Risk Assessment of Workers Exposed to Crystalline Silica Aerosols in the East Zone of Tehran

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ABSTRACT

Background: The term "crystalline silica" refers to crystallized form of SiO_2 and quartz, as the most abundant compound on earth crust, is capable of causing silicosis and lung cancer upon inhaling large doses in course of occupational exposure.

Materials and Methods: In this study, airborne respirable dust samples were collected on mixed cellulose filters (25 mm diameter, 0.8 mm pore size), by using a cyclone separator at the flow rate of 2.2 l/min for a maximum volume of 800 liters. Infrared absorption spectrometry was used according to the "National Institute of Occupational Safety and Health" (NIOSH) method No. 7602 for analysis of samples. Risk assessment techniques predictive of silicosis and lung cancer were employed.

Results: The geometric mean of workers' exposure to crystalline silica in ten industrial fields (stone milling and cutting, foundry work, glass manufacturing, asphalt, construction, sand and gravel mining, sand blast, ceramics, bricks and cement manufacturing) was in the range of 0.132 to 0.343 mg/m^3. Mortality rate of silicosis was predicted to be in range of 1 to 52 per one thousand exposed individuals. Risk of lung cancer mortality in exposed workers in the east zone of Tehran based on geometric mean exposure of industrial activity and 45 years of exposure was in range of 50 to 129 per one thousand. In terms of risk assessment of silicosis mortality, cumulative exposure of 21 percent of population complied with the notion of acceptable risk. In regard to lung cancer mortality, 100 percent of the population were expected to have an unacceptable risk after 45 years of active work experience.

Conclusion: This study is the first of its kind in Iran demonstrating a profile of exposure in different groups of workers in the east zone of Tehran's greater city, covering 5.5 million populations. Considering the total population of one hundred thousand workers exposed to quartz in east zone of Tehran and aging of the current young workforce, numerous cases of silicosis and lung cancer are forecasted in near future. **(Tanaffos 2009; 8(3): 43-50)**

Key words: Silicosis, Quartz, Lung cancer, Risk assessment and management

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INTRODUCTION

The term crystalline silica refers to crystallized form of SiO_2 known as quartz, cristobalite or tridymite and is the most abundant compound on earth crust capable of causing silicosis and lung cancer upon inhaling large doses in course of occupational exposure (1). In nature, the alpha form of quartz is the most common form of crystalline silica (2). According to National Institute of Occupational Safety and Health (NIOSH), industries and activities that pose the greatest potential risk for workers exposed to crystalline silica are: stone cutting and milling, foundry work, glass manufacturing, asphalt, construction, sand and gravel mining, sand blast, ceramics, bricks and cement manufacturing (3).

NIOSH estimates that at least 1.7 million U.S. workers are potentially exposed to respirable crystalline silica (4). Silicosis, usually a nodular pulmonary fibrosis, is a disease mostly associated with exposure to respirable crystalline silica. Although, the reported mortality associated with silicosis has declined over the past several decades, 300 silicosis-associated deaths still occur each year in America (5). According to a report from the U.S. Surgeon General, cigarette smoking has no significant causal role in the etiology of silicosis, and, the most important factor in the development of silicosis is the "dose" of respirable dust containing crystalline silica and duration of exposure in the workplace setting (6-7). A worker may develop one of three types of silicosis: chronic silicosis, accelerated silicosis and acute silicosis depending on the cumulative dose of respirable crystalline silica (8).

International Agency for Research on Cancer (IARC), recently reviewed the epidemiologic studies of lung cancer and occupational exposure to crystalline silica, and categorized the crystalline silica in form of quartz and cristobalite as a group 1 carcinogen (9).

Risk assessment is one of the newest approaches of toxicology, whereby scientific information on the hazardous properties of toxic agents and the extent of exposure result in a statement regarding the risk of harm to the exposed populations. This process is a scientific attempt to identify and estimate the true risks and is the result of considering potential hazards of toxicants, dose-response (effect) relationship, and risk characterization which rationalize risk management (10).

Mannetje et al (11), as a pioneer in risk assessment of crystalline silica exposure, reported that the excess risk of silicosis mortality per one thousand exposed individuals was increasing nearly in a monotonic fashion with cumulative exposure. They categorized the cumulative exposures in various ranges of 0 to 28.1 mg/m^3-year and reported excess risk of silicosis mortality for various ranges of cumulative exposures in range of 1 to 63 per one thousand, respectively (11). Recently, by using Mannetje et al. model the excess risk of death from silicosis up to age 65 after 45 years of exposure at 0.1 mg/m^3 silica (the current standard in many countries) was assessed and reported to be about 13 per one thousand exposed individuals (12).

Risk assessment of lung cancer in workers exposed to crystalline silica was presented by Rice et al. (13) and they predicted excess lifetime risks of mortality from lung cancer with the assumption of 45 years of continual work experience and lagged time of 10 years. According to this model, the excess lifetime risk at the current Occupational Safety and Health Administration (OSHA) standard (14) of 0.05 mg/m^3 for respirable crystalline silica was reported to be 19 per one thousand. Prevention and elimination of silicosis and silica-related diseases in the United States has been the main priority of the American Lung Association and all other regulatory agencies, and, as a result mortality due to silicosis has declined over the past decades (15).

There are few reports on prevalence of silicosis among stone cutters in Malayer-Azandarian region, suggesting the prevalence of acute silicosis with a

history of less than five years of exposure (16-18). Generally, there is no clear profile of exposure to crystalline silica among the Iranian workforce in Iran. Lack of information might be due to the high costs of sampling and unavailability of analytic methods for most researchers.

This study aimed to obtain the profile of exposure and conduct risk assessment on workers highly exposed to quartz dusts in the east zone of Tehran's greater city.

MATERIALS AND METHODS

In this study occupational exposure of workers in industrial sectors such as stone cutting and milling, foundry work, glass manufacturing, asphalt, construction, sand and gravel mining, sand blast, ceramics, bricks and cement manufacturing with a history of exposure to crystalline silica in the east zone of Tehran's greater city was studied.

Assuming a 50% incidence rate of silicosis, 95% confidence interval and 7% error, 200 workers were studied, and 50 workshops (five in each of 10 industrial sectors) were selected randomly and 4 employees from each workshop were selected for personal monitoring of exposure to crystalline silica dusts.

A variety of analytical techniques are used for the quantitative determination of crystalline silica (19-20). The three most common analytical methods used are x-ray diffraction (XRD), infrared absorption (IR) and colorimetric spectroscopy. Due to the unavailability of x-ray diffraction spectroscopy method for extensive monitoring of workers' exposure in Iran, infrared absorption spectroscopy according to the NIOSH method No. 7602 (21) was validated for this study. In this method, airborne respirable dust samples were collected on mixed cellulose filters (25 mm diameter, 0.8 mm pore size), by using a cyclone separator (Higgins and Dewell) at the flow rate of 2.2 l/min for a maximum volume of 800 liters.

Standards of quartz were prepared by spiking 10, 25, 50, 100, 150, 200 and 250 µg of quartz on mixed cellulose filters. Filter samples, standards and blanks (mixed cellulose filter) were washed with 9% w/w hydrochloric acid and they were placed in porcelain crucibles and were burned in muffle furnace at 600°C. Dried KBr (300 mg) was added to each porcelain dish and they were mixed thoroughly with a pestle. Mixed sample and KBr were subsequently pressed into a pellet form. For maximum sensitivity, absorbance of standards was measured at 800 cm^{-1} wavelength and samples were quantified according to regression formula of standard samples. Validity of applied IR–Spectroscopy method (NIOSH Method No. 7602) was tested in terms of coefficient of variation of triplicates of standards of quartz samples.

Risk assessment of silicosis mortality was estimated according to Mannetje's model (11). In this model cumulative exposures mg/m^3-year [typical exposure (mg/m^3) X duration of exposure (year)] in various ranges of 0.0 to 0.99, 0.99 to 1.97, 1.97 to 2.87, 2.87 to 4.33, 4.33 to 7.12, 7.12 to 9.58, 9.58 to 13.21, 13.21 to 15.89, 15.89 to 28.1 and more than 28.1 mg/m^3-year, were associated to assess the relative rate of silicosis-related mortality in range of 1.0, 3.39, 6.22, 9.40, 13.69, 22.64, 23.97, 40.25, 52.11 and 63.63 respectively (11).

Risk assessment of excess lifetime risks of mortality from lung cancer due to crystalline silica was calculated by regression linear relative rate model presented by Rice et al. (13), and was calculated for our data in a linear regression model (relative excess rate of mortality=0.77+373.69 geometric mean exposure) with the assumption of 45 years of continual work experience and lagged time of 10 years.

RESULTS

Two hundred workers from fifty workshops in ten different industrial fields were studied. Subjects of this study mostly worked more than eight hours a day

during the six working days of a week. Sixty six percent of workers were younger than 30 years old, the mean work experience of all exposed workers was 11±13 years and 87% of them were illiterate and 79% of them were nonsmokers.

IR–Spectroscopy method (NIOSH Method No. 7602) was tested in term of coefficient of variation of triplicates of standards in range of 10, 50, 150, and 250 µg of quartz samples and the coefficient of variations of samples was 15, 10, 9 and 8 percent, respectively. Coefficient of variation of IR spectroscopy method developed in this study is in accord with various studies of analytical methods reviewed by NIOSH (22).

Exposure of workers to crystalline silica in ten industrial sectors was in the range of geometric mean of 0.132 to 0.343 (Table 1).

Table1. Occupational exposure of workers to crystalline silica (mg/m³-year) in various industrial sectors

Industrial Activity	No. of workers studied	Representative Exposure Geometric Mean (mg/m³) (Confidence Interval 95%)	Geometric Mean (mg/m³)
Stone cutting & milling	20	(0.191 – 0.397)	0.275
Foundry work	20	(0.231 – 0.510)	0.343
Glass manufacturing	20	(0.070 – 0.250)	0.132
Asphalt preparation	20	(0.131 – 0.369)	0.267
Construction	20	(0.124 – 0.301)	0.193
Sand & Gravel Mining	20	(0.184 – 0.372)	0.261
Sand blast operation	14	(0.172 – 0.429)	0.272
Ceramic manufacturing	20	(0.238 – 0.452)	0.328
Brick manufacturing	20	(0.079 – 0.326)	0.160
Cement manufacturing	20	(0.131 – 0.369)	0.220

Various industrial sectors had different rates of exposure to crystalline silica and the highest mean exposures in a descending fashion were found in Foundry work, ceramic manufacturing, stone cutting & milling, sand blast operation, asphalt preparation, sand and gravel mining, cement manufacturing, construction, brick manufacturing, , and glass manufacturing.

Pooled exposure of all exposed workers in various industrial sectors was organized according to Mannetje's categorization for cumulative exposure ranges. Table 2 demonstrates the percentage of exposed population in various categories of cumulative exposures. Percentage of exposed population in various cumulative exposure categories was in the range of 0 to 21 percent for the relative risk of silicosis mortality in the range of 1 to 52.11 per one thousand (Table 2).

Table 2. Risk of silicosis- related mortality in exposed workers in east of Tehran according to their cumulative exposure (mg/m³-year) to crystalline silica

Risk assessment of silicosis according to Mannetje et al.		No(%) of exposed workers in the east zone of Tehran
Cumulative exposure	Relative risk of silicosis-related mortality per one thousand exposed	
0.0 to 0.99	1	41(21.1)
0.99 to 1.97	3.4	38(19.6)
1.97 to 2.87	6.2	31(16)
2.87 to 4.33	9.4	13(6.7)
4.33 to 7.12	13.7	30(15.5)
7.12 to 9.58	22.6	19(9.8)
9.58 to 13.21	24.0	14(7.2)
13.21 to 15.89	40.2	2(1)
15.89 to 28.1	52.1	6(3.1)

Risk of lung cancer mortality in exposed workers in the east zone of Tehran was calculated according to Rice et al. model (13) based on geometric mean

exposure of crystalline silica and 45 years of exposure (Table 3). The risk of lung cancer in exposed population of various industrial sectors was in range of 50 to 129 per one thousand.

Table 3. Risk of lung cancer mortality per one thousand exposed workers in the east zone of Tehran

Industrial activity	Geometric mean of exposure (mg/m³)	Estimated excess lifetime risks of mortality from lung cancer based on the model presented by Rice et al.
Stone cutting & milling	0.275	103
Foundry work	0.343	129
Glass manufacturing	0.132	50
Asphalt preparation	0.267	100
Construction	0.193	73
Sand & gravel Mining	0.261	98
Sand blast operation	0.272	102
Ceramic manufacturing	0.328	123
Brick manufacturing	0.160	60
Cement manufacturing	0.220	83

DISCUSSION

This study presents the first profile of occupational exposure of workers to quartz dusts in the east zone of Tehran covering 5.5 million populations. A high variability of exposure was observed among the ten working groups recommended by NIOSH (3) which could be due to the limited number of subjects in 50 chosen workplaces for this study. In addition, results of this study are merely an estimation of true risk imposed on exposed workers. Exposure of different working groups to quartz, in the east zone of Tehran's greater city in term of geometric means was in the range of 0.132 to 0.343 mg/m^3, which is much higher than the geometric mean of their counterparts in the United Kingdom with an exposure level of 0.09 mg/m^3 (23) and Iranian allowable exposure level of 0.05 mg/m^3

(24). Generally, average exposure of workers in foundry work, ceramic manufacturing, and stone cutting and milling was higher than that of the remaining working groups.

Since comparison of workers' exposure with hygienic standards does not project a clear view of health status, the newest approach of occupational toxicology in terms of risk assessment (10) for the incidence of silicosis and lung cancer was employed in this study. According to Mannetje et al. (11) and the classification of cumulative exposure, 21% of exposed population had cumulative exposure in range of 0-0.99 mg/m^3-yr corresponding to notion of acceptable risk (one per one thousand) in regard to silicosis-related deaths (25). However, the remaining exposed workers (79 %) had relative excess risk of silicosis mortality in range of 3 to 52 per one thousand.

Comparison of the risk assessment of silicosis in this study with the actual risk of cohort study of 3010 Chinese workers is noteworthy, where 33.7% of workers had silicosis, and 69% of those with silicosis had cumulative exposure to respirable crystalline silica of 5.4 mg/m^3-years (26). For a better perception of future risks of exposed workers in the east zone of Tehran, actual risk of another cohort study of 4,626 industrial sand workers, studied during 1974-1995, with average employment length of 9 years and estimated average exposure of 0.05 mg/m^{3}was studied and a standardized mortality ratio of 18.2 was reported for silicosis (27). Generally, the model used in this study for calculation of risk assessment of silicosis-related mortality may result in a lower risk than actual figures reported in former cohort studies. For example, according to Mannetje A, et.al model (11), relative risk of silicosis mortality for cumulative exposure of 5.4 mg/m^3-years indicates 13.7% per one thousand, rather than actual 33.7%

population diagnosed with silicosis reported by the Chinese cohort study (26).

Risk assessment of lung cancer in workers exposed to quartz in this study was calculated according to a regression linear relative rate model (13). Regression linear relative rate model is a common model used by other studies (28). According to the linear relative rate, the excess risk of lung cancer mortality for life time exposure to silica for 45 years with typical exposure of 0.05 mg/m^3 (previous threshold limit value by American Conference of Governmental Industrial Hygienists) is 19 per 1000 exposed persons (29). The current reduced threshold limit value set by ACGIH at 0.025mg/m^3 (30), may not provide the required safety at acceptable risk level of 1 per one thousand (25). Due to the high exposure variability in each working group, geometric mean in range of 0.132 to 0.343 mg/m^3 and regression linear relative rate model, were considered for computation of risk assessment, and lung cancer mortality in range of 50 to 129 per one thousand exposed population after 45 years of continuous work is expected. Regarding the notion of acceptable lifetime risks of less than 1 per one thousand (25), the estimated risk assessment of workers in this study is high and could result in considerable compensation payments by employers and national welfare insurance system.

Despite the high estimated risk of exposed workers in terms of mortality of lung cancer in the east zone of Tehran's greater city, the outcome of exposure of relatively young workforce to quartz and lag time of 10 years for development of lung cancer may not be visible yet. Generally, due to risk estimates and estimated 100,000 workers with a history of exposure to quartz dust and aging of the current young workforce, a comparable crisis of silicosis cases similar to Malayer-Azandarian region

(16-18) might be foreseen in the future.

Authors of this study admire Iranian physicians for treating silicosis patients by lung transplantation, but this treatment is very costly and along with compensations paid to incapacitated silicosis patients, is a true burden on insurance system and employers. Since prevention of silicosis is possible technologically and economically, risk management of workforce must be considered as a main priority by industrial management sectors. Therefore, it is imperative that routine control measures (3) in terms of upgrading industrial processes, application of ventilation, improved working conditions and use of standard personal protective equipments, should be introduced to the management of industrial sectors as a proper action for prevention of silicosis and lung cancer along with avoiding high compensation payments for victims.

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