SHORT REPORT

Prevalence of beryllium sensitization among aluminium smelter workers

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Background Beryllium exposure occurs in aluminium smelters from natural contamination of bauxite, the principal source of aluminium.

Aims To characterize beryllium exposure in aluminium smelters and determine the prevalence rate of beryllium sensitization (BeS) among aluminium smelter workers.

Methods A population of 3185 workers from nine aluminium smelters owned by four different aluminium-producing companies were determined to have significant beryllium exposure. Of these, 1932 workers participated in medical surveillance programmes that included the serum beryllium lymphocyte proliferation test (BeLPT), confirmation of sensitization by at least two abnormal BeLPT test results and further evaluation for chronic beryllium disease in workers with BeS.

Results Personal beryllium samples obtained from the nine aluminium smelters showed a range of <0.01–13.00 μg/m³ time-weighted average with an arithmetic mean of 0.25 μg/m³ and geometric mean of 0.06 μg/m³. Nine workers were diagnosed with BeS (prevalence rate of 0.47%, 95% confidence interval = 0.21–0.88%).

Conclusions BeS can occur in aluminium smelter workers through natural beryllium contamination of the bauxite and further concentration during the refining and smelting processes. Exposure levels to beryllium observed in aluminium smelters are similar to those seen in other industries that utilize beryllium. However, compared with beryllium-exposed workers in other industries, the rate of BeS among aluminium smelter workers appears lower. This lower observed rate may be related to a more soluble form of beryllium found in the aluminium smelting work environment as well as the consistent use of respiratory protection.

Key words Aluminium; beryllium; sensitization; smelter; surveillance.

Introduction

Exposure to beryllium (Be), a lightweight metal commonly used in applications in a variety of industries, can cause beryllium sensitization (BeS), an immune-mediated response, and chronic beryllium disease (CBD), an immune-mediated granulomatous interstitial lung disease [1]. Beryllium occurs naturally in varying concentration in the geological formation of bauxite ore, the primary source of aluminium [2]. The beryllium present in bauxite ore can become concentrated during the aluminium production process, particularly during aluminium smelting, which involves electrolytic reduction of aluminium oxide to produce metallic aluminium in smelters. Consequently, aluminium smelter workers have the potential for beryllium exposure. The authors previously reported a BeS rate of 0.27% among 734 workers with significant beryllium exposure from four aluminium smelters owned by one company [3]. In another study of 362 employees from a Norwegian aluminium smelter who were evaluated for BeS, one individual had confirmed sensitization or a BeS rate of 0.28% [4]. The objectives of this study were to further characterize beryllium exposure in aluminium smelters and determine the prevalence rate of BeS in aluminium smelter workers by pooling exposure and surveillance data from four aluminium production companies.
Methods

Four aluminium production companies identified their smelters with significant beryllium exposure based on the source of alumina from the refineries that supply these smelters and personal sampling data taken at their smelters. Nine aluminium smelters located in the USA, Canada, Italy and Norway were determined to have significant beryllium exposure. Each company used different criteria for determination of workers considered to be significantly exposed to beryllium, including an action level of $\geq 0.1 \, \mu\text{g/m}^3$ 8 h time-weighted average (TWA) or $\geq 1.0 \, \mu\text{g/m}^3$ on a 15 min short-term exposure level for $\geq 12$ days/year, any worker in a similar exposed group with a single value of beryllium exposure $\geq 0.1 \, \mu\text{g/m}^3$ 8 h TWA and all employees at smelters with the highest level of beryllium exposure. Workers from the nine smelters determined to have significant exposure to beryllium were invited to participate in a medical surveillance programme that included the serum beryllium lymphocyte proliferation test (BeLPT) to detect BeS. Workers with BeS, defined as an abnormal BeLPT on at least two blood tests [5], were referred to a respiratory physician for further evaluation to rule out CBD. The beryllium exposure data and the results of the beryllium medical surveillance programmes from the four companies were combined to determine the beryllium exposure profile and the prevalence rate of BeS in these aluminium smelters.

Results

Eight hour TWAs of 1345 personal beryllium samples taken from the nine smelters ranged from 0.0002 to 13.0 $\mu\text{g/m}^3$. The arithmetic mean of the samples was 0.25 $\mu\text{g/m}^3$ (SD = 0.92) with a geometric mean of 0.06 $\mu\text{g/m}^3$ [geometric standard deviation (GSD) = 4.42]. A total of 3185 workers were determined to be at risk from the nine smelters and 1932 workers participated in the surveillance programme between 2000 and 2006. Nine workers were diagnosed with BeS (Table 1). Two of these workers were diagnosed with probable CBD after additional workup (finding previously reported) [3].

<table>
<thead>
<tr>
<th>Company</th>
<th>Number of smelters</th>
<th>At-risk workers</th>
<th>Workers tested</th>
<th>BeS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>1278</td>
<td>734</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>423</td>
<td>328</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>1100</td>
<td>508</td>
<td>4</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>384</td>
<td>362</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>3185</td>
<td>1932</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 1. Medical surveillance for BeS in aluminium smelters

Discussion

The prevalence rate of BeS in this cohort of aluminium smelter workers pooled from four companies was 0.47% with a 95% confidence interval of 0.21–0.88%. This result is similar to previously reported sensitization rates from this industry and is relatively low compared with a range of 0.90–14.6% reported in other beryllium-exposed industrial workforces [1].

The 60% participation rate among the at-risk smelter workers in this study could potentially underestimate the sensitization rate in this workforce, however, because the study was conducted only in aluminium smelters determined to have significant beryllium exposure; therefore, the prevalence rate among all aluminium smelter workers is probably much lower than the 0.47% we report.

Several host and exposure-related factors contribute to the risk of developing BeS and CBD. The primary known host factor is genetic susceptibility [6]. However, genetic susceptibility is unlikely to explain these results given the geographic and ethnic diversity of the study population.

Process-related activities that generate respirable beryllium particles have also been demonstrated to increase the risk of BeS and CBD [1]. Aluminium smelting is an electrolytic reduction process during which aluminium oxide is dissolved in molten cryolite bath (sodium aluminium fluoride) contained in a large carbon- or graphite-lined steel container, known as a pot, at approximately 960°C. During the smelting process, beryllium is concentrated in the molten cryolite bath. During reduction, the pot emits sulphur dioxide, hydrogen fluoride, particulate fluoride, alumina and coal tar pitch volatiles. Control of these emissions relies on ventilation systems for collection at the source and respiratory protection during the performance of certain tasks such as opening the hoods on the pots. The aluminium smelter workers diagnosed with BeS either directly operated the pot lines or performed maintenance work on the aluminium pots, all tasks with high potential for exposure to the cryolite bath. However, none of these activities involve processes like machining, burring or grinding, tasks that have been reported to result in higher rates of BeS in other exposed workforces [1].

Physicochemical characteristics of beryllium, such as particle chemical composition, size, number, surface area and solubility, may influence bioavailability and risk of BeS and CBD. The soluble form of beryllium is thought to be less toxic because the particles dissolve and becomes less available to the immune system [7]. Studies to characterize beryllium particles in aluminium smelters have shown that beryllium concentrations encountered in this environment are within ranges associated with sensitization and CBD in other industries; however, a more soluble form of Be predominates [8].

A major strength of this study is the use of exposure measurements and surveillance data from several aluminium smelters across a variety of geographic regions.
Consequently, these results are most likely representative of exposure and sensitization rates for aluminium smelter workers. However, this report also has some limitations. Each company used different criteria for determination of workers considered to be significantly exposed. Another limitation was the use of different laboratories for BeLPT analyses by the different companies due to their diverse geographical locations. Inter-laboratory variability in BeLPT results among laboratories from split sample testing has been reported; however, confirmation of abnormal results and serial testing may limit errors from this variability [9]. Finally, there was limited exposure data available to reconstruct cumulative exposure for each worker and the cited exposures exclude the effects of respiratory protection.

In conclusion, BeS can occur in aluminium smelters both through natural beryllium contamination of the bauxite ore and concentration in cryolite bath during the smelting process. Exposure levels to beryllium observed in aluminium smelters are similar to those seen in other industries that utilize beryllium. However, compared to beryllium-exposed workers in other industries, the prevalence rate of BeS is lower in this workforce.

Potential explanations for this observation are the presence of the more soluble form of beryllium identified in the aluminium smelting work environment and the use of respiratory protection among aluminium smelter workers. Continued efforts to minimize exposure as well as to further characterize the properties of Be in the aluminium smelting environment are encouraged.

**Key points**

- Beryllium sensitization can occur in aluminium smelter workers through natural contamination of the bauxite.
- The rate of beryllium sensitization observed in aluminium smelter workers is relatively lower compared with other industries where beryllium is used in the industrial process.
- Potential explanations for this observation are the presence of the more soluble form of beryllium in aluminium smelters and work practices adopted in aluminium smelters.

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**Conflicts of interest**

None declared.

**References**