EFFECTS OF HIGH SILICA EXPOSURE ON RESPIRATORY DISORDERS AMONG STONE-MORTAR WORKERS IN NORTHERN THAILAND

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Abstract. Particulate matter less than ten micrometers in diameter (PM_{10}) containing crystalline silica if inhaled can cause respiratory symptoms. We aimed to determine exposure levels of Thai stone-mortar workers to PM_{10} containing crystalline silica and its potential link to respiratory disorders. This cross-sectional study was conducted among all available workers who had worked at stone-mortar factories for at least one year in the study area. Subjects were divided into two groups: stone cutters (n=29) and stone grinders (n=28). We had a control group which consisted of 20 age and sex matched agricultural workers. All subjects were aged ≥18 years. We measured the exposure levels to PM_{10} containing crystalline silica using a filter-based gravimetric method. We obtained a history of respiratory symptoms from each subject using the American Thoracic Society Division of Lung Disease questionnaire (ATS-DLD-78A). We checked the respiratory effect of exposure using a lung function test and by performing chest radiographs. We used the chi-square, Fisher's exact and Kruskal-Wallis tests and multiple linear regression analysis to examine associations between selected variables and respiratory disorders. The mean crystalline silica levels found among stone cutter subjects (mean±SD, 0.096±0.094 mg/m^3) and stone grinder subjects (mean±SD, 0.130±0.106 mg/m^3) were significantly greater (p<0.001) than those found in controls (mean±SD, 0.004±0.005 mg/m^3). The numbers of subjects with abnormal chest radiographs and abnormal FEV_1/FVC ratios in the exposed groups were significantly higher than the abnormal numbers found in controls. Three cases of silicosis were diagnosis among stone cutters and grinders but none among controls. The crystalline silica levels found in the studied stone cutters and grinders were negatively associated with the percent predicted levels for FEV_1 (p=0.002), FVC (p=0.011), and FEV_1/FVC (p=0.002). Our findings show PM_{10} containing crystalline silica exposure is associated with respiratory disorders and lung function impairment among studied stone-mortar workers. Stone cutters and grinders in the study area should be monitored for the presence of silica exposure and silicosis. Personal protective equipment should be available and mandatory for these high risk groups in the study area.

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INTRODUCTION

Air pollution, especially particulate matter <10 micrometers in diameter (PM_{10}), is a cause of respiratory symptoms (Ibhafidon *et al*, 2014; Lu *et al*, 2015). PM_{10} is contained in many different chemical products. The content varies by the source; the physical characteristics can potentially cause symptoms (Kelly and Fussell, 2012). In the stone industry, which includes mining, masonry, carving, stone grinding and mortar making (CDC, 2002; Nambunmee *et al*, 2014; Tse *et al*, 2015; Silanun *et al*, 2017) factorial processes use an open system which may have ventilation problems with inadequate clearance of PM_{10} and crystalline silica in the workplace. This may lead to higher concentrations of damaging particulate matter in air inspired during stone-mortar production, which often utilizes informal labor (Mukhopadhyay *et al*, 2011; Nambunmee *et al*, 2014; Rafeemanesh *et al*, 2014).

PM_{10} containing crystalline silica is produced during rock cutting, which includes stone cutting, drilling, crushing, grinding, and abrasion (CDC, 2002). Inhalation of PM_{10} containing crystalline silica is a hazard encountered by workers in this industry (CDC, 2002; Bhagia, 2012). Inhalation of PM_{10} containing crystalline silica is a specific problem (Bhagia, 2012; Kelly and Fussell, 2012). Short-and long-term exposure to PM_{10} containing crystalline silica can cause eye and skin irritation, affect the respiratory and cardiovascular systems and is a risk factor for increased mortality due to occupational lung diseases, such as silicosis (Bhagia, 2012; Chen *et al*, 2012; Lu *et al*, 2015). The International Agency for Research on Cancer (IARC) has classified crystalline silica in the form of quartz or cristobalite as a human carcinogen (Guha *et al*, 2011).

After inhalation of crystalline silica, the particles may descend to the lower respiratory tract and activate the phagocytic cells to release cytokines and inflammatory mediators, which then lead to the induction of lung inflammation (Grunig *et al*, 2014; Pollard, 2016). Silica-induced inflammation can cause pulmonary tissue damage and degeneration of the extracellular matrix, leading to granuloma formation, lung remodeling and silicosis (Lopes-Pacheco *et al*, 2016; Pollard, 2016).

Silicosis is an incurable, irreversible lung disease (Sato *et al*, 2018). In 1995, 9% of workers in stone grinding factories in Saraburi, Thailand had radiologic evidence of silicosis (Aungkasuvapala *et al*, 1995). More recently, the overall prevalence of respiratory symptoms among stone carvers in Thailand was reported to be 16.8% while silicosis was reported to occur in 36.1% (Silanun *et al*, 2017). Another study among stone carvers in Thailand reported radiographic abnormalities in 8.9% of those studied (Silanun *et al*, 2017). A study among stone-mortar and pestle workers in Thailand reported 19 subjects with silicosis (Nambunmee *et al*, 2014).

The large proportion of sandstone workers in one study were found to have lung function abnormalities (Chaiear *et al*, 2017). The Department of Primary Industries and Mines for Thailand reported in 2017 there were 436 registered quarrying facilities and factories in Thailand (Department of Primary Industries and Mines, 2018). We conducted a pilot survey of stone-mortar factories in Phayao Province, Thailand and found 11 unregistered household stone-mortar factories. Stone-mortar production uses granite and sandstone as raw material. Stone-mortar production includes stone cutting and grinding, which generates PM_{10} containing crystalline silica. The stone cutters cut and roughly shape the stones, and the stone grinders turn and smooth the stone-mortars with a lathe.

Most workers in household industries are informal laborers who do not have access to health monitoring (Kongtip *et al*, 2015). The ventilation in household stone working workplaces is inadequate; resulting in dust accumulation and respiratory problems (Rafeemanesh *et al*, 2014). Exposure to PM_{10} containing crystalline silica not only affects the workers but may also affect the residents in the community surrounding these stone working workplaces (Mukhopadhyay *et al*, 2011; Ibhafidon *et al*, 2014). Little data is available for the study area regarding PM_{10} and crystalline silica exposure among stone cutters and grinders. Therefore, we aimed to determine the exposure of Thai stone-mortar workers to PM_{10} containing crystalline silica and its potential link to respiratory disorders.

MATERIALS AND METHODS

Study design, setting and participants

We conducted a cross-sectional study among workers at 11 home stone-mortar factories from January to March 2017 in Ban-sang Sub-District, Phayao Province, Thailand. The study was conducted among all available stone-mortar workers who were willing to participate, which consisted of 29 stone cutters and 28 stone grinders. Participants must have worked at their jobs for at least 1 year to be included in the study. Our study also included a control group which consisted of 20 agricultural workers who were age and sex matched with the study subjects. All subjects were aged at least 18 years. Exclusion criteria for cases and controls were those unable to communicate in the Thai language and those having neuropathy.

Questionnaire

Each subjects was interviewed using a questionnaire asking about demographic characteristics, including age, sex, education level, PM_{10} exposure duration and personal protective equipment (PPE) use, such as cotton and N95 masks used while working; social habits, including pack-year smoking history and amount of alcohol consumed; past medical history and respiratory symptoms which were asked about using the American Thoracic Society Division of Lung Disease questionnaire (ATS-DLD-78A) (Helsing *et al*, 1979).

PM_{10} and crystalline silica exposure testing

We tested for PM_{10} exposure and crystalline silica exposure in each subject using a personal sampling pump (SKC, Eighty-Four PA) with a filter cassette containing a 37 mm polyvinyl chloride (PVC) filter screening particulate matter down to 5.0 μm with a flow rate of 1.7 liters/minute for an 8 hour work day period, the PVC filter was weighed and then the concentration of PM_{10} was analyzed using the National Institute of Occupational Safety and Health (NIOSH) method 0600 (NIOSH, 1998). The crystalline silica concentration was determined using the NIOSH method 7601 (NIOSH, 2003), with a visible absorption spectrophotometer. The concentration of PM_{10} and crystalline silica were expressed for an eight hour time-weighted average (8 hour-TWA) (OHSA, 2018).

Lung function testing

We used a spirometer (MicroLab 3500 Spirometer, Dorset, UK) to determine the forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and ratio of FEV_1 to FVC (FEV_1/FVC) following the standard method of the American Thoracic Society (ATS) (Miller *et al*, 2005). The average percent predicted for each lung function test was calculated after measurement and compared to the healthy Thai population (Dejsomritrutai *et al*, 2000). Obstructive airway disease was defined as a FEV_1/FVC value below the fifth percentile for the predicted value; restrictive lung disease was defined as a FVC value below the fifth percentile for the predicted value with a normal FEV_1/FVC value; mixed airway disease was defined as a reduction in the FEV_1/FVC value; and a FVC value below the fifth percentile for the predicted value (Pellegrino *et al*, 2005).

Chest radiography

Chest radiographs were taken for each subject at Phayao Hospital and interpreted by a physician from the Central Chest Institute of Thailand following International Labor Organization (ILO) guidelines (ILO, 2011).

Statistical analysis

The collected data were analyzed using the R program, version 3.2.2 (R Development Core Team, 2015). The chi-square, Fisher's exact and Kruskal-Wallis tests were used to compare demographic characteristics (age, sex, education level, duration of exposure and mask used while working); social habits (smoking and alcohol use); medical history (history of underlying disease, respiratory symptoms, lung function test results, chest radiographic findings); and the amount of PM_{10} and crystalline silica collected. Multiple linear regression analysis was used to analyze the association between the exposure levels to PM_{10}, crystalline silica and lung function. Statistical significance was set at p<0.05.

Ethical considerations

The study was approved by the Research Ethics Committee of the Faculty of Medicine, Chiang Mai University, Thailand (No. 243/2016). Written informed consent was obtained from all subjects prior to inclusion in the study.

RESULTS

Stone cutters roughly cut and shaped the stone, while stone grinders turned and smoothed the stone on a lathe (Fig 1).

The study subject characteristics are summarized in Table 1. A total of 57 subjects and 20 controls were included in the study; 90% of stone cutter study subjects were males. The mean age of stone cutter study subjects was 48 years. The mean length of time cutting stone was 23 years. Ninety-three percent stone grinder study subjects were males. The mean age of stone grinder study subjects was 46 years. The mean length of time grinding stone was 21 years. Seventy-five percent of control subjects were males. The mean age of control subjects was 47 years. The percentages of stone cutters, stone grinders and control subjects who used cotton masks while working were 41%, 54% and 20%, respectively. The percentages of stone cutters, stone grinders and control subjects who used N95 masks while working were 17%, 14% and 10%, respectively. The numbers of subjects with underlying disease among stone cutters, stone grinders and controls were 5, 5 and 2, respectively. The underlying diseases present among stone cutters were hypertension (n=3), diabetes mellitus (n=1) and both

A. Stone cutting area B. Stone grinding area

Fig 1-A stone-mortar factory showing the stone cutting area (A) and the stone grinding area (B).

diabetes mellitus and hypertension (n=1). The underlying diseases present among stone grinders were asthma (n=2), hypertension (n=1), diabetes mellitus (n=1) and both hypertension and asthma (n=1). The underlying diseases present among controls were hypertension (n=1), and diabetes mellitus (n=1) (data not shown). There were no significant differences among stone cutters, stone grinders, and control subjects in terms of demographic characteristics, including age, sex, education levels, duration of exposure, cotton and N95 mask use while working, current smokers, pack-years smoked, alcohol use and underlying diseases.

In our study, stone cutters (0.286±0.296 mg/m^3) and stone grinders (0.416±0.596 mg/m^3) had significantly (p<0.001) greater PM_{10} levels than controls (0.033±0.021 mg/m^3), but all subjects had PM_{10} levels within safe levels recommended by the Association for Advancing Occupational and Environmental Health (ACGIH) guidelines (3 mg/m^3) (Hearl, 1998). In our study, stone cutters (0.096±0.094 mg/m^3) and stone grinders (0.130±0.106 mg/m^3) had significantly greater (p=0.000) silica levels than controls (0.004±0.005 mg/m^3). Silica levels in the stone cutters and stone grinders did exceed safe cut-off levels recommended by ACGIH guidelines (0.025 mg/m^3) (Table 2).

There were significantly more (p=0.042) abnormal chest radiographs among stone cutters and stone grinders than controls. Eight stone cutters/stone grinders had abnormal chest x-rays; one stone cutters and 2 stone grinders had chest radiographs consistent with silicosis. Two stone grinders had non-specific radiographic abnormalities, one had emphysematous changes and one had cardiomegaly with mild chronic lung changes. One stone cutter had upper lobe pulmonary fibrosis. On lung function testing, 4 stone cutters had obstructive lung disease and 2 had restrictive lung disease; three stone grinders had obstructive lung disease, 3 had restrictive lung disease and 2 had mixed obstructive/ restrictive lung disease. Among controls, 3 subjects had restrictive lung disease. Fifty-five percent of stone cutters had respiratory symptoms consisting of coughing with phlegm (24%), cough only (17%), cough with wheeze

Table 1
Demographic characteristics of study subjects.

Characteristic	Stone cutter (n=29)	Stone grinder (n=28)	Control (n=20)	p-value
Mean age in years (±SD)[a]	48±13	46±12	47±11	0.794
Sex, n (%)[b]				
Male	26 (90)	26 (93)	15 (75)	0.167
Female	3 (10)	2 (7)	5 (25)	
Education level, n (%)[c]				
≤ Primary school	15 (52)	19 (68)	8 (40)	0.149
> Primary school	14 (48)	9 (32)	12 (60)	
Mean duration of exposure in years (±SD)[a]	23±17	21±17	-	-
PPE (Cotton mask used while working), n (%)[b]	12 (41)	15 (54)	4 (20)	0.064
PPE (N95 mask used while working), n (%)[b]	5 (17)	4 (14)	2 (10)	0.776
Current smokers, n (%)[c]	15 (52)	17 (60)	7 (35)	0.211
Mean pack-years smoking (±SD)[a]	5±11	7±10	3±6	0.371
Alcohol use, n (%)[c]	21 (72)	18 (64)	12 (60)	0.641
Underlying diseases, n (%)[b]	5 (17)	5 (18)	2 (10)	0.724

[a]Kruskal-Wallis test; [b]Fisher's exact test statistic; [c]Chi-square test. SD, standard deviation.

Table 2
Concentrations of PM_{10} and crystalline silica collected in 8 hours among study subjects.

Subject group	PM_{10} concentration in mg/m^3			Crystalline silica concentration in mg/m^3		
	Mean±SD	Min-max	Median	Mean±SD	Min-max	Median
Stone cutters (n=29)	0.286±0.296*	0.045-1.253	0.200	0.096±0.094*	0.003-0.316	0.074
Stone grinders (n=28)	0.416±0.596*	0.050-2.706	0.183	0.130±0.106*	0.024-0.453	0.099
Control subjects (n=20)	0.033±0.021	0.010-0.087	0.031	0.004±0.005	0.001-0.022	0.001

*p<0.01 compared with control group. SD, standard deviation.

and phlegm (10%) and phlegm only (3%). Forty-three percent of stone grinders had respiratory symptoms consisting of cough with phlegm (25%), cough only (11%) and cough with wheeze and phlegm (7%) (Table 3). Twenty-five percent of control subjects had respiratory symptoms consisting of cough only (data not shown).

Table 3
Respiratory conditions among study subjects.

Respiratory condition	Stone cutter (n=29)	Stone grinder (n=28)	Control subject (n=20)	p-value
Respiratory symptoms, n (%)[a]	16 (55.2)	12 (42.9)		
Mean lung function test results (±SD)[b]				
FEV_1 (L)	2.6 ± 0.7	2.8 ± 0.8	2.6 ± 0.7	0.467
FVC (L)	3.1 ± 0.7	3.3 ± 0.9	3.1 ± 0.9	0.300
FEV_1/FVC ratio	84.7 ± 9.5	83.6 ± 10.5	86.7 ± 5.7	0.591
FEV_1 (%predicted)	93 ± 24	97 ± 24	96 ± 25	0.903
FVC (%predicted)	88 ± 18	92 ± 20	88 ± 26	0.752
FEV_1/FVC (%predicted)	101 ± 11	100 ± 13	107 ± 7	0.049[f]
Lung function, n (%)[c]				
Normal	23 (79.3)	20 (71.5)	17 (85.0)	0.308
Obstructive	4 (13.8)	3 (10.7)	0 (0.0)	
Restrictive	2 (6.9)	3 (10.7)	3 (15.0)	
Mixed	0 (0.0)	2 (7.1)	0 (0.0)	
Chest radiograph findings, n (%)[c]				
Normal	27 (93.1)	22 (78.6)	20 (100.0)	0.042[f]
Abnormal	2 (6.9)[d]	6 (21.4)[e]	0 (0.0)	

[a]Chi-square test, [b]Kruskal-Wallis test, [c]Fisher's exact test,
[d]1 case of silicosis and 1 case of upper lobe fibrosis. [e]2 cases of silicosis, 2 cases with a nonspecific lesion or mild occlusion, 1 case with emphysematous change and 1 case with cardiomegaly and mild chronic lung changes, [f]$p<0.05$.

Table 4
Association between PM_{10} and crystalline silica concentrations with lung function test results on multiple linear regression analyses.

Associated factor (n=77)	FEV_1 (%predicted)	FVC (%predicted)	FEV_1/FVC (%predicted)
PM_{10} concentration in mg/m^3	0.000[b]	0.000[b]	0.000[b]
Silica concentration in mg/m^3	0.002[b]	0.011[a]	0.002[b]

Adjusted for age, duration of exposure, cotton and N95 mask used while working and pack-years smoking; [a]$p<0.05$, [b]$p<0.01$.

In our study, the PM_{10} exposure level was significantly associated with the FEV_1 level (p=<0.001), the FVC level (p=<0.001) and the FEV_1/FVC level (p=<0.001) and the crystalline silica exposure level was significantly associated with the FEV_1 level (p=0.002), the FVC level (p=0.011) and the FEV_1/FVC level (p=0.002) after adjusting for age, duration of exposure, cotton mask and N95 mask use while working and pack-year smoking history.

DISCUSSION

In our study, the studied stone cutters and stone grinders had higher exposure levels to PM_{10} and silica than control; PM_{10} exposure level did not exceed cut-off levels but silica exposure levels did (OSHA, 2018). This finding is similar to previous studies which were conducted among Thai stone workers (Nambunmee *et al*, 2014; Chaiear *et al*, 2017; Chanvirat *et al*, 2018) and in Iranian stone workers (Mohammadi *et al*, 2017).

Significantly more stone cutters and stone grinders in our study had abnormal chest radiographs than controls. Fourteen percent of stone cutters/grinders had abnormal chest x-rays in our study, 3 had findings consistent with silicosis. A study from Iran reported 16.4% of studied stone grinders had abnormal chest radiographs (Rafeemanesh *et al*, 2014). In our study, the percentage of study subjects with abnormal chest radiographs was higher than a previous study from Thailand (8.9%) (Silanun, 2014).

Crystalline silica exposure in our study was associated with reduced lung function; therefore, stone workers should be investigated with lung function testing. Some stone cutters and grinders in our study had obstructive lung disease and others had restrictive lung disease. This is similar to the findings of a study from Iran that found the most common abnormality among stone workers was obstructive lung disease followed by restrictive lung disease (Aghilinejad *et al*, 2012).

In our study, 55% of stone cutters and 43% of stone grinders had respiratory symptoms, such as cough with phlegm, cough alone, and cough with wheeze and phlegm. This finding is similar to previous studies (Yingratanasuk *et al*, 2014; Rafeemanesh *et al*, 2014; Silanun *et al*, 2017).

In our study, exposure to crystalline silica dust was associated with reduction in FEV_1, FVC and FEV_1/FVC levels similar to previous studies (Hertzberg *et al*, 2002; Mohammadi *et al*, 2017; Lamichhane *et al*, 2018).

A strength of our study was the use of personal air sampling to determine PM_{10} and crystalline silica exposure in order to simulate human breathing (Koehler and Peters, 2015). A limitation of this study was its small sample size. We did recruit all available stone-mortar workers in the study area. The PM_{10} and crystalline silica levels were monitored only when the workers were actually working.

In conclusion, our findings show study subjects were exposed to excessive crystalline silica dust level but not excessive PM_{10} levels. This exposure was associated with respiratory disorders and lung function impairment among study subjects. Crystalline silica dust exposure is a preventable health hazard. Stone workers in the study area should be required to use adequate personal protective equipment consistently and should be screened periodically for lung impairment and respiratory silicosis. Further studies are needed to determine if strict enforcement of using personal protective equipment will result in reduction of respiratory disorders and risk of silicosis.

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