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ORIGINAL RESEARCH ARTICLE

Underdiagnosis of silicosis revealed by reinterpretation of chest radiographs in Thai ceramic workers

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ABSTRACT

Background: In Thailand, epidemiological data on silicosis in the ceramic sector is lacking and the underdiagnosis of silicosis remains an extensive concern. Therefore, this study aimed to determine the prevalence of silicosis and the extent of underdiagnosis among Thai ceramic workers by reinterpreting chest radiographs previously taken by a health check-up unit.

Methods: This retrospective cross-sectional study was conducted on ceramic workers undergoing health surveillance using chest radiographs in one ceramic factory in September 2018. All chest radiographs were done retrospectively, then were reinterpreted by professional readers specially trained in using the ILO International Classification of Radiograph of Pneumoconioses (ILO/ICRP). Chest radiographs with a profusion of 1/1 or greater were suggestive of silicosis.

Results: Out of the 244 participants undergoing chest radiography, the prevalence of silicosis was 2.9%. Overall, the mean age of the participants was 41 years, and 72.1% were female. Among individuals with silicosis, the median age was 43 years; 71.4% were male; the average employment duration was 26.9 years; while the male sex was the significant variable associated with silicosis with an odds ratio of 7.01 (95% confidence interval 1.31 to 37.4). Regarding the underdiagnosis, the health check-up unit failed to recognize all individuals with silicosis, and could not detect any radiographic chest abnormalities in 57.1% of those with silicosis.

Conclusions: Despite the low prevalence of silicosis among Thai ceramic workers, this finding indicates ongoing exposure to silica in the ceramic industry. In addition, a significant proportion of the silicosis cases were underrecognized. Future efforts to prevent underdiagnosis and improve an occupational health surveillance service in Thailand are needed.

Key words: silicosis, ceramics, thoracic radiography, mobile health unit, occupational health physician.

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Introduction

Silicosis is an incurable and life-limiting pulmonary disease caused by inhaling respirable crystalline silica (RCS). Lung cancer, tuberculosis, chronic obstructive pulmonary disease (COPD), and connective tissue diseases have all been linked to silicosis [1]. The International Labor Organization (ILO) and the World Health Organization (WHO) collaborated in 1995 to create a program to eliminate silicosis by 2030 [1]. Despite significant preventive efforts, silicosis continues to be a global problem due to new exposures, a lack of awareness about dust hazards, and unsafe practices [2]. The Global Burden of Disease study estimated 11,300 deaths and 235,700 lost years of life from silicosis in 2017 [3].

Along with primary prevention, which is regarded as the most effective method of eliminating silicosis, health surveillance for those exposed to silica is critical to early disease detection. Because of the availability and affordability of chest radiography, surveillance is primarily based on periodic chest radiographs, the interpretation of which requires physicians' expertise. As a result, physician awareness and competencies in recognizing silicosis, as well as an effective surveillance program, are critical. The ILO Classification of Radiographs of Pneumoconioses (ILO/ICRP) is an internationally recognized tool for pneumoconiosis surveillance. It is also widely used in epidemiological research and data comparison on pneumoconioses.

RCS exposure is a risk for ceramic handling workers during the mixing, molding, glaze or enamel spraying, and sculpting processes [2]. Previous research found that the prevalence of silicosis in those workers ranged from 1.7 to 13.3% [4,5]. Ceramic manufacturing is prominent in Thailand's Northern region. Despite this, little is known about the prevalence of silicosis among ceramic workers in Thailand, where most studies have concentrated on stone-related industries [6-8]. As a result, prevention and control of silicosis in the ceramic industry may be overlooked. Furthermore, silicosis underrecognition can lead to underdiagnosis of silicosis cases. As a result, the diagnosis is delayed and the opportunity to stop the silica exposure is lost [9]. Several case reports underpinned the underdiagnosis of silicosis [10,11]. However, its extent has not been thoroughly investigated. The current study aimed to determine the prevalence of silicosis and the magnitude of underdiagnosis among Thai ceramic workers by reviewing chest radiographs retrospectively using the ILO/ICRP scheme, as well as to describe the discrepancy in the interpretation of chest radiographs compatible with silicosis. Furthermore, the secondary goal was to identify its associated characteristics in Thai ceramic workers.

Methods

Study design, setting, and population

This retrospective cross-sectional study re-evaluated the chest radiographs of the workers at a ceramic factory in Northern Thailand, which employed 364 people in total. The study included all consecutive workers at risk for occupational RCS exposure who were undergoing occupational health surveillance provided by a private mobile health check-up unit in September 2018. At-risk employees were those involved in production line tasks such as mixing, molding, glazing, sculpting, firing, and packing, and they were also housed in the same building. Originally, an occupational medicine physician employed by this health check-up unit reported all chest radiograph results. Those who did not have chest radiographs performed for any reason were excluded. The study was conducted in accordance with the Helsinki Declaration, and no personal information about the participants was disclosed.

Radiographic assessment and definition of silicosis

A panel of three physicians trained in using the ILO/ICRP reinterpreted posteroanterior (PA) chest radiographs from a private mobile health check-up. One pulmonologist, one radiologist, and one Asian Intensive Reader of Pneumoconioses (AIR Pneumo) [12,13] certified general practitioner comprised the panel. The first two were B readers approved by the National Institute of Occupational Safety and Health (NIOSH) [14]. To detect radiographic abnormalities suggestive of silicosis, all readers independently interpreted the chest radiographs according to the 2011 ILO/ICRP detailed elsewhere [15]. In brief, small round opacities are categorized by diameter size into p (up to 1.5 mm), q (1.5 to 3 mm), r (3 to 10 mm). Similarly, small irregular opacities are classified by size into s, t, and u, using the same width ranges as small round opacities. The classification scheme for the profusion of small opacities is categorized into four major scales (0, 1, 2, and 3). Each major scale is subdivided into three minor scales, giving a total of twelve categories of increasing profusion (0/-, 0/0, 0/1, 1/0, 1/1, 1/2, 2/1, 2/2, 2/3, 3/2, 3/3, and 3/+ respectively). The extent of large opacities is classified as A, B, or C. Category A is defined as one or more opacities with a combined greatest dimension longer than 1 cm but less than 5 cm. One or more opacities in category B have a combined greatest dimension greater than 5 cm but do not exceed the equivalent area of the right upper lung zone. Category C is greater than category B as the sum of the areas that exceed the equivalent area of the right upper lung zone. The diagnosis of silicosis in this study was based on an occupational exposure history and chest radiography compatible with a profusion of 1/1 or greater according to the ILO/ICRP, which is Thailand's current diagnostic threshold for silicosis. The three panelists held a conference call to resolve any disagreements that arose.

Information collected

Age, gender, employment duration (≤10 and >10 years), smoking status (never and ever smokers), diabetes mellitus (DM), and prior pulmonary tuberculosis (PTB) were all included in the demographic data. To assess the likelihood of chronic simple or accelerated silicosis, employment duration data was collected as ≤10 or >10 years, given that the latency period of chronic simple silicosis typically takes at least ten years of exposure [2]. We later obtained definite employment duration data for each silicosis case through chart review. Former and current smokers were referred to as ever-smokers; while chest radiographic data included findings interpreted by the check-up unit and reinterpreted by professional readers using the ILO/ICRP scheme.

Statistical analysis

All analyses were performed using IBM SPSS Statistics (version 25; IBM Corp., Armonk, NY, USA). Categorical variables were presented as count and percentage. Continuous variables were presented as mean with standard deviation (SD) or median with interquartile range (IQR). The significance of categorical variables was assessed by the Chi-square test or Fisher's exact test as appropriate, and the significance of the continuous variable was tested by the *t*-test or Mann-Whitney test, depending on the distribution of data. Associated variables with a $p<0.2$ in the univariable analysis were included in the further binary logistic regression model. Odds ratios (ORs) and 95% confidence intervals (95%CIs) were calculated. A $p<0.05$ was considered statistically significant.

Results

During the study period, among 364 workers, a total of 244 ceramic handling workers at risk for RCS exposure underwent chest radiography and were included in the study. Out of the 244 participants, 7 (2.9%) were diagnosed with silicosis. Overall, the age of the participants ranged from 20 to 58 years, with a mean age of 41.0 (SD 6.5) years. 27.9% were male, 13.9% were ever-smokers, and 73.0% had more than 10 years of employment. Among the individuals with silicosis, the median age was 43 (IQR 42 to 44) years; 71.4% were male, and 28.6% were ever-smokers. All silicotic participants had more than 10 years of employment (20 to 34 years), with a mean employment duration of 26.9 years. In the univariable analysis, there were no statistically significant differences between silicotic and non-silicotic participants, except for the male sex, which favored the silicotic group (26.6% *vs* 71.4%, p=0.019). Table 1 displays the univariable analysis between the two groups. After analyzing the binary logistic regression, the male sex remained the only significant factor associated with silicosis (OR 7.01, 95%CI 1.31 to 37.4, p=0.023), while the increasing age had an OR of 1.10 (95%CI 0.97 to 1.24, p=0.154) for having silicosis.

Concerning the underdiagnosis, none were identified by a health check-up unit as having suspicion of silicosis. The chest radiographs of three silicotic participants were originally interpreted as having: opacities in both lungs, opacities in the right lung, and opacities in the right upper lung. In contrast, the panel of experts in our investigation interpreted them as diffuse nodular opacities with a profusion of q/q 3/2, q/q 2/2, and q/p 2/2, respectively. The chest radiographs of the other silicotic participants (57.1%) were reported as normal by the health check-up unit. They were interpreted as compatible with silicosis with a profusion of p/p 1/1, p/q 1/1, p/p 1/2, and p/p 2/3 by the panel of experts. Table 2 presents information on silicosis-diagnosed participants. Figures 1 and 2 show two silicotic participants' chest radiographs which were initially interpreted as normal. Figure 3 depicted the chest radiograph of the silicotic participant, labeled as having abnormal opacities by the physician at the health check-up unit.

Out of the total 244 chest radiographs assessed, following the ILO/ICRP classification scheme, 7 (2.9%) had good image quality (grade 1), while the remaining radiographs had acceptable image quality (grade 2), primarily revealing overlapping scapula. The panelists ultimately identified two chest radiographs that exhibited varying levels of minor profusion, indicating compatibility with silicosis. Notably, the profusion ratings given by the panelists were as follows: 1/1 and 1/2 for a patient with a major profusion of 1 and 2/2 and 2/3 for a patient with a major profusion of 2. Following a discussion during the conference session, the panelists reached a consensus on their findings.

Discussion

To the best of our knowledge, this is the first study to estimate the prevalence of silicosis among ceramic workers in Thailand. The prevalence in this study was lower than the result from a recent Turkish study recalculated based on a profusion diagnostic threshold of 1/1 (11.1%) [4]. In larger companies, broader job classifications with lower dust exposure levels are more common, as are more robust preventive measures and medical surveillance programs [5]. While this may have contributed to the low prevalence of silicosis in our study at a large ceramic factory, it is worth noting that none of the workers wore respirators while on the job. Instead, the majority of people wore fabric masks. This implies that the lower prevalence may be due to lower levels of dust exposure

Table 1. **Overall characteristics and univariable comparisons of the participants.**

	Overall* (n=244)	Non-silicotic group° (n=237)	Silicotic group° (n=7)	p#
Age (years)	41.0±6.5	42 (37,46)	43 (42,44)	0.186§
Sex: male	68 (27.9%)	63 (26.6%)	5 (71.4%)	0.019^
Employment duration				0.350^
≤10 years	47 (19.3%)	47 (19.8%)	-	
>10 years	178 (73.0%)	171 (78.4%)	7 (100%)	
Unknown	19 (7.8%)	19 (8.0%)	-	
Ever-smokers	34 (13.9%)	32 (13.5%)	2 (28.6%)	0.253^
DM	12 (4.9%)	12 (5.1%)	-	1.000^
Prior PTB	1 (0.4%)	1 (0.4%)	-	1.000^

*Data shown as mean ± SD or n (%); °data shown as median (Q1,Q3) or n (%); #comparison between non-silicotic and silicotic groups; §Mann-Whitney U test; ^Fisher's exact test.

Table 2. **Details and interpretations of the participants with silicosis.**

Patient no.	Sex	Age (years)	Employment duration (years)	Check-up unit interpretation	Expert interpretation
1	Female	54	34	Opacities in both lungs	q/q 3/2
2	Male	42	29	Opacities in the right lung	q/q 2/2
3	Male	44	28	Normal	p/p 1/2
4	Male	43	26	Normal	p/p 2/3
5	Female	44	25	Opacities in the right upper lung	q/p 2/2
6	Male	43	26	Normal	p/p 1/1
7	Male	41	20	Normal	p/q 1/1

rather than the use of protective equipment. Moreover, this study found a relatively lower prevalence of silicosis compared to silica-exposed workers in various occupational settings, where prevalence ranged from 14% to 96% [16]. The result is also in line with evidence that the frequency of silicosis in the ceramic sector tends to be lower than in other sectors [17]. According to the available job exposure matrix data (SYN-JEM), the RCS exposure level among clay slip makers was 0.05 mg-m^{-3}, while that among stone cutters and carvers was 0.09 mg-m^{-3} [18]. We assume that the differences in diagnostic criteria, regions, and industry types reflecting different levels of silica exposure [19] may be responsible for a considerable variation in silicosis prevalence. Nonetheless, our findings indicate that RCS exposures are still present in the ceramic industry, emphasizing the critical need for awareness and adher-

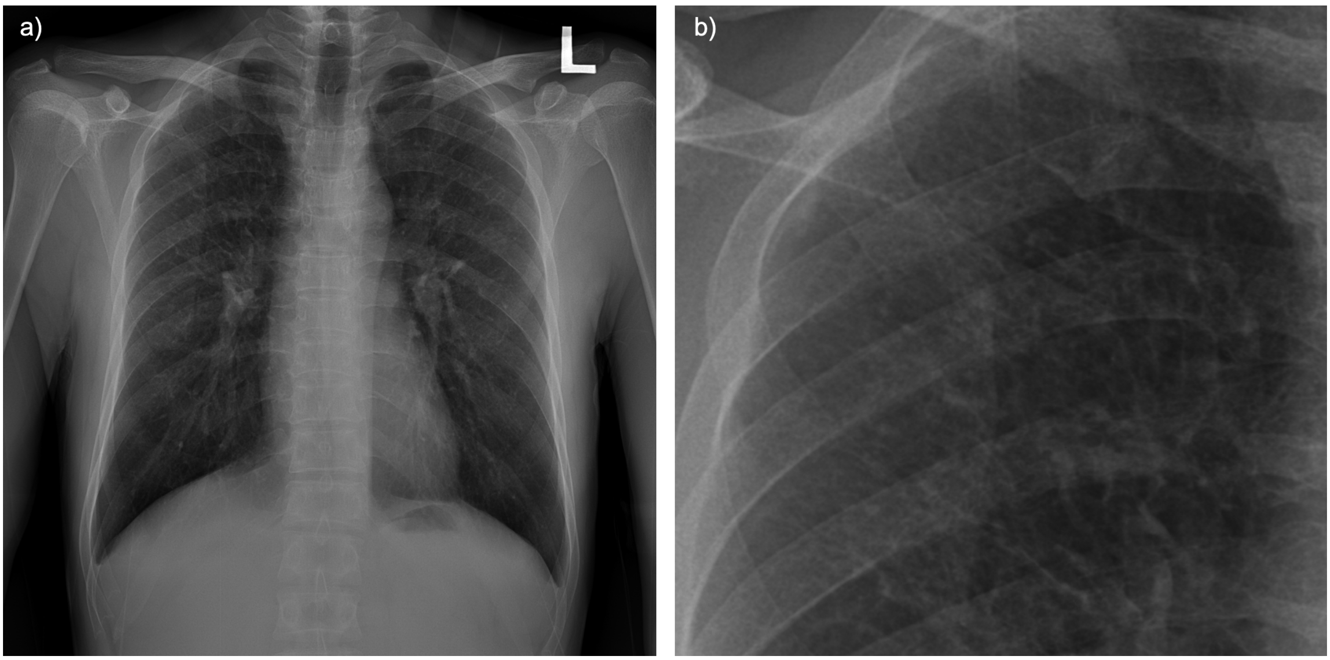

Figure 1. **Patient # 4. a) Chest radiograph (posteroanterior) showing a profusion of p/p 2/3. b) Magnification of the chest radiograph.**

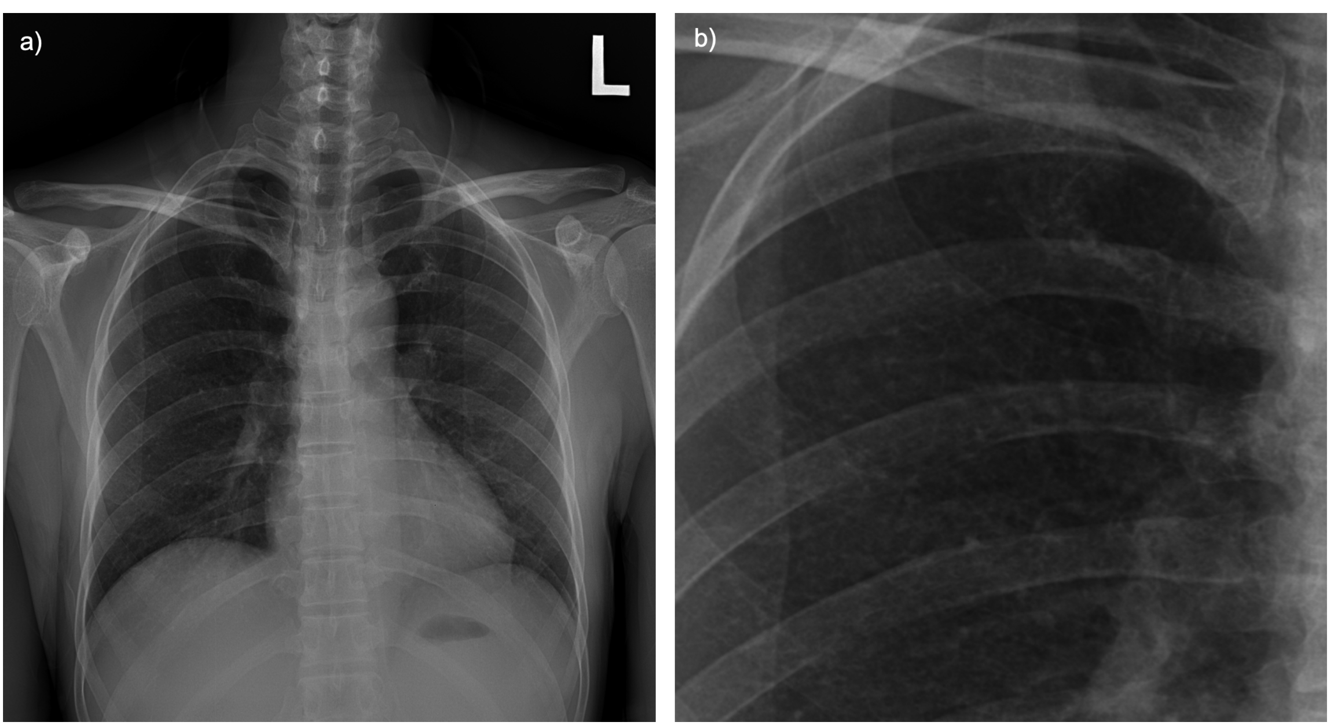

Figure 2. **Patient #3. a) Chest radiograph (posteroanterior) showing a profusion of p/p 1/2. b) Magnification of the chest radiograph.**

ence to preventive measures. This includes proper respirator selection and respiratory health surveillance [15]. Following the disease investigation, health surveillance can enable exposure control at the workplace. Even though a respiratory health surveillance program may detect only a small number of silicotic cases, this is not a reason to discontinue the program [2]. Indeed, the primary goals of health surveillance are early disease detection and facilitating the removal of those who have been exposed. [20]. Significantly, silicosis can progress even after silica exposure is stopped. Dumavibhat *et al*., for example, found radiologic evidence of progression in 51% of Japanese tunnel workers who were no longer exposed to silica, with an average time to progression of 17 years [21]. Thus, early disease detection and prompt removal of the patient from exposure will reduce the severity of the disease in the long run. Furthermore, identifying any case of silicosis indicates that other workers at their company are probably at risk for silicosis due to workplace exposure to silica.

In the present study, among ceramic workers, the male sex was significantly associated with silicosis despite the predominance of female workers. Similarly, Poinen-Rughooputh *et al*. found that males had an increased risk of silicosis in Chinese pottery workers (relative risk 4.34, 95%CI 3.57 to 5.56) [22]. The data from two national registries of the UK and Poland also showed that males accounted for 98% and 96% of silicosis patients, respectively [23,24]. Male susceptibility, involvement in high-dust processing tasks among male workers, gender bias, and smoking habits may all have an impact on the findings [25,26]. Interestingly, a recent animal study demonstrated that factors predisposing to fibrosis were downregulated in female silicotic mice in the early phase [27]. However, previous studies found no significant difference in the prevalence of silicosis between male and female workers in the agate and ceramic industries [28,29]. Although the association between sex and the development of silicosis is still unclear, one should be aware that silicosis can occur in any sex as the risk appears to depend on a dose-response relationship [26].

Concerning the exposure duration, all silicosis patients in this study had more than ten years of employment duration, which is a surrogate for the duration of exposure. As a result, all identified cases of silicosis were likely to be chronic simple silicosis, given that this type usually develops after 10 to 25 years of exposure [2]. However, there were no significant differences in the proportions of those with employment durations exceeding ten years between the two groups. The majority (85.7%) of silicosis patients had 25 years or over of employment duration. According to Cavariani and colleagues' study, the cumulative risk of silicosis in male ceramic workers rose at the fastest rate when the exposure duration was around 25-30 years; the hazard ratio was up to 14.6 in those having 30 years or more of exposure [30]. In addition, a pooled analysis of cohort studies found that the silicosis mortality rate (per 100,000 person-years) increased from 4.7 for cumulative silica exposure of 0-0.99 mg m^{-3}-years to 233 for the exposure of >28.1 mg m^{-3}-years [31]. These findings support the premise that optimal dust-control practices are imperative for silicosis prevention.

The current study found a significant proportion of major disagreements between the health check-up unit and the experts. In more than half of the silicosis cases, the chest radiograph findings were initially interpreted as normal. Furthermore, despite the fact that the physician at the health check-up unit interpreted three abnormal chest radiographs, none of them were flagged as silicosis-related. This raises an important observation: the patients in question were not diagnosed with silicosis by the occupational medicine physician, despite the potential need for follow up or further evaluation such as a review by experts. Underdiagnosis brings widespread concerns as it impacts individual and workplace health, i.e., delayed diagnosis and ongoing exposure among workers [11,25,32]. Physicians' lack of knowledge about the disease, disregard for occupational history, and limited skills in interpreting pneumoconiosis chest radiographs all contribute to silicosis underrecognition and underdiagnosis [33]. Therefore, our findings highlight the importance of increasing the awareness and competencies

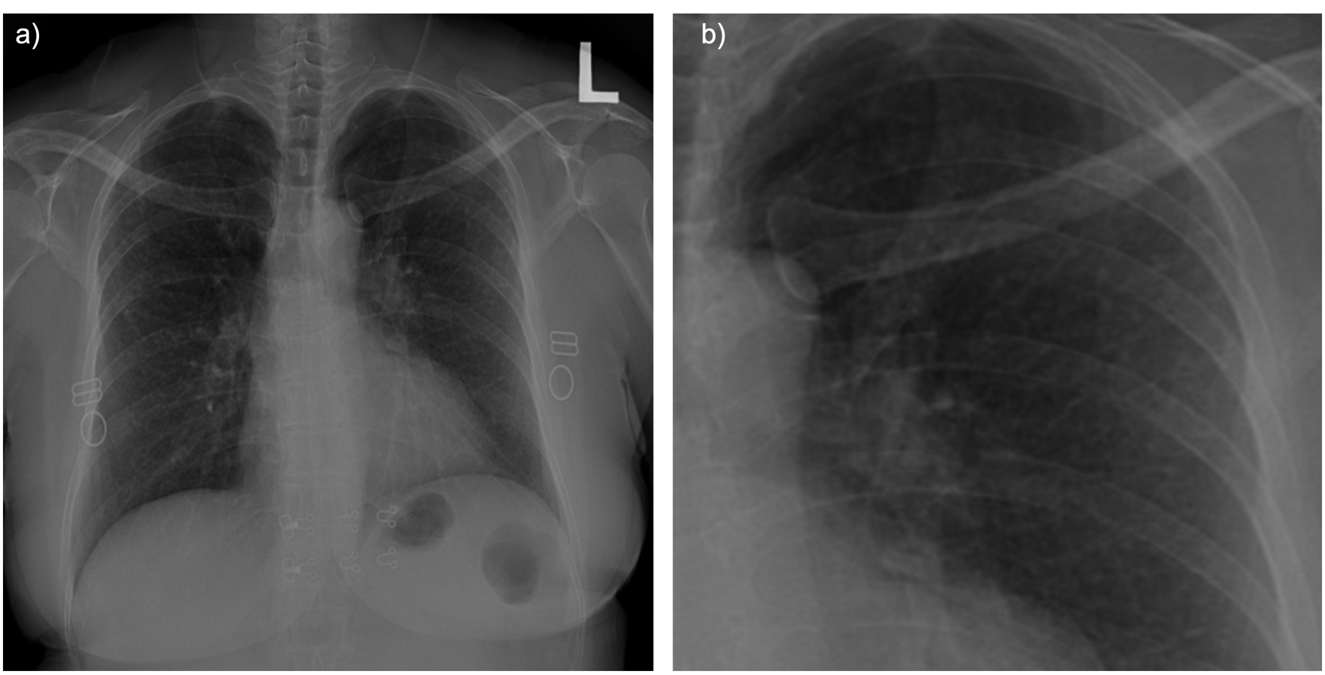

Figure 3. Patient #1. a) Chest radiograph (posteroanterior) showing a profusion of q/q 3/2. b) Magnification of the chest radiograph. Adapted from Stitsmith *et al*., BKK Med J 2021;17:142-5, with permission.

of physicians working in occupational health settings, who are key players in disease surveillance.

Diagnosis of pneumoconiosis can be difficult. Almost every chest radiograph with a normal initial report had a profusion category 1. In comparison, all abnormal chest radiographs detected by the physician at the health check-up unit were consistent with a profusion category 2 or higher, indicating a more severe level of severity. This observation was understandable given that occupational lung diseases are characterized by non-specific symptoms and subtle radiologic appearances, especially in the early stages [32]. Proper training in pneumoconiosis chest radiography interpretation, such as NIOSH B reader and the Air Pneumo trainings, is likely to improve the competencies of physicians in relevant fields. Ngatu *et al*. showed that short-period training with the ILO/ICRP and Japan Pneumoconioses Study Group (JPSG) study materials could enhance physicians' skills in reading pneumoconiosis chest radiographs [34]. Hence, promoting and implementing such training programs for physicians working in occupational health settings may help reduce pneumoconiosis underdiagnosis.

The limitations of this study should be considered. First, because this was done at a single ceramic factory, generalizing the results should be done with caution. Second, since this study used a cross-sectional design and collected subject characteristics over a short period of time, it may not have established a causal relationship between the variables. Third, due to the study's retrospective nature, some important variables (such as dust concentrations and detailed work processes) are missing. Furthermore, the inclusion of current and former smokers may have obscured differences in their silicosis risks, potentially influencing the study's findings. Larger, well-designed observational studies are still required.

Conclusions

This study retrospectively reinterpreted chest radiographs of ceramic workers who were undergoing health surveillance by a private mobile health unit. Silicosis was found in 2.9% of Thai ceramic workers at a single factory. The only factor linked to silicosis was male sex. Notably, this study found an unusually high rate of silicosis underdiagnosis. As a result, the risk of silicosis among ceramic handling workers, as well as underdiagnosis, must be considered. Our findings highlight pneumoconiosis underdiagnosis and call for improved respiratory health surveillance services and physician competencies in interpreting pneumoconiosis chest radiographs in Thailand.

Abbreviations

Air Pneumo, Asian Intensive Reader of Pneumoconioses;
COPD, chronic obstructive pulmonary disease;
DM, diabetes mellitus;
ICRP, International Labor Organization Classification of Radiographs of Pneumoconioses;
ILO, International Labor Organization;
PTB, pulmonary tuberculosis;
RCS, respirable crystalline silica.

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