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### Exposure to respirable silica among clay brick workers in Kathmandu valley, Nepal

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**Introduction**

Inhalation of crystalline silica (quartz) is among the most important respiratory exposures affecting workers worldwide. Occupational exposure to respirable (< 5 µm) silica is associated with the development of silicosis, lung cancer, chronic obstructive pulmonary disease (COPD), and autoimmune and other diseases. Clay and other raw materials used in brick manufacturing often contain free silica, which can make up approximately 2–20% of the respirable fraction of suspended dust in the clay brick industry. While silica-related illnesses are well documented among refractory “fire” brick workers, studies show that clay brick workers may also be at risk. Clay brick manufacturing is a major industry in the Kathmandu valley, Nepal. Currently, there are over 100 operating brick kilns in the valley, employing approximately 30,000 seasonal workers. However, silica exposures are largely unstudied among brick workers in this region.

To date, few studies report respirable silica exposure levels for workers in the clay brick industry. Love et al. (1999) report mean respirable silica exposures ranging from 40–620 µg/m³ in Hoffman, intermittent, and tunnel kilns in the U.K. Similarly, Myers et al. (1989) found respirable silica levels ranging from 0 – 230 µg/m³ for workers in Hoffmann, Downdraught, and automated kilns in South Africa. However, there is no data on silica exposures among workers in fixed chimney Bull’s trench kilns, the predominant kiln type in Nepal. Bull’s trench kilns are noted for producing more ambient air pollution than kilns using more modern technology, such as Hoffman kilns and vertical shaft brick kilns. However, it is unknown if differences in kiln type significantly influence occupational silica exposures, warranting research in this area.

Differences between Hoffman and other more modern kiln types make it difficult to directly compare exposures to workers in fixed chimney Bull’s trench kilns. The purpose of this study, therefore, was to evaluate breathing zone respirable silica exposures across similar exposure groups (SEGs) in fixed chimney Bull’s trench kilns in the Kathmandu valley, Nepal. Knowledge of how exposures vary by SEG in this population may help guide future interventions to prevent silica-related illnesses.

**Methods**

Ethical approval for this study was obtained from the institutional review committee of Kathmandu University, School of Medical Sciences.
At the time of this study, there were 106 operating brick kilns in the Kathmandu Valley, including 62 in Bhaktapur, 26 in Lalitpur, and 18 in Kathmandu district. Multi-stage probability proportionate to size (PPS) sampling was applied to select fixed chimney Bull’s trench kilns \( (N = 16) \) based on the tentative number of workers involved,\(^{17}\) and we have taken 15.0\% of the brick kilns of the valley as well. In total, 9 kilns from Bhaktapur, 4 kilns from Lalitpur, and 3 kilns from Kathmandu district were selected. We defined similar exposure groups (SEGs) in this study as groups of brick kiln workers having similar general exposure profiles to respirable silica due to the similarity and frequency of the tasks they perform.\(^{18}\)

Workers employed for more than one year were recruited for sampling based on SEGs. Brick kiln SEGs were classified as green brick molding (GBM), green brick stacking/carrying (GBS/C), red brick loading/carrying (RBL/C), coal crushing/carrying preparation (CP), and fireman (FM). The workers’ socio-demographic characteristics were assessed by questionnaire as part of a larger study,\(^{19}\) but we were unable to link the specific workers who were sampled to their individual data, with the exception of age. Participation in the study was voluntary and written consent or thumbprint (for those workers who are illiterate) was obtained from the brick kiln owners and workers before obtaining any data. We approached 100 workers for participation in the study, of which 86 consented. Some study data was lost due to computer failure, resulting in a final sample of \( N = 46 \) participants. The lost data included workers with no recorded age, which had been saved in a separate file. There were multiple reasons why age was not collected on several of the workers, such as language, unknown age, and work demands. Thus, any selection bias should be minimal.

Sampling for respirable dust was completed during February – March 2015. Kilns included in the study operated 24 hours per day, seven days per week. Typical work was 6 days per week, up to 14 hours per day. Due to consistent work patterns and continuous operation of the kilns we assumed little variation in exposures over the workweek. Thus, samples were collected irrespective of the day of the week or time of day. Workers did not transfer to other tasks, so we assumed that dust exposures remained constant throughout the workday. Air samples were collected following National Institute for Occupational Safety and Health (NIOSH) Method 7500 for silica.\(^{20}\) During the course of the survey, breathing zone samples for respirable silica were obtained using SKC AirChek\textsuperscript{®} 52 (SKC Inc., Eighty-Four, PA, USA) personal air sampling pumps pre-calibrated to a volumetric flow standard (Mesa Labs, Butler, NJ, USA). Samples were collected on pre-weighed 5.0 \( \mu \text{m} \) PVC membrane filters (37 mm), and particulates were pre-separated using an in-line aluminum cyclone with a 4.0-\( \mu \text{m} \) cut-point (SKC Inc., Eighty-Four, PA, USA). Sample filters, and field and laboratory blanks, were analyzed gravimetrically and by X-ray diffraction (XRD) for quartz at ALS Laboratories in Salt Lake City, Utah, USA.

The average sampling time was 170 ± 10 minutes per worker, one sample per worker. Thus, all values were converted to eight-hour time weighted averages (TWA) using the following formula: TWA = \( [(C_1 \times T_1) + (C_2 \times T_2) + (C_n \times T_n)]/480\text{ min} \); where \( C = \) concentration for \( T_n (\mu g/\text{m}^3) \), and \( T = \) sampling time (min). Thus, for \( C_2 \) we used the same concentration as \( C_1 \), and for \( T_2 \) we used the remainder of the shift that was not sampled.

Mean and standard deviation were calculated for age. Due to the silica exposures being positively skewed, we logged the values. Means and 95\% confidence intervals were back transformed using the anti-log to the original scale. Thus, respirable silica exposures are presented as geometric means and 95\% confidence intervals. One-way ANOVA with the Tukey’s post-hoc test was used to compare silica exposures across SEGs. Statistical analyses were performed using SAS version 9.3 (SAS Institute Inc., Cary, NC, USA).

### Results

The mean age of workers was 35.8 ± 13.5 years. Analysis of the respirable dust samples by XRD showed the mean quartz content was 13.8\% ranging from 11.3 – 54.0\%. Among the five SEGs, geometric means and 95\% confidence intervals for breathing zone quartz concentrations were as follows: 331(233, 471) \( \mu g/\text{m}^3 \) for RBL/C; 223 (157, 318) \( \mu g/\text{m}^3 \) for GBM; 102 (72, 145) \( \mu g/\text{m}^3 \) for CP, and 92 (61, 140) \( \mu g/\text{m}^3 \) for FM (Table 1).

We performed an analysis of variance (ANOVA) to compare differences in respirable silica exposures by SEG (Figure 1). Results of the ANOVA test were significant \( F (4, 41) = 11.17, p < 0.001 \). A post-hoc Tukey’s

<table>
<thead>
<tr>
<th>Similar Exposure Groups (SEGs)</th>
<th>N</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Brick Molding (GBM)</td>
<td>5</td>
<td>71</td>
<td>45</td>
<td>240</td>
</tr>
<tr>
<td>Red Brick Loading/Carrying (RBL/C)</td>
<td>11</td>
<td>331</td>
<td>120</td>
<td>810</td>
</tr>
<tr>
<td>Coal crushing/carrying preparation (CP)</td>
<td>8</td>
<td>92</td>
<td>51</td>
<td>270</td>
</tr>
<tr>
<td>Fireman (FM)</td>
<td>11</td>
<td>102</td>
<td>26</td>
<td>290</td>
</tr>
<tr>
<td>Green Brick Stacking/Carrying (GBS/C)</td>
<td>11</td>
<td>223</td>
<td>140</td>
<td>400</td>
</tr>
</tbody>
</table>

Note. Mean = geometric mean of eight-hour TWA exposure in \( \mu g/\text{m}^3 \); Min = minimum; Max = maximum.
test showed that RBL/C differed significantly from GBM, FM, and CP at p ≤ 0.001. GBS/C also differed significantly from GBM at p ≤ 0.001, and from FM and CP at p < 0.05. There was no significant difference between GBM, FM, and CP. There was also no significant difference between RBL/C and GBS/C.

Discussion

We found that the eight-hour TWA silica exposures in our study exceeded the NIOSH recommended exposure limit (REL) of 50 μg/m³ in all work zones. Furthermore, workers in our study were exposed to respirable silica concentrations that were 1.4 to 6.6 times higher than the NIOSH limit. To our knowledge, this is the first study to report respirable silica levels among clay brick workers employed in fixed chimney Bull’s trench kilns.

Respirable silica levels reported here are similar to previous studies of clay brick workers. Although there are differences in brick manufacturing processes between kiln types, the average free silica content in the respirable dust fraction was very similar between studies. Love (1999), Wiecek (1982) and Myers (1989) reported respirable silica content ranging from 2 – 20%. By comparison, the average free silica content of our samples was 13.8%. It is common in the Kathmandu valley for workers to extract clay from the grounds immediately surrounding the kiln. Thus, differences in the respirable silica content will be influenced by spatial variation in quartz deposits around the valley. Additional studies directed at understanding the distribution of clay silica content in the Kathmandu valley may offer a potential point of intervention. While the selection of the kilns is representative, it is likely that some kilns in the valley may have greater or lesser exposure levels. Likewise, this study is limited to Kathmandu valley and may not be representative of kilns of the same type in other parts of Nepal or elsewhere.

Among the five SEGs evaluated in our study, the red brick loading/carrying SEG had the highest mean exposure (331 μg/m³). Exposure for the red brick SEG was 1.5 – 4.7 times greater than the other SEGs. In contrast to green bricks, which are moist and thus produce less airborne dust, red bricks have been baked, resulting in low moisture content and easy resuspension of settled dust particles. Based on these findings, we recommend dust control measures using water to reduce dust when possible. We recommend the use of respiratory protection for tasks where wet methods are not feasible, or where wet methods do not sufficiently reduce exposures. Priority should be given to workers performing tasks related to red brick loading and carrying and green brick stacking and carrying.

Acknowledgments

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