Silicosis in Automobile Foundry Workers: A 29-Year Cohort Study

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Objectives The purposes were to determine the relationship between silicosis among foundry workers and their cumulative exposure to silica dust, and to establish a regression model to predict the risk for developing silicosis by a given length of employment and air concentrations of silica at worksites. **Methods** A 29-year cohort study was conducted, including all those employed for more than one year during January 1, 1980 to December 31, 1996 and all members of the cohort were followed-up to December 31, 2008. In total, 2 009 workers of an automobile foundry in Shiyan, Hubei province were recruited in the study, 1 300 at eight worksites including sand preparation, cast shakeout, and finishing, melting, moulding, core-making, overhead crane operation and pouring as exposed group, and the other 709 auxiliary workers at the same factory, such as electricians, inspectors, fitters, and so on, as control group. Person-years of observation were calculated by persons observed and years followed-up for each of them. Person-year incidence of silicosis and its relative risk (RR) or odds ratio (OR) and 95% confidence intervals (CI) among the workers were estimated, adjusted for relevant factors with logistic regression model using SPSS version 15.0 software. **Results** Totally, 2 009 workers were followed-up for 37 151 person-years and 48 cases of silicosis were found, with an overall incidence of 1.34 per thousand, 2.02 per thousand in exposed group, and 0.15 per thousand in control one. Risk of silicosis was significantly higher in the exposed group than that in the control one (RR=13.13, 95% CI 3.18-54.13), higher in men than that in women (RR=13.92, 95% CI 1.92-100.93). Risks of silicosis varied by job, highest in those exposed to cast shakeout and finishing (RR=28.14, 95% CI 6.43-123.11), followed by those exposed to pouring (RR=22.23, 95% CI 5.01-98.55) in the foundry. Average length of employment at onset of silicosis was 25.94 years, and silicosis incidence increased with length of employment. Average age at onset of silicosis was 47.83 years old. The risk of silicosis in workers with pulmonary tuberculosis was 2.57 folds as those without it ($P<0.01$). Ten deaths were recorded in those with silicosis, with a case-fatality rate of 20.83 percent three of them died of lung cancer, three of liver cancer, two of ischemic heart disease, and two of other diseases as their immediate causes of death. Incidence of silicosis in foundry workers positively correlated with their cumulative silica exposure (OR=3.00, 95% CI 2.34-3.83). Risks of silicosis increased by 4.38 folds with an increase of 1 mg/m^3-year of cumulative silica exposure, and by 3.79 folds with smoking, respectively, adjusted for alcohol drinking and age. Based on a logistic regression model fitted, incidence of silicosis is expected to be 44.6 per thousand for those with daily exposure to silica of 4.18 mg/m^3 in average for 30 years, and if incidence of silicosis is expected to be less than 1 per thousand, daily exposure to silica should be controlled below 0.2 mg/m^3 for those with 20 years of employment, or below 0.1 mg/m^3 for those with 30 or 40 years of silica exposure. **Conclusions** At present, foundry workers in China still face high risk of developing silicosis. For lowering occurrence of silicosis in exposed workers, it seems necessary that current occupational exposure limits for silica at worksites in China should be reexamined and silica dust control measures be strengthend.

Key words: Foundry; Silica; Silicosis; Occupational exposure limit; Cohort study; Incidence; Person-year; Relative risk (RR); Odds ratio (OR)

INTRODUCTION

There have been clear evidences that foundry working can cause silicosis[1-14]. There is a known exposure-response relationship between accumulative exposures to silica and development of silicosis, which is applied to setting and assessing national occupational exposure limits (OELs) in developed countries[1]. Previous studies showed that free crystalline silica accounted for over 20% of total

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silica dust in foundry[15], with high dispersion[10, 15]. Scanning electron microscopy-energy dispersive X-ray analysis (SEM-EDS) suggested that particles in surface of silica contained higher content of free silica with higher toxicity. Until recently, few studies on silicosis morbidity and its relationship with accumulative exposure to silica dust in foundry was available in China, and current OELs for silica in the country are 10 to 100 times higher than those in developed countries[16-17], however, its expected morbidity was lower than that in developed countries. Assuming that protection level of OELs set for silica is 1 per thousand of cumulative risk of developing silicosis in those with a daily total silica exposure of 1 mg/m^3 or respirable silica exposure of 0.7 mg/m^3 for 30 years, it shound that this assumption could not be realized in China, now. On the other hand, air concentration of silica in foundry has been dramatically dropped because of phenol formaldehyde resin sand being introduced into foundry process and comprehensive silica-proof measures being taken since 1980s[15, 18-20], but actual silica leve where foundry workers exposed was usually higher than those set in national OELs for silica in China. Therefore, foundry workers in this country still face a high risk of developing silicosis. This study was designed to determine relationship between incidence of silicosis in foundry workers and their cumulative exposure to silica dust, as well as to establish a regression model to predict risk of developing silicosis by a given length of employment and concentration of silica at worksites of foundry.

MATERIAS AND METHODS

Selection of Study Sites and Subjects

A cohort study was conducted including all those employed for more than one year during the period of January 1, 1980 to December 31, 1996 in a foundry under a state-owned large-scale automobile company in Shiyan, Hubei province. The cohort was followed up to December 31, 2008. In total, 1 300 of 2 009 workers at eight worksites of sand preparation, cast shakeout, and finishing, melting, moulding, core-making, overhead crane operation, and pouring in foundry were defined as exposed group, and the other 709 auxiliary workers of the same factory , such as electricians， inspectors, fitters, and so on, as control group. Those workers who had any other previous exposure to other silica or other chemicals, or exposed to wood silica or X-rays were all excluded. In this cohort, the exposed group meant high- and medium-exposure to silica, and the control group was at low-exposure because their working hours at the same worksite were only one quarter of those as foundry workers during the same period.

Data Collection

Industrial hygienic files have been developed and kept since 1979 in the factory, and perfected and updated gradually since 1989. From 1979, occupational health surveillance and occupational diseases registration system have also been established. Employees exposed to silica were subject to initial medical examinations and further periodic examinations every three years, including chest (posterior-anterior) radiographs. A standard medical record form was completed for each employee by occupational physicians at each visit, containing the following information: name, gender, date of birth, job, or work process employed including name of job and workshop, length of any previous work including dates of starting and ending, exposures to other dust, asbestos, or other chemicals, cigarette smoking, and alcohol drinking behavior, medical history with diagnosed illness, and date for diagnosis for the employees.

Diagnosis for Silicosis

Silicosis was diagnosed based on the National Diagnostic Criteria for Silicosis (GBZ 70-2002)[21] by a group of experts based on consensus, including radiologists, physicians, and industrial hygienists, with the date of diagnosis as the date of silicosis onset.

Survey Methods

Demographic data and medical records of the employees, and industrial hygienic files in the study were obtained from the kept files mentioned above, with a series of forms which were pre-tested in a sample of 20 workers before the study to ensure their feasibility, validity and plausibility.

Air concentrations of total silica at worksites were monitored from static samplers (more than 2 000 samples collected) twice each year during 1978 to 2008 in the foundry and determined by filter membrane weighing method. Air concentrations of silica before 1978 were estimated based on those of 1978 with conversion from those at the same job-specific worksite.

Several investigators responsible for information collection were trained before field study. Multiple quality control measures were taken to control lost to follow-up as low as far as possible.

Calculation of Estimated Silica Exposure

Individual exposure data were obtained from employment history, including locations and length of work.

For each cohort member, cumulative exposure was calculated by summing up all the products multiplying interval (days) from the first employment to the last employment by the estimated exposed silica concentrations at all jobs in various workshops of the foundry. Average exposure was derived by dividing cumulative exposure by total days employed. Estimated silica exposure by job was obtained by two ways, i.e., for the exposed group, exposure was estimated by routine monitored concentrations, and for the control group, it was estimated as one quarter of mean concentration of the same workshop or the factory as a whole during the same period, respectively.

Statistical Analysis

Exposure start was defined as the time of first employment in foundry, and exposure end as the time of silicosis onset, job transfer or retirement.

All data were input with EpiData version 3.1 software and Office Excel 2003 software for Windows from a dataset. The data were compiled and cleaned with SAS version 8.1 software. Person-year incidence, relative risk (RR), or odds ratio (OR) with various factors and their 95% confidence intervals (CI) for silicosis in the workers were estimated, adjusted for related factors with logistic regression model using SPSS version 15.0 software.

RESULTS

Air Concentration of Silica Dust at Worksites

Results of monitoring for air concentrations of total silica dust from 1978 to 2008 are presented by Figs. 1 and 2.

Overview of Follow-up for the Cohort

Cohort members in this study numbered 2009 individuals, with 1 405 men (70%) and 603 women (30%), with one unclear in gender information. Missing information in age, length of employment, cigarette smoking, and alcohol drinking was 5.2 percent, 0.2 percent, 1.9 percent, and 1.9 percent, respectively. Twenty-two were lost to follow-up, with an overall response rate of 98.91 percent, and a total of 37 151 person-years during the 29-year follow-up. Forty-eight cases of silicosis were recorded and no case progressed to higher classifications of silicosis since first diagnosis was found. Characteristics of the cohort members and cases of silicosis were shown in (Table 1).

Silicosis Incidence and Mortality

Person-year incidence of silicosis was 2.02 per thousand in the exposure group and 0.15 per thousand in the control group, respectively, majority at

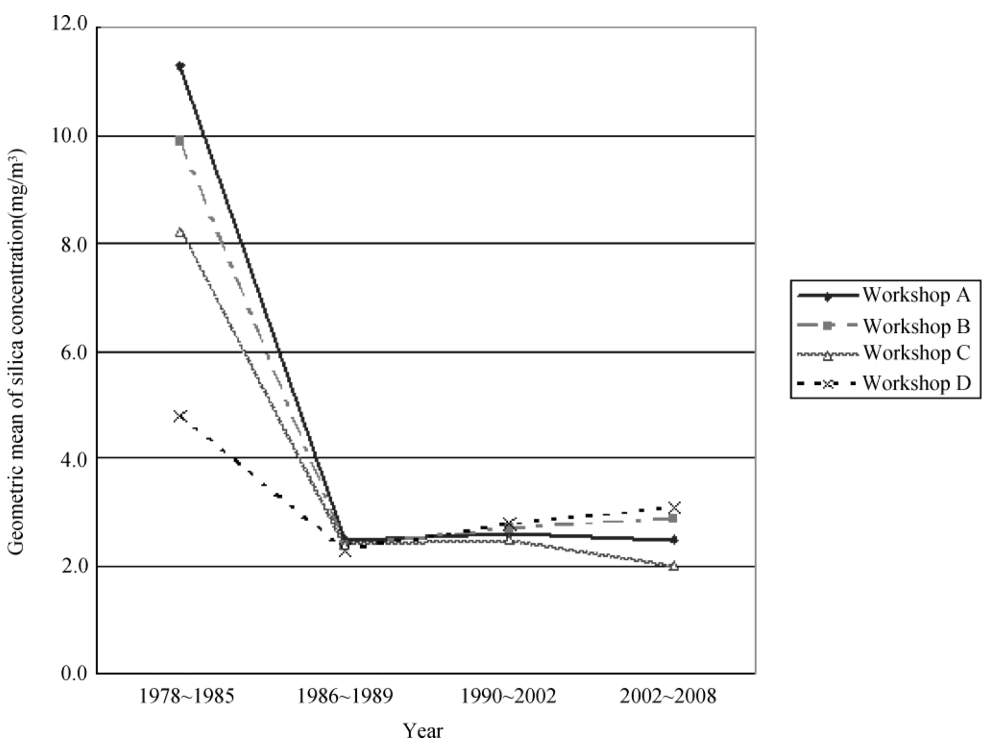

FIG. 1. Changes of geometric means of air concentrations of total silica dust by worksites in foundry during 1978 to 2008 (No. sample=2 777).

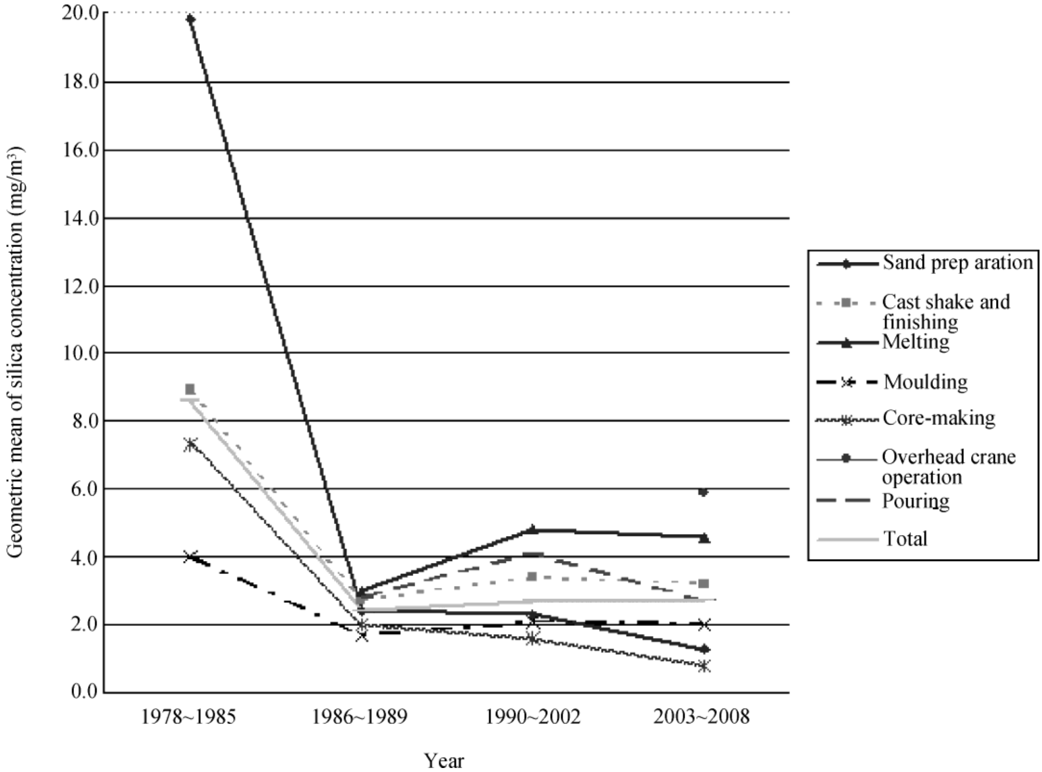

FIG. 2. Changes of geometric means of air concentrations of total silica by job in foundry during 1978 to 2008 (sample No.=2 889).

job of cast shakeout and finishing, and no case at overhead crane operation. Incidence of silicosis was higher in men than that in women, and increased with length of employment (Table 2).

Average length of employment at onset of silicosis was 25.94 years, with shortest at job of cast shakeout and finishing (19.04 yrs), followed by rank at jobs of sand preparation (28.16 yrs), melting (27.62 yrs), core-making (27.44 yrs), pouring (22.04 yrs), and molding (32.09 yrs). Average age at onset of silicosis was 47.83 years. There were 10 deaths in silicosis cases, with a case-fatality ratio of 20.83 percent, and three died of lung cancer, three of liver cancer, two of ischemic heart disease and two of other diseases as immediate causes of death.

TABLE 1

Characteristics of Study Subjects in Foundry during1980 to 2008

Characteristics		Exposure Group		Control Group		Total	
		No. Workers (%)	No. Silicosis Cases (%)	No. Workers (%)	No. Silicosis Cases (%)	No. Workers (%)	No. Silicosis Cases (%)
Gender	Male	805 (61.9)	45 (97.8)	600 (84.7)	2 (100.0)	1 405 (70.0)	47 (97.9)
	Female	495 (38.1)	1 (2.2)	108 (15.3)	0 (0.0)	603 (30.0)	1 (2.08)
	Total	1 300 (100.0)	46 (100.0)	708 (100.0)	2 (100.0)	2 008 (100.0)	48 (100.0)
Age (yrs)	15-35	42 (3.4)	0 (0.0)	42 (6.2)	0 (0.0)	84 (4.4)	0 (0.0)
	36-45	294 (23.9)	14 (30.4)	180 (26.7)	1 (50.0)	474 (24.9)	15 (31.3)
	46-60	564 (45.9)	30 (65.2)	293 (43.4)	1 (50.0)	857 (45.0)	31 (64.6)
	>60	330 (26.8)	2 (4.3)	160 (23.7)	0 (0.0)	490 (25.7)	2 (4.2)
	Total	1 230 (100.0)	46 (100.0)	675 (100.0)	2 (100.0)	1 905 (100.0)	48 (100.0)

(to be continued)

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Characteristics		Exposure Group		Control Group		Total	
		No. Workers (%)	No. Silicosis Cases (%)	No. Workers (%)	No. Silicosis Cases (%)	No. Workers (%)	No. Silicosis Cases (%)
Length of Employment (yrs)	≤10	322 (24.8)	1 (2.2)	158 (22.4)	0 (0.0)	480 (24)	1 (2.1)
	11-20	436 (33.6)	1 (2.2)	218 (30.9)	0 (0.0)	654 (32.6)	1 (2.1)
	21-30	381 (29.3)	8 (17.4)	245 (34.8)	0 (0.0)	626 (31.2)	8 (16.7)
	>30	160 (12.3)	36 (78.2)	84 (11.9)	2 (100.0)	244 (12.2)	38 (79.1)
	Total	1 299 (100.0)	46 (100.0)	705 (100.0)	2 (100.0)	2 004 (100.0)	48 (100.0)
Cigarette Smoking	No	848 (66.4)	14 (30.4)	457 (65.9)	1 (50.0)	1 305 (66.2)	15 (31.3)
	Yes	430 (33.6)	32 (69.6)	236 (34.1)	1 (50.0)	666 (33.8)	33 (68.7)
	Total	1 278 (100.0)	46 (100.0)	693 (100.0)	2 (100.0)	1 971 (100.0)	48 (100.0)
Alcohol Drinking	No	1 053 (82.4)	34 (73.9)	586 (84.6)	1 (50.0)	1 639 (83.2)	35 (72.9)
	Yes	225 (17.6)	12 (26.1)	107 (15.4)	1 (50.0)	332 (16.8)	13 (27.1)
	Total	1 278 (100.0)	46 (100.0)	693 (100.0)	2 (100.0)	1 971 (100.0)	48 (100.0)

TABLE 2

Person-year Incidence of Silicosis by Exposure Groups in Foundry during 1980 to 2008

Groups		No. of Workers	Person-years Observed	No. of Cases	Person-year Incidence (1/1000)	RR (95% CI)
Jobs in Exposure Group	Total	1 298	22 801.87	46	2.02	13.47 (3.27-55.49)*
	Sand Preparation	140	2 675.52	3	1.12	7.24 (1.21-43.35)*
	Cast Shakeout and Finishing	192	3 443.82	15	4.36	28.14 (6.43-123.11)*
	Melting	240	4 450.64	4	0.90	5.81 (1.06-31.73)*
	Molding	202	3 776.93	14	3.71	24.73 (5.62-108.86)*
	Core-making	293	4 670.12	8	1.71	11.07 (2.35-52.15)*
	Overhead Crane Operation	163	2 519.09	0	0.00	
	Pouring	68	1 265.76	2	1.58	10.21 (1.44-72.55)*
Control Group		705	12 916.71	2	0.15	
Total		2 003	35 718.59	48	1.34	
Gender						
Men	Exposure Group	804	16 226.02	45	2.77	15.39 (3.73-63.45)*
	Control Group	598	11 352.65	2	0.18	
Women	Exposure Group	494	6 575.85	1	0.15	
	Control Group	106	1 553.96	0	0.00	
Total	Exposure Group	1 298	22 801.87	46	2.02	13.47 (3.27-55.49)*
	Control Group	704	12 906.61	2	0.15	
Length of Employment (yrs)						
≤10	Exposure Group	322	1 588.47	1	0.63	
	Control Group	158	822.26	0	0.00	
11~20	Exposure Group	436	6 501.47	1	0.15	
	Control Group	218	3 190.84	0	0.00	
21~30	Exposure Group	381	9 664.04	8	0.83	
	Control Group	245	6 094.99	0	0.00	
>30	Exposure Group	160	5 047.89	36	7.13	10.04 (2.42-41.73)
	Control Group	84	2 808.62	2	0.71	
Total	Exposure Group	1 299	22 801.87	46	2.02	13.47 (3.27-55.50)
	Control Group	705	12 916.71	2	0.15	

Note. *indicating statistical significance of difference.

Factors Related to Silicosis Incidence

Smoking and pulmonary tuberculosis in workers could increase their risk of silicosis development (Table 3).

TABLE 3

Incidence of Silicosis by Some Variables in Foundry Workers during 1980 to 2008

Variables		No. Workers	Person-years	No. Cases	Person-year Incidence (1/1 000)	RR (95% CI)
Cigarette Smoking	Yes	666	15 465.53	33	21.34	2.81 (1.53-5.18)*
	No	1 305	19 727.70	15	7.60	
Alcohol Drinking	Yes	332	7 801.37	13	16.66	1.30 (0.69-2.46)
	No	1 639	27 391.85	35	12.78	
Pulmonary Tuberculosis	Yes	88	2 223.84	7	31.47	2.57 (1.15-5.74)*
	No	1 921	33 494.75	41	12.24	

Note. *$P<0.05$.

Results of multivariate logistic regression analysis showed that risk of silicosis increased by 4.38 folds with increase of 1 mg/m^3-year of cumulative silica exposure and by 3.79 folds with smoking, respectively, adjusted for alcohol drinking, and age (Table 4).

TABLE 4

Multivariate Logistic Regression Analysis for Factors Influencing Silicosis in Foundry Workers during 1980 to 2008

Variables	B	Wald χ^2	*P*-value	OR (95.0% CI)
Cumulative Silica Exposure**	1.68	93.02	0.00	5.38 (3.82-7.57)
Cigarette Smoking**	1.57	16.25	0.00	4.79 (2.24-10.27)
Alcohol Drinking	-0.51	1.50	0.22	0.60 (0.26-1.36)
Age**	-0.18	51.29	0.00	0.83 (0.79-0.88)
Constant	-2.48	6.81	0.01	0.08

Note. **$P<0.01$.

Logistic Regression Model for Silicosis Prediction

A logistic regression model used to predict risk for silicosis in relation to cumulative silica exposure was described as follows:

$$P=\frac{\exp[\beta_0+\beta\ln(ab)]}{1+\exp[\beta_0+\beta\ln(ab)]}$$

where P=cumulative risk for silicosis, β_0=constant (intercept), β=coefficient of regression, a=daily average exposure to silica (mg/m^3), b=length of employment (year).

Results of logistic analysis showed that risk of silicosis increased two folds with an increase in cumulative silica exposure of 1 mg/m^3-year in the exposed group (Table 5).

TABLE 5

Logistic Regression Analysis for Silicosis by Cumulative Silica Exposure in Foundry Workers during 1980 to 2008

Variables	B	Wald χ^2	*P*-value	OR (95% CI)
Cumulative Silica Exposure**	1.10	76.03	0.00	3.00 (2.34-3.83)
Constant	-8.37			

Note. **$P<0.01$.

According to results in Table 5, β is estimated as 1.1 and β_0 as -8.37, which then were substituted in the predictive model mentioned above, and risk for developing silicosis could be predicted at a given length of employment and exposure to daily silica concentration in foundry workers. Incidence of silicosis was expected to be 44.6 per thousand with average daily exposure to 4.18 mg/m^3 of silica for 30 years, and if incidence of silicosis was expected to be less than 1 per thousand, their daily average exposure to silica should be controlled below 0.2 mg/m^3 for 20 years of employment, or below 0.1 mg/m^3 for 30 or 40 years of employment (Fig. 3).

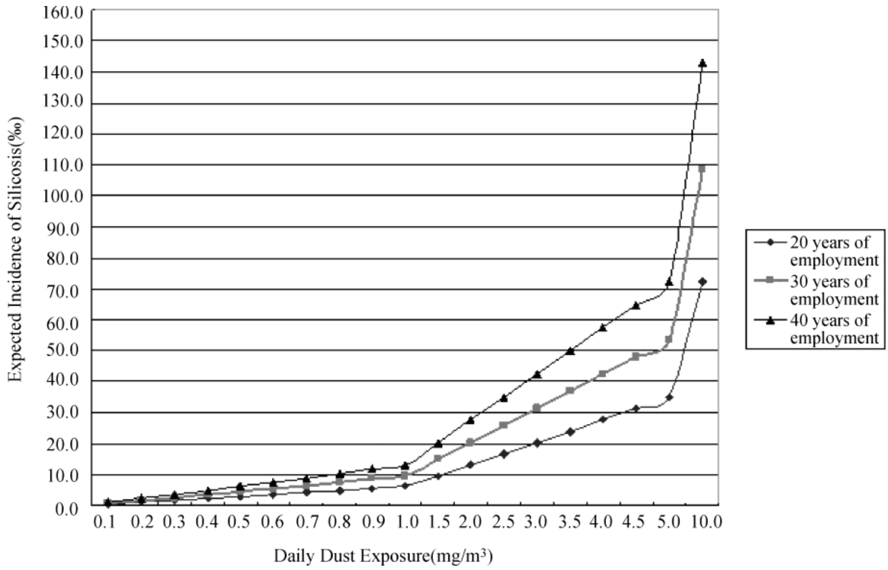

FIG. 3. Expected incidence of silicosis at varied daily silica exposure and length of employment.

DISCUSSIONS

A 29-year cohort study was conducted to explore relationship between silica exposure, other relevant factors, and potential confounders with silicosis in foundry workers, with qualified basic data collected through various channels. Data were sourced from routine environmental monitoring and occupational health surveillance at worksites by professional bodies. Quality control was instituted throughout all phases of design, implementation, data input, and analysis for the study. Eligibility of inclusion and exclusion of cohort members were clearly defined. Various measures were used to control loss to follow-up in the cohort. Adequate statistical analysis methods were used to calculate person-years of observation for the workers, incidence of silicosis, its distribution by various characteristics, and factors related. Therefore, the results of the study are reliable.

Although some studies on silicosis among foundry workers in China were conducted previously, their limitations were obvious, such as un-adjusted potential confounding, few in cohort study. This 29-year cohort study elaborated factors related to silicosis among foundry workers. Person-year of observation among foundry workers was calculated. A logistic regression model was established for prediction of risk for developing silicosis at a given length of employment and exposure to silica dust in foundry workers, resulting in a valid exposure-response relationship.

Results of the study show person-year incidence of silicosis was 2.02 per thousand in the exposure group and 0.15 per thousand in the control one, respectively; but if at current silica exposure level (4.18 mg/m^3) for 30 years, incidence of silicosis was 44.6 per thousand. In 1987, a study from China[13] reported expected risk for developing silicosis was less than 1 percent, if air concentration of silica at worksite was controlled below 3.69 mg/m^3, or 0.5 percent if air silica concentration below 3.12 mg/m^3 in workers with 40 years of employment. But methods of data collection, and the control of the potential confounders were not clear in that study.

Person-year incidence of silicosis was 4.36 per thousand in workers at cast shakeout and finishing, 3.71 per thousand at moulding, 1.71 per thousand at core-making, 1.58 per thousand at pouring, 1.12 per thousand at sand preparation, and 0.9 per thousand at melting, respectively. Risk for silicosis was significantly higher in the exposed group than that in the control one (RR=13.13, 95% CI 3.18-54.13). Risk for silicosis varied by jobs, highest at cast shakeout and finishing (RR=28.14, 95% CI 6.43-123.11), followed at moulding (RR=22.23, 95% CI 5.01-98.55), core-making (RR=11.07, 95% CI 2.35-52.15), pouring (RR=10.21, 95% CI=1.44-72.55), sand preparation (RR=7.24, 95% CI=1.21-43.35), and melting (RR=5.81, 95% CI 1.06-31.73).

For the whole cohort, incidence of silicosis was higher in men than that in women, with an RR of 13.92 and its 95% CI of 1.92-100.93. In exposure group, person-year incidence of silicosis in male workers was 2.71 per thousand, significantly higher than that in female workers (0.15 per thousand), with an RR of 18.07 and its 95% CI of 2.49-131.16. In the control group, person-year incidence of silicosis was 2.71 per thousand in men, but no silicosis case was found in women.

The average length of employment at onset of silicosis was 25.94 years, shortest in those exposed to cast shakeout and finishing (19.04 years), followed by pouring (22.04 years), core-making (27.44 years), melting (27.62 years) and sand preparation (28.16 years), respectively, and longest in those exposed to moulding (32.09 years). The average age at onset of silicosis was 47.83 years. A cross-sectional study[22] showed an average length of employment at onset of silicosis of 25.7 years, shortest of 10 years in those exposed to pouring, while longest of 40 years in moulding, and an average age at onset of silicosis 50.8 years.

In this cohort, 10 cases of silicosis died during follow-up, with a case fatality rate of 20.83 percent. Main causes of death included lung cancer (30%), liver cancer (30%), and ischemic heart diseases (20%). Case fatality ratio of silicosis was highest in those exposed to melting (50%), followed by those in sand preparation (33%), and cast shakeout and finishing (27%). Previously, a retrospective cohort study in China[23] showed a highly case fatality ratio for lung cancer in foundry worker's silicosis (SMR=2.15, 95% CI 1.15-3.68). Chuanwei Gan[24] reported that case fatality ratio for silicosis was 15.66 percent (13/83), with the main causes of death by cor pulmonale (4/13), and lung cancer (3/13), but no information about silica concentration and confounders were mentioned in that study.

Logistic regression analysis in this study showed that risk for silicosis increased with cumulative silica exposure, and risk for silicosis increased by two folds with an increase in cumulative silica exposure of 1 mg/m^3-year (OR of 3 and its 95% CI of 2.34-3.83). Taking occurrence of silicosis as dependent variable, and cumulative silica exposure, smoking, alcohol drinking, and age as independent variables for multivariate logistic regression analysis, results showed that silicosis increased with cumulative silica exposure (OR of 5.38 and its 95% CI of 3.82-7.57) and smoking (OR of 4.79 and its 95% CI of 2.24-10.27), and risk for silicosis increased by 4.38 folds with increase in cumulative silica exposure of 1 mg/m^3-year and 3.79 folds in the smoking group, respectively, adjusted for alcohol drinking and age. Silicosis inciodence also increased with length of employment. Difference in risk for silicosis between alcohol drinking and non-drinking groups did not reach statistical significance. Risk for silicosis in high-and medium-exposure groups was 13.77 folds (95% CI of 3.24-58.51) and 12.19 folds (95% CI of 2.86-52.04) as that in control group, respectively. Patients with pulmonary tuberculosis had 2.57 folds of risk for silicosis as those without it (P=0.00).

Previous studies at home and abroad demonstrated that working in foundry can cause silicosis and similar results were obtained in the present study, which showed that incidence of silicosis varied by jobs in foundry due to three factors, cumulative exposure to silica represented by a product multiplying average exposure by length of exposure, nature of silica such as dispersion of silica and its surface components, and other occupational hazards coexisted in foundry to damage the respiratory system, such as sulfur dioxide, ammonia, manganese dioxide, phenol, cadmium, chromium, nickel, formaldehyde, phosphine, benzene, toluene, xylene, and so on.

In developed countries, setting and assessing national occupational exposure limits were widely based on relationship between silicosis among foundry workers and their cumulative exposure to silica[1]. ACGIH[17] stated in its document that because time between initial exposure and signs of fibrosis is characteristically very long, as much as 30 to 40 years, the margin of safety for exposure to crystalline silica at proposed TLV-TWA is not known precisely. Given the observed association between silicosis and lung cancer, it is recommended that air concentration of silica be maintained as far below the proposed TLV as prudent practices will permit. The recommended TLV-TWA of 0.025 mg/m^3 of respirable particulate mass, is intended to prevent pulmonary fibrosis that may be a risk factor for lung cancer. Malmberg and colleagues commented that silica exposures at about twice as TLV-TWA of 0.1 mg/m^3 at that time posed a risk for airway obstruction and increased compliance rather than lung fibrosis[25]. Muir and coworkers suggested that risk calculated over an assumed period of 40-year exposure was 0.4 percent (95% CI of 0.2-0.8) for respirable silica dust of 0.05 mg/m^3 and 1.2 percent (95% CI of 0.7-2.1) for exposure to 0.1 mg/m^3 of silica dust[26]. Hnizdo and Sluis-Cremer[27] stated that latency was independent of dose. Risk for silicosis of 0.2 percent associated with cumulative silica exposure of 0.9 mg/m^3-years for average exposure period of 24 years during follow-up, assuming 30 percent of respirable silica in the sample collected and analyzed. A 5.0 percent of cumulative risk for developing silicosis associated with silica exposure of 0.05 mg/m^3 for 40 years. Steenland and Brown[28] concluded that risk for silicosis was less than 1 percent for those with cumulative silica exposure equal to or less than 0.5 mg/m^3-years and increased to 68 percent to 84 percent for those exposed to more than 4 mg/m^3-years, with an average length of follow-up since initial exposure of 37 years. In China, current exposure limit set for silica dust was assumed that 1 per thousand cumulative risk for developing silicosis associated with total silica exposure of 1 mg/m^3 or respirable silica exposure of 0.7 mg/m^3 for 30 years. Obviously, OELs for silica in China was less strict than that in developed countries. Results of logistic regression model for prediction of silicosis in the present study indicated that if incidence of silicosis was expected to be less than 1 per thousand, daily exposure to silica should be controlled below 0.2 mg/m^3 for workers with 20 years of employment, or below 0.1 mg/m^3 for those with 30 or 40 years of silica exposure, suggesting that current occupational exposure limits for silica in China should be adjusted or revised.

CONCLUSIONS

Results in the present cohort study indicate that foundry workers still face high risk for developing silicosis under current work conditions. And, current occupational exposure limits for silica in China cannot meet the requirements for that cumulative risk for developing silicosis should be less than 1 per thousand over 30-year exposure to 1 mg/m^3 of total silica or to 0.7 mg/m^3 of respirable silica.

Limitation may exist in this study. Chest radiographs (posterior-anterior) for diagnosing silicosis were not fully conformed to the diagnostic criteria for silicosis radiographs set by the International Labor Organization (ILO). Further study should be focused on determining relationship between silicosis in foundry workers and their cumulative exposure to respirable silica dust, to provide more accurate evidence for adjustment of current occupational exposure limits for respirable silica.

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