demolition workers (15 samples from each studied site). The sample size (n) was calculated according to Eq. (1):

$$n = \left(\frac{t_{1-\frac{\alpha}{2}} \times sd}{d}\right)^2 \tag{1}$$

where $t_{1-\frac{\alpha}{2}}$ is the quantile of the Student t distribution, sd is standard deviation, and d is desired precision [18].

Workers who had full shift exposure to respirable silica particles and same work (only demolition workers) were randomly selected from four sites. Top-down demolition operation was performed in each studied site. Trucks were used to remove demolition debris. Approximately 14 roll-off bins were removed from each site at 1–2 weeks.

Personal air sampling was carried out from April 2010 to June 2011. Samples were collected during work hours (08:00–16:00) of work days. Meteorological parameters including air temperature and wind speed were observed in each studied site. Several analytical methods were used for analysis of crystalline silica. Personal breathing zone samples were collected during an 8-hour shift working. The National Institute for Occupational Safety and Health (NIOSH) method 7601 was used to determine silica dust in air samples using visible spectrophotometry at 420 nm (Camspec M501 Single Beam Scanning UV/Visible; Camspec Ltd., Leeds, UK) [19–22]. Weighted-mixed cellulose ester (MCE) filter membranes (25 mm diameter, 0.8 mm pore size; SKC Inc., Eighty Four, PA) were used to collect respirable dust from air. A personal sampling pump (Model LTD; SKC Ltd., Blandford Forum, UK) with a flow rate of 1.7 L/min was used for silica dust collection [18,19]. Calibration curves were obtained by spiking 1 mg, 1.5 mg, 2 mg, 2.5 mg, and 3 mg of quartz on MCE filters then absorbance was measured to prepare the standard curve. Silica dust concentrations were calculated according to Eq. (2):

$$C = \frac{A - B}{m.\mathrm{V}} \tag{2}$$

where C is the concentration of crystalline silica, (mg/m^3), A and B are the absorbance of the sample and reagent blank, m is the slope of appropriate calibration curve, and V is the air volume [20].

The Mannetje et al's model [17] is one of the more practical ways of assessing silicosis mortality. This model was chosen to examine the rate of silicosis-related mortality with a lag of 10 years. In the Mannetje et al model, cumulative exposure to silica dust (mg/m^3/y) in range of 0–0.99 to > 28.10 with the relative rate of mortality from silicosis in range of 1.00–63.63 was considered. Forty-five years of exposure was determined for calculating the cumulative lifetime exposure for silica dust. For the purpose of risk assessment of silicosis-related mortality, the years of exposure was multiplied by cumulative exposure to silica dust (mg/m^3/y) [8].

The study of the excess lifetime risk of mortality from lung cancer for workers exposed to silica dust was done based on the Rice et al [14] model and formula presented by Azari et al [8] work for 45 years of silica exposure with a lag of 10 years of 0.05 mg/m^3 silica exposure. Excess risks were estimated for workers exposed for 45 years of working lifetime to respirable crystalline silica dust.

Table 1
Occupational exposure to respirable silica dust in demolition workers

Sampling area	n	AM (mg/m^3)	SD	GM (mg/m^3)	GSD	Median	95% CI for GM	
South	15	0.206	0.13	0.158	2.29	0.155	0.03	0.46
East	15	0.209	0.142	0.156	2.37	0.185	0.130	0.288
West	15	0.148	0.154	0.085	3.19	0.095	0.062	0.234
Center	15	0.195	0.123	0.143	2.65	0.165	0.127	0.263
Total	60	0.190	0.138	0.132	2.65	0.145	0.03	0.46

AM, arithmetic mean; CI, confidence interval; GM, geometric mean; GSD, geometric standard deviation; SD, standard deviation.

It was assumed that the maximum age of 85 years was considered for calculating the risks of excess lifetime risk of mortality from lung cancer in a year [8,14]. Lung cancer mortality was calculated according to Eq. (3) [8]:

$$A = 0.77 + 373.69 \text{ geometric mean of exposure} \tag{3}$$

2.1. Statistical analysis

Descriptive statistic tests were applied for determination the means and standard deviation values for all exposures. For determination of differences in workers' exposure with occupational exposure levels (OELs) in four sites, t test was performed. Kolmogorov–Smirnov test was used to check the normality of the distribution of exposure values. The Kolmogorov–Smirnov test demonstrated a normal distribution of the exposure values ($p = 0.45$). The statistical analysis was done using SPSS version 16.0 for Windows (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Occupational exposure

The mean age of workers was 28 $\pm$ 6.3 years with 7 years of work experience; and 27% of them smoked cigarettes. The average air temperatures in Sites 1–4 were 30.6°C, 30.8°C, 28.2°C, and 28.8°C, respectively. The average wind speeds in Sites 1–4 were 2 m/s, 2.8 m/s, 2.4 m/s, and 2.6 m/s, respectively. According to meteorological data, the effects of air temperature and wind speed on exposure measurements were negligible. Measurements were done on days with no rain. Workers in studied sites work > 8 hours in a day during 6 working days. The building demolition workers did not use appropriate personal protective equipment in doing their tasks. Arithmetic and geometric mean of respirable silica dust in the breathing zone air of workers are presented in Table 1. The highest exposure to silica dust was observed in the workers at Site 1 (geometric mean = 0.158). The minimum exposure was found in demolition workers in the west region of Tehran at Site 3 (geometric mean = 0.085). A comparison of the demolition workers' exposure with reported OELs reveals that 80% of workers had higher exposure than standard levels ($p < 0.001$), despite the well-described effects of silica exposure on workers' health.

Table 2
Airborne total dust concentrations

Sampling area	No. of samples	Mean (mg/m^3)	SD	Minimum	Maximum	% SiO_2
South	15	14.99	5.44	5.00	28.00	0.001
East	15	11.86	4.36	5.20	18.00	0.52
West	15	11.93	5.97	5.60	28.00	0.51
Center	15	14.68	2.77	11.46	20.79	0.04
Total	60	13.37	4.90	5.00	28.00	0.24

SD, standard deviation.

Table 3
The results of relative risk of silicosis related mortality in demolition workers

Cumulative exposure ($mg/m^3/y$)	Relative risk of silicosis-related mortality based on Mannetje et al model	No. of exposed workers in demolition sites (%)
0–0.99	1	28 (46.6)
0.99–1.97	3.39	11 (18.3)
1.97–2.87	6.22	5 (8.3)
2.87–4.33	9.40	8 (13.3)
4.33–7.12	13.69	6 (10)
7.12–9.58	22.64	1 (1.7)
9.58–13.21	23.97	1 (1.7)
13.21–15.89	40.25	0 (0)
15.89–28.1	25.11	0 (0)
> 28.1	63.63	0 (0)

The airborne total dust concentrations in the breathing zone of demolition workers in studied workplaces are reported in Table 2. No significant differences were found between the total dust concentrations in the breathing zone air of workers and location of studied sites ($p > 0.05$).

3.2. Risk assessment of silicosis mortality

The results of risk assessment based on Mannetje et al's [17] model for determining the relative risk of silicosis mortality demonstrated that the range of relative risk of silicosis related mortality was increased from 1 in the workers with the lowest exposure level to 22.64/1,000 in the employees with a high exposure level (Table 3).

3.3. Risk of mortality from lung cancer in demolition worker

The results of estimating the excess lifetime risk of mortality from lung cancer for workers exposed to silica dust in building demolition sites presented that the range of the excess lifetime risk of mortality from lung cancer was in the range of 32–60/1,000 silica-exposed workers. These data were obtained from exposure analyses performed based on 45 years of workers' exposure. The results obtained from this analysis are shown in Table 4.

4. Discussion

It is becoming increasingly difficult to ignore the occupational safety and health issues in construction firms [23,24]. This project was undertaken to determine the amount of workers' exposure to crystalline silica dust in building demolition sites and assessing the

Table 4
The excess lifetime risk of mortality from lung cancer for workers exposed to silica dust

Area	No. of samples	GM (mg/m^3)	The excess lifetime risk of mortality from lung cancer
South	15	0.158	60
East	15	0.156	59
West	15	0.085	32
Center	15	0.143	54
Total	60	0.132	50

GM, geometric mean.

relative risk of silicosis mortality and the excess lifetime risk of mortality from lung cancer in demolition workers. One of the more significant findings to emerge from this study is that geometric and arithmetic means of exposure were higher than the threshold limit value for silica dust in all demolition sites. The results of 60 personal sampling from workers' exposure showed that the geometric mean was 0.132 mg/m^3. Silica exposure sampling among 36 construction sites in the USA showed that silica dust exposure was unacceptable in this industry and exposure control measures should be considered [3]. The geometric mean of exposure for hand-held demolition workers was 0.14 mg/m^3 (GSD 4.3) in Flanagan et al's [4] study and workers' exposure to silica dust during demolition activities on construction sites need to be reduced. This study produced results that corroborate the findings of a great deal of the previous work in this field [3,4,8]. Also, the findings of risk assessment of workers exposed to crystalline silica aerosols in the east zone of Tehran indicated that occupational exposure to crystalline silica aerosols in construction sites was higher than the current (0.025 mg/m^3) and previous (0.05 mg/m^3) threshold limit values provided by the American Conference of Governmental Industrial Hygienists. The reported geometric mean of exposure was 0.193 mg/m^3 in studied construction sites [8].

Many attempts have been made to determine the relationship between silica exposure and silicosis-related mortality and lung cancer. The exposure-response studies showed a highly significant relationship between the exposure to respirable crystalline silica dust and risk of lung cancer and silicosis mortality [14,17].

The results of relative risk of silicosis related mortality in building demolition workers was done based on the Mannetje et al [17] model. For this purpose, cumulative exposure (mg/m^3/y) of workers were determined. It was shown that the risk of silicosis mortality for 28% of workers with cumulative exposure in the range of 0–0.99 mg/m^3/y were acceptable according to OSHA's criteria. The risk of silicosis mortality for 72% of demolition workers in the exposure range of 0.99–13.21 mg/m^3/y was unacceptable. The reported silicosis related mortality rate in the Mannetje et al [17] study was 28/100,000 and 230/100,000 for the pooled cohort and the highest exposure group, respectively. The results of Mannetje et al's [17] study also estimated that silicosis related mortality based on OSHA permissible exposure limit (0.1 mg/m^3, % $SiO_2 = 100$) was 13 per 1,000 from age 20 years to 65 years, which was higher than OSHA acceptable level of risk (1/1,000). Estimated silicosis mortality rate according to the NIOSH recommended exposure limit (0.05 mg/m^3) for cumulative exposure of 2.25 mg/m^3/y was 6/1,000 [17]. The result of risk assessment of silicosis and lung cancer among 1,335 construction and natural stone workers exposed to respirable quartz indicated that the average silica cumulative exposure was 5.7 mg/m^3/y. A lifetime risk of silicosis was $>$ 5% in construction workers. Among studied workers, 0.8% showed sign of silicosis in their chest X-rays. Another important finding was that occupational exposure to silica dust in construction sites including demolition parts can increase the risk of silicosis among construction workers [11]. A strong relationship between the amount of occupational exposure and silicosis-related mortality has been reported in Azari et al's [8] study.

This study corroborates the findings of Azari et al [8], who suggested that 79% of workers in their study had unacceptable level of risk of silicosis related mortality in the range of 3–25/1,000 workers [8]. The risk of silicosis-related mortality in the cumulative exposure range of 9.58–13.21 (highest exposure group) in this study (1.7%) was lower than that in Azari et al's study [8] (7.2%). It seems possible that these results are due to differences in sample size between the two studies.

The excess lifetime risk of mortality from lung cancer for workers exposed to 0.05 mg/m^3 of silica dust for 45 years in the building demolition sites was 32 in the workers with the lowest exposure level to 60/1,000 in the employees with the highest exposure level. The most obvious finding to emerge from Rice et al's [14] study is that the excess lifetime risk of mortality from lung cancer for 2,342 California diatomaceous earth mining workers exposed to silica dust for 45 years and up to age 85 years was 19/1,000 workers. The excess lifetime risk of mortality from lung cancer in Vermont granite workers exposed to silica dust for 45 years exposure with 0.05 mg/m^3 of silica dust from age 20 years to 64 years was 27/1,000 exposed workers [25]. The results of risk assessment of workers exposed to crystalline silica aerosols in the east zone of Tehran showed that the excess lifetime risk of mortality from lung cancer in the studied construction sites was 73/1,000 workers, which was higher than that obtained from this study [8]. This result may be explained by the fact that sample size and the levels of exposure were different in the studies. According to Azari et al [8], the models used to predict excess lifetime risks of mortality from lung cancer and to assess silicosis mortality may be applicable to construction workers.

This investigation found that workers had not used proper personal protective equipment such as respiratory protection devices. Flanagan et al [4] suggested that appropriate respiratory protection devices may decrease the amount of workers' exposure to silica dust below the recommended exposure limits. Twenty-seven percent of building demolition workers smoked cigarettes. Synergistic effects of smoking and exposure to crystalline silica on lung cancer have not been defined clearly but some studies indicated that combine exposure may increase the risk of lung cancer in exposed individuals [26]. The excess lung cancer risk was reported in New York, USA tunnel workers due to exposure to silica dust but in the study, the confounding effects of radon exposure was not controlled [27]. Among 44,160 silica exposed miners, 663 deaths from lung cancer reported [28].

Asbestos may be found in construction materials. During the demolition of buildings, asbestos fibers may be released in to air and demolition worker may be exposed to these fibers. Asbestos fibers in the other previous published study at these sites were analyzed using phase-contrast optical microscopy (PCM), scanning electron microscopy (SEM) equipped with an energy dispersive X-ray analysis, and polarized light microscopy methods. The results indicated that the levels of workers' exposure were in the range of 0.01–0.15 PCM f/mL (0.02–0.42 SEM f/mL). The geometric mean concentrations of asbestos in the personal air samples (0.07 PCM f/mL, 0.20 SEM f/mL) were higher than that recommended by the American Conference of Governmental Industrial Hygienists (0.1 f/mL). Chrysotile asbestos was observed in analyzed samples [7].

There are uncertainties about the exposure assessment and assessment of the relative risk of silicosis and the excess lifetime risk of mortality from lung cancer. Some confounding data are related to the interaction between smoking and occupational exposure to silica dust and excess lifetime risk of mortality from lung cancer. Simultaneous exposure to silica and asbestos is the other uncertain variable. Selection of an appropriate model and applicability of risk estimate model for risk analysis is the other sources of uncertainty [14]. Estimation of historic levels of exposure and uncertainties in the actual levels of silica exposure are some uncertainty variables in the risk assessment for silicosis mortality.

Workers' exposure to silica dust in building demolition sites should be limited. Wet cleaning, compressed air to remove silica dust from clothes, and personal protective equipment can be used to control silica dust exposure in building demolition sites [21]. A limitation of this study is that the numbers of sampling sites was relatively small and the associations between cigarette smoking and silicosis and lung cancer were not examined. It is recommended that further research be undertaken in building demolition sites with a large sample size. More broadly, research is also needed to consider the impact of seasonal changes on occupational exposure to silica dust in demolition sites.

Conflicts of interest

The authors declare that they have no conflict of interest.

Acknowledgments

We are really grateful from Tehran University of Medical Sciences, Tehran, Iran. This project could not be completed without their support. Dr. Hossein Kakooei sadly passed away and this paper is dedicated to his memory.

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