



Risk Assessment of Occupational Exposure to Crystalline Silica in Small Foundries in Pakdasht, Iran

*Ali OMIDIANIDOST¹, *Mehdi GHASEMKHANI¹, Hossein KAKOOEI¹, Seyed Jamaledin SHAHTAHERI¹, Masud GHANBARI²*

1. Dept. of Occupational Health, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran
2. Dept. of Occupational Health Engineering, School of Public Health, Kermanshah University of Medical Sciences, Iran

***Corresponding Author:** Email: ghasemkh@tums.ac.ir

(Received 21 Jun 2015; accepted 11 Sep 2015)

Abstract

Background: The term crystallized silica refers to the crystallized form of SiO₂ and quartz, the most frequency composition in the earth's crust that can cause silicosis and lung cancer through occupational exposure and inhalation of its large quantities.

Methods: Occupational exposure of workers in Pakdasht, Iran, in 2011 was investigated in four different casting processes in small foundries with less than 10 workers. Sampling respirable dust was collected on MCE filter, using HD cyclone at a flow rate of 2.2 lit/min. The filters were analyzed for dust using NIOSH Method 7601. Gravimetric and visible absorption spectrophotometer was used to determine amounts of inhalable dust and free silica, respectively. Risk assessment techniques were also used to predict silicosis and lung cancer.

Results: Geometric means of occupational exposure to crystalline silica in 4 different casting processes were studied within the range of 0.009-0.04 mg/m³. Mortality rate due to silicosis was in the range of 1-13.7 per 1000 persons exposed. Risk of mortality due to lung cancer in exposed workers in small casting workshops in Pakdasht, Iran ranged 4-16 per 1000 persons exposed based on geometric mean and 45 years of exposure. According to risk assessment, mortality due to silicosis, cumulative exposure of 96% of population was at an acceptable level of 1/1000.

Conclusion: Fifty percent of workers were exposed to crystalline silica dust in excess of Recommended Exposure Limit -NIOSH and Threshold Limit Value ACGIH (0.025 mg/m³). Several cases of silicosis and lung cancer are anticipated for this occupational group in near future.

Keywords: Crystalline silica, Small casting foundries, Silicosis, Lung cancer, Risk assessment

Introduction

“Silica is a chemical term for silicon dioxide (SiO₂). Silica can crystallize as one of at least eight polymorphs (α-quartz, P-quartz, cristobalite, tridymite, stishovite, coesite, moganite, and keatite), each of which occurs in nature. In addition, silica can occur in noncrystalline forms, and several amorphous materials” (1). “Numerous studies have demonstrated that samples of quartz can be biologically active, and under some conditions exposure to quartz appears to result in fibrosis or tumors or both” (1). Silica is a mineral, composed

of one atom of silicon and two atoms of oxygen (SiO₂), with melting point of 1600 °C; it is an odorless, colorless, non-combustible solid (2).

Crystalline silica is used in many industries including cement production, glass, concrete products, ceramic, clay soil (clay and bricks), casting, sand-blast, abrasives, pottery, porcelain, and many construction activities (3, 4). Silica dust is considered an inhalation risk. Considering improved working conditions and dust control in developed countries, incidence rate of silicosis is decreasing in

these countries (5). However, in developing countries, contact with dust is still an important health hazard. National Institute for Occupational Safety and Health (NIOSH) estimates that at least 1.7 million American workers are potentially exposed to inhalable crystalline silica (6). Silicosis is the most important work-related lung disease, resulting from constant inhalation of crystalline silica-containing dust, in which lung tissue is damaged, thereby reducing the capacity for oxygen intake (2, 7). Silicosis is usually a pulmonary nodular fibrosis, and is primarily associated with exposure to inhalable crystalline silica. Despite reduced silicosis-related mortality rate in the past few decades, annually 300 silicosis-related deaths still occur in America (8). Depending on the amount of exposure to crystalline silica, every worker may have one of the three types of silicosis: acute, chronic, and accelerated (9). Reports on exposure to free silica in casting industry indicate the incidence of exposure to quartz. Recently, International Agency for Research on Cancer (IARC) conducted an epidemiological review study on lung cancer and occupational exposure to crystalline silica, and introduced silica in the form of quartz and cristobalite as group 1 carcinogenic humans (2, 16).

Risk assessment is one of the latest toxicology methods that express risk of harm to the population exposed through scientific data obtained on hazardous properties of toxic agents and the amount of exposure. This scientific process attempts to identify and estimate real risks. It is in fact the result of assessment of potential risk of toxic substances, dose-response relationship (effects) and risk characteristics, which is the same as management of rational risk statement (10). Mannelje et al., as the pioneers in risk assessment of exposure to crystalline silica reported that risk of silicosis-related deaths per 1000 people exposed, in relation to cumulative exposure, is continuously increasing. They classified cumulative exposure in various ranges from 0 to 28.1 mg/m³-year, and reported the risk of silicosis-related death in different cumulative exposures between 1 and 63 per 1000 exposures (11). Lately, using Mannelje et al. model, risk of silicosis-related deaths, up to the age of 65 years and 45 years of crystalline silica

exposure in the range of 0.1 mg/m³ (common standard in some countries) was reported at 13 per 1000 persons exposed (12). Rice et al. presented risk assessment of lung cancer in workers exposed to crystalline silica, and anticipated life-long risk of mortality due to lung cancer, assuming 45 years continuous work history and 10-year interval (13). According to this model, constant life-long risk of inhalable crystalline silica within the proposed standard range of American Conference of Governmental Industrial Hygienists ACGIH (0.05 mg/m³) was 19 per 1000. In the United States, prevention and elimination of silicosis is a major priority for the American Lung Association and other legal institutions, and as a result, in the last decade, silicosis-related mortality has reduced (14). Due to lack of information about exposure concentration to crystalline silica among Iranian workers, this study aims to obtain exposure concentration and risk assessment management in workers of small casting foundries exposed to free silica.

This study was conducted in Pakdasht (East Tehran), Iran for the first time, in various small foundries (Cast iron, brass, aluminum, and alloys) with less than 10 workers, in 2011, the so-called forgotten industries.

Materials and Methods

In this study, occupational exposure of workers in 2011 was investigated in 4 different casting processes (Cast iron, brass, aluminum, and alloys) in small foundries with less than 10 workers, with a history of exposure to crystalline silica in Pakdasht Iran. Twenty-nine small casting foundries were randomly selected, and 80 workers were studied. From each workshop, 2 to 4 workers from various units were selected to monitor exposure to crystalline silica dust. The filters were analyzed for dust using NIOSH Method 7601. Gravimetric and visible absorption spectrophotometer at wavelength of 420 nm was used, which has an acceptable rigor for analysis of samples, to determine the amount of free silica (quartz) in dust samples. In this method, air sampling devices including personal sampler pump Model SKC Inc. (TX 44-224) at a flow rate of 2.2 l/min and volume of 400 li-

ters, HD cyclone and mixed cellulose ester (MC E) filter, 37-mm, 0.8- μm , were used to sampling respirable dust. The amount of quartz was determined in mg/m^3 (15). Data obtained from measurements were analyzed with SPSS version 16 software, using student's *t*-test and one-way analysis of variances ANOVA. *P*-value < 0.05 was considered statistically significant. Silicosis-related mortality risk assessment was estimated according to Marnettje model (11). In this model, cumulative exposure in $\text{mg}/\text{m}^3\text{-year}$ {normal exposure (mg/m^3) \times duration of exposure (years)} in the range: (0.00-0.99) –(0.99-1.97) –(1.97-2.87) –(2.87-4.33) –(4.33-7.12) –(7.12-9.58) –(9.58-13.21) –(13.21-15.89) –(15.89-28.1) and greater than 28.1 $\text{mg}/\text{m}^3\text{-year}$, was associated with relative risk of mortality due to silicosis in the range: 1-3.39 – 6.22 -9.40 -13.69 -22.64 -23.97 -40.25 -52.11 and 63.63, respectively⁽¹¹⁾. Risk assessment frequency of long-term risks of mortality associated with crystalline silica was calculated using relative linear regression model (13). Data were analyzed according to linear regression model, as follows: Relative excess rate of mortality (A)= $0.77+373.69^*$ geometric mean (GM)exposure, assuming 45 years continuous work history and a 10-yr interval in incidence of disease after 45 years of exposure.

Table 1: Arithmetic and geometric mean of crystalline silica in various casting processes (mg/m^3)

| Casting processes type | Number of samples | Arithmetic mean | Geometric mean | Min | Max |
|------------------------|-------------------|-----------------|----------------|-------|------|
| Cast iron | 46 | 0.032 | 0.05 | 0.001 | 0.32 |
| Brass | 12 | 0.032 | 0.06 | 0.001 | 0.36 |
| Aluminum | 3 | 0.009 | 0.01 | 0.01 | 0.02 |
| Alloys | 19 | 0.04 | 0.04 | 0.01 | 0.20 |

Table 2: Risk assessment of occupational exposure to crystalline silica in the various processes and foundry sectors based on cumulative exposure ($\text{mg}/\text{m}^3\text{-year}$)

| Number of worker No. (%) | Relative risk of death (No. / 1000 exposures) | Cumulative exposure ($\text{mg}/\text{m}^3\text{-year}$) |
|-----------------------------|--|---|
| 77(96.25%) | 1.0 | 0.0-0.99 |
| 2(2.5%) | 3.4 | 0.99-1.97 |
| - | 6.2 | 1.97-2.87 |
| - | 9.4 | 2.87-4.33 |
| 1(1.25%) | 13.7 | 4.33-7.12 |
| - | 22.6 | 7.12-9.58 |
| - | 24.0 | 9.58-13.21 |
| - | 40.2 | 13.21-15.89 |
| - | 52.1 | 15.89-28.1 |

Results

Eighty workers from 29 workshops with 4 different processes were studied. Study subjects mainly worked more than 8 h per day, and 6 days per wk. Thirty-five workers (43%) were in the age range 15-25 years, 29 (36%) had less than one year's work experience, and 42 (52%) had work experience of 1-10 years. Fifty percent of workers were exposed to crystalline silica dust in excess of Recommended Exposure Limit -NIOSH and Threshold Limit Value ACGIH ($0.025 \text{ mg}/\text{m}^3$)^(15, 19). Workers' exposure to crystalline silica dust in 4 different casting processes was in the range 0.001 to $0.36 \text{ mg}/\text{m}^3$ (Table 1).

Different casting processes had different amounts of exposure to crystalline silica, from the most to least: brass, Cast iron, alloys (composed of the other three processes) and aluminum, respectively. Cumulative exposure of all exposed workers in different casting processes was performed according to classified Marnettje model for cumulative exposure in different ranges. Table 2 presents percentage of exposed population in different exposure groups.

Risk of silicosis-related mortality was in the range of 1-13.7 per 1000 exposures. Risk of mortality due to lung cancer in exposed workers in casting foundries in Pakdasht, Iran was calculated according to Rice et al. model (13), based on geometric

mean of exposure to crystalline silica and 45 years of exposure (Table 3). Risk of lung cancer in exposed population in different casting processes was in the range 4-16 workers per 1000 exposures.

Table 3: Risk assessment of lung cancer in foundry workers in different processes based on Rice and Associates regression models

| Casting processes type | Number of samples | Arithmetic mean mg/m ³ | Number of worker at risk |
|------------------------|-------------------|--------------------------------------|--------------------------|
| Cast iron | 46 | 0.032 | 13 |
| Brass | 12 | 0.032 | 13 |
| Aluminum | 3 | 0.009 | 4 |
| Alloys | 19 | 0.04 | 16 |

Discussion

This study presents the first history of occupational exposure of workers to quartz dust in small casting foundries unit (less than 10 workers) in Pakdasht, Iran. The present study has the advantage of dealing only with small casting foundries, with lower production capacity, whereas other studies have been conducted on larger foundries or a combination of the two. Furthermore, the present study focused on different casting processes (Cast iron, brass, aluminum, or alloy of all three) in terms of rate of exposure to crystalline silica concentration.

The results are only an estimate of the real risk in exposed workers. The arithmetic mean of exposure of workers to crystalline silica in 4 different processes ranged from 0.01 to 0.06 mg/m³, and geometric mean ranged from 0.009 to 0.04 mg/m³. Since there are no studies conducted so far to compare 4 different processes in terms of exposure to crystalline silica dust, thus, no comparison was possible with other studies. Mean exposure of workers in aluminum casting process was less than other processes. Since comparison of workers' exposure with health standards does not provide a clear outlook on their health status, thus in this study, according to method based on risk assessment Robert et al. model (10) was used for incidence of silicosis and lung cancer. Moreover, with Marnette et al. model (11) and cumulative exposure classification, 96% of exposed population

were in the cumulative exposure range of 0-0.99 mg/m³-year, which agreed with relative acceptable risk of silicosis-related mortality, i.e., one per one thousand, and the remaining workers (3.75%) were exposed to frequency risk from 3-13 in 1000 exposure, which was higher than the rate found at this range (15%) in a study that reported silicosis-related mortality risk between 1% and 52% per 1000 workers, which was higher than that found in present study, due to young age of workers, with little work history and lower cumulative exposure, and also that since present study was conducted on small foundries only, where spread of dust is less than in larger foundries (16). Since workers were young and had little work history (Marnette classification is based on annual cumulative exposure, and risk is determined accordingly), despite unacceptable risk level for 3 workers, pollution should be controlled, as within 10 years, this number will probably reach 50 workers, so the number of people exposed to unacceptable risk levels will increase.

Many studies have been conducted on the relationship between exposure to free silica and risk of silicosis. This study assessed the relationship between cumulative exposure (free silica and duration of exposure in years) and risk of silicosis according to Marnette model, in which relative risk of mortality for cumulative exposure of 5.4 mg/m³-year, was 13.7% per 1000 workers, and in

the present study, 1 worker (1.25%) was within this range, which can be due to small sample size, young workers and therefore little work history and lower cumulative exposure of workers. Comparing silicosis risk assessment in this study with the real risk in a cohort study conducted on 3010 Chinese workers, with results showing 33.7% of workers had silicosis, was not very unexpected. 69% of those with silicosis had cumulative exposure to crystalline silica dust of 5.4 mg/m³-year (17). The model used in this study for risk assessment of silicosis-related deaths may show lower risk levels compared to the above cohort study, for example, according to Marnett et al. model, relative risk of death due to silicosis for cumulative exposure of 5.4 mg/m³-year was 13.7 per 1000, and in the Chinese cohort study, 33.7% of those with silicosis were indentified (17). To better understand future risk of exposed workers in Pakdasht-Iran, a comparison was made with real risk in another cohort study on 4626 workers in sand industry from 1974 to 1995, with a mean work history of 9 years and a mean exposure to crystalline silica of 0.05 mg/m³-year, in which silicosis-related mortality rate was estimated at 18.2 (18). In addition to silicosis problem in workers exposed to free silica, the risk of lung cancer was reported 18-19 workers per 1000, according to NIOSH studies on workers' lifetime exposure to crystalline silica with concentration of 0.05 mg/m³(11).

In this study, lung cancer risk assessment in workers exposed to quartz was carried out according to relative linear regression model (13), commonly used in other studies (19). Accordingly, frequency of risk of mortality due to lung cancer for long-term exposure of 45 years to 0.05 mg/m³ (ACGIH-TLV) is 19 per 1000 exposed people (20). Recently, this has been reduced by ACGIH to 0.025 mg/m³, which makes the risk 10 per 1000 exposed (21). But, it may not provide the safety required for acceptable risk level of 1 per 1000 (22). Due to the changeable nature of exposure in each process, ranging from 0.04 to 0.032 mg/m³, relative linear regression model was used, which anticipated mortality rate due to lung cancer in the range of 4-16 per 1000 exposed population in 45 years of continuous work. According to the theory

of acceptable long-term risk of less than 1 per 1000 (22), estimated risk assessment in this study is high, and can lead to significant payment of damages by the company and the Office of National Insurance. Despite the high estimate of risk of death due to lung cancer in casting workers of Pakdasht-Iran, the outcomes of exposure to quartz (given the young age of most workers and interval of 10 years to develop lung cancer) after 45 years of exposure are yet to be observed.

Conclusion

Due to dispersion of exposure to crystalline silica in each process, which was within the range 0.009 to 0.04 mg/m³, relative linear regression model was used to calculate the risk of lung cancer, accordingly found in the range 4-16 per 1000 exposed people after 45 years of continuous work. Such a high risk can lead to substantial payment of damages by the company and Office of National Insurance. Given the young age of most workers and interval of 10 years to develop lung cancer, despite the high estimate of risk of death due to lung cancer in casting small foundry workers of Pakdasht, Iran, the outcomes of exposure to quartz after 45 years of exposure are yet to be observed. Thus, it is essential to carry out routine control procedures (23) including use of ventilation, improved working conditions, and use of appropriate personal protective equipment according to different processes in casting industry, as an action to prevent silicosis and lung cancer, and to avoid payment of damages to the victims.

Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

Acknowledgments

The authors would like to acknowledge manager of Health Center of Pakdasht, Iran (Ranjbar H)

whose efforts made this study possible. This work was funded by the School of Public Health, Tehran University of Medical Sciences. The authors declare that there is no conflict of interests.

References

- Guthrie GD, Heaney PJ (1995). Mineralogical characteristics of silica polymorphs in relation to their biological activities. *Scand J Work Environ Health*, 21 (Suppl 2), 5- 8.
- International Agency for Research on Cancer (1987). Silica, some silicates, IARC, Monographs on the evaluation of carcinogenic risks to hum mans. 42, 39–41. Lyon, France. World Health Organization.
- Altindag ZZ, Baydar T, Isimer A, Sahin G (2003). Neopterin as a new biomarker for the evaluation of occupational exposure to silica. *Int Arch Occup Environ Health*, 76, 318–322.
- Flanagan ME, Seixas N, Majar M, Camp J, Morgan M (2003). Silica dust exposures during selected construction activities. *Am Ind Hyg Assoc J*, 64, 319–328.
- Occupational Safety and Health Administration (2001). *Air contaminants*. 29 CFR 1910.1000. Washington, DC.
- National Institute for Occupational Safety and Health (2002). *Health effects of occupational exposure to respirable crystalline silica*. Department of Health and Human Services. Centers for Disease Control and Prevention.
- International Agency for Research on Cancer (1997). *Silica, some silicates, coal dust and para-aramid fibrils*. IARC Monographs on the evaluation of carcinogenic risks to hum mans. 68. 42–242. Lyon, France. World Health Organization.
- Linch KD, Miller WE, Althouse RB, Groce DW, Hale JM (1998). Surveillance of respirable crystalline silica dust using OSHA compliance data (1979-1995). *Am J Ind Med*, 34 (6), 547- 58.
- Davis GS, Harber P, Schenker MB, Balmes JR (1996). *Occupational and environmental respiratory disease*. 1st ed. St. Louis, MO: Mosby—Year Book, Inc, pp.: 373–99.
- Robert CJ, Williams PL, Roberts SM (2000). Risk assessment. In: *Principles of toxicology, environmental and industrial applications*. Eds, Williams PL, James RC, Roberts SM. Wiley-Inter Science Publication. pp. 437-77.
- Mannetje A, Steenland K, Attfield M, Boffetta P, Checkoway H, DeKlerk, N, Koskela RS (2002). Exposure-response analysis and risk assessment for silica and silicosis mortality in a pooled analysis of six cohorts. *Occup Environ Med*, 59 (11), 723- 8.
- Sherson D (2002). Silicosis in the twenty first century. *Occup Environ Med*, 59(11), 721- 2.
- Rice FL, Park R, Stayner L, Smith R, Gilbert S, Checkoway H (2001). Crystalline silica exposure and lung cancer mortality in diatomaceous earth industry workers. A quantitative risk assessment. *Occup Environ Med*, 58 (1), 38- 45.
- US Department of Labor (1996). *Press release on joint campaign on silicosis prevention. Labor Secretary calls for an end to silicosis*. Washington, DC. Department of Labor, Office of Public Affairs.
- National Institute for Occupational Safety and Health (2003). *Silica, Crystalline*. by VLS. NIOSH Manual of Analytical Methods (NMAM), 4th ed., 7601.
- Rezazadeh Azari, M, Rokni M (2009). Risk assessment of workers exposed to crystalline silica aerosols in the east zone of Tehran. *Tanaffos*, 8(3), 43-50.
- Chen W, Zhuang Z, Attfield MD, Chen BT, Gao P, Harrison JC (2001). Exposure to silica and silicosis among tin miners in China exposure-response analyses and risk assessment. *Occup Environ Med*, 58 (1), 31- 7.
- Steenland K, Sanderson W (2001). Lung cancer among industrials sand workers exposed to crystalline silica. *Am J Epidemiol*, 153 (7), 695- 703.
- Steenland K, Mannetje A, Boffetta P et al. (2001). Pooled exposure-response analyses and risk assessment for lung cancer in 10 cohorts of silica-exposed workers: an IARC multicentre study. *Cancer Causes Control*, 12 (9).773- 84.
- American Conference of Governmental Industrial Hygienists (2002). *Threshold Limit Values (TLV) and Biological Exposure Index (BEI)*, Cincinnati, 2311, Ohio.
- American Conference of Governmental Industrial Hygienists (2011). *Threshold Limit Values (TLV) and Biological Exposure Index (BEI)*, Cincinnati, 2311, Ohio.
- Rodricks JV, Brett SM, Wrenn GC (1987). Significant risk decisions in federal regulatory agencies. *Regul Toxicol Pharmacol*, 7(3), 307-20.
- National Institute for Occupational Safety and Health (1998). *A guide to working safely with silica*. U.S. Department of labor.