Cadmium Pollution in La Oroya, Peru

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INTRODUCTION

La Oroya, an ore processing center and city of 40,000 inhabitants, is located about 3,800 m above sea level in Peru's Central Andes (Figure 1). The Central Peru Mining Enterprise (Empresa Minera del Centro del Perú, S.A., also known as Centromin Perú) has its metallurgical center here, where it produces, in descending order, copper, lead, zinc, silver, gold, selenium, tellurium, cadmium, indium, sulfuric acid, arsenic trioxide, and other products. Its high-altitude foundry, which has the highest industrial smokestack in the world, emits a daily average of 10 tons of polluting solids, vapors, and fumes for a distance of approximately two kilometers; the plant also discharges additional pollutants into the Mantaro River that flows around the city. Centromin Perú's Safety Department has detected high levels of environmental contamination as far as 10 kilometers away from the foundry's central stack (Figure 2).

The element cadmium is used in alloys because it resists corrosion and in the manufacture of pigments, alkaline batteries, and other items. A respiratory irritant, cadmium is toxic to the kidneys and also causes a type of osteomalacia. Centromin Perú produces about 35,000 pounds of cadmium per month at La Oroya as a by-product of lead and zinc refining. Cadmium oxide (CdO), formed in this process from CdS, is highly toxic.

Because of cadmium's presence and proven toxicity, in 1983 we undertook an evaluation of 40 Centromin Perú workers who were not exposed to cadmium by their work, but who did live in La Oroya, and who should therefore have shown signs of exposure to this element.

The aim of this study was to determine the possible relationship existing between continuous, non-work-related exposure to cadmium and radiographic laboratory indicators that could point to cadmium-related pathology in the resident La Oroya population. Accordingly, the study subjects were examined to determine their pulmonary ventilatory function (PVF), the levels of cadmium and beta-2-microglobulin in their urine, and radiologic signs of osteomalacia (1-5).
MATERIALS AND METHODS

The Survey Subjects

The study, conducted during the summer, was carried out with male Centromin Perú workers who were not directly exposed to cadmium through their work, but who resided a minimum of six days per week in the city of La Oroya, and who worked in the production and administration offices, all of which are located between two and five kilometers from the foundry. Persons living within a one-kilometer radius of the foundry were excluded. We also excluded those workers whose duties caused them to enter the industrial facilities and those who showed any overt symptoms of illness. (It should also be noted that smoking is virtually nonexistent among inhabitants of the Peruvian highlands.) From the remaining population of eligible personnel, the 40 participating workers were selected at random (6).

Test Procedures

The level of cadmium in each subject's urine was determined by means of atomic absorption spectrometry following extraction (7), and the level of beta-2-microglobulin in the urine was found by the Tsuchiya-Biuret method (8). Functional respiratory testing was
performed using a Warren Collins electronic spirometer with a digital display (3, 9). The values quantified were (a) peak expiratory flow (PEF), measured in liters per minute; (b) forced expiratory volume in the first second (FEV$_1$), measured in liters; (c) forced vital capacity (FVC), measured in liters; and (d) the ratio between FEV$_1$ and FVC, expressed as a percentage.

In addition, the air was sampled for the 480 minutes of each work shift, using the continuous collection technique described by Hanson (10) and Jacobs (11). An average of six samples per shift was taken at each of the four points indicated in Figure 2. The ambient temperature during the sampling period ranged from a daytime average at 10–12°C to a nighttime average of 3–6°C. The weather at this time was variable with sporadic showers.

### RESULTS

As Table 1 shows, the average age of the study subjects was 40.1 years and the level of urea in their blood (determined by the Fawcett-Scott-Searcy method—12) ranged from 15 to 29 mg %. Regarding cadmium in their urine, the average level found was 4 μg per liter, with the highest observed level being 8 μg and the lowest being 2 μg. The observed levels of beta-2-microglobulin in the subjects' urine ranged from 0.5 to 1 mg per liter. None of the radiologic results obtained indicated osteomalacia.

The parameters of pulmonary ventilatory function were within normal limits for the subjects' altitude of residence 3,800 m above sea level. All of the study subjects were nonsmokers.

Cadmium was found in the air tested, the average amount being 18 μg per cubic meter over 24 hours, within a range of 9.1 μg at 10 km from the foundry to 26.7 μg at 1 km from the foundry.

### TABLE 1. Data obtained from 40 male test subjects regarding environmental cadmium pollution in La Oroya, Peru.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average</th>
<th>Range</th>
<th>Standard deviation</th>
<th>Standard error</th>
<th>Test method used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>40.1</td>
<td>26-60</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Length of employment (years)</td>
<td>14.4</td>
<td>8-30</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Hemoglobin (g/l)</td>
<td>169</td>
<td>136-190</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Urea (mg%)</td>
<td>20.7</td>
<td>15-29</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Cadmium in urine (μg/l)</td>
<td>4</td>
<td>2-8</td>
<td>±4.95</td>
<td>0.71</td>
<td>Fawcett, Scott, Searcy (12)</td>
</tr>
<tr>
<td>Beta-2-microglobulin (mg/l)</td>
<td>0.7</td>
<td>0.5-1</td>
<td>±5.95</td>
<td>0.72</td>
<td>Tsuchiya-Bluret (8)</td>
</tr>
<tr>
<td>Peak expiratory flow (l/min)</td>
<td>451</td>
<td>406-490</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Forced vital capacity in liters (FVC)</td>
<td>3.99</td>
<td>3.2-4.8</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Forced expiratory volume in first second in liters (FEV$_1$)</td>
<td>2.47</td>
<td>3.0-4.4</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>FEV$_1$/FVC (%)</td>
<td>89.2</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
DISCUSSION

Owing to the nature of its activities, and despite a variety of safety measures that have been adopted, La Oroya is an industrial city with pollution problems. Moreover, in the past, protection for local residents was always provided by actions designed to keep the concentrations of certain more obvious pollutants within permissible limits—these pollutants being lead, arsenic, and sulfur dioxide. Cadmium, which has a biological half-life of 30 years and cumulative effects ranking in toxicologic importance with lead and arsenic (>1, was overlooked.

The portal of entry for cadmium in our population is through the respiratory tract. That is, the element enters as airborne CdO. Figures 2 and 3 show the levels of contamination found at the sampling sites around La Oroya. It should be pointed out that the metallurgical process for cadmium at Centromin Perú is continuous.

The maximum allowable airborne limits recommended by WHO for industrial exposure to cadmium range from 0.1 to 0.2 µg per cubic meter in eight hours (13, 14). When we reviewed the literature on this subject, we found no maximum values established for non-occupational exposures. However, actual exposure levels found by studies in various countries give a rough idea of the problem: in the United States the National Air Sampling Network found levels in 20 large cities that averaged between 0.006 and 0.036 µg per cubic meter (5). In New York, Kneip et al. (15) recorded values of 0.014 to 0.023 µg per cubic meter. In Poland, Just and Kzelus (16) obtained values ranging from 0.002 to 0.05 µg per cubic meter. In Tokyo, Nagata et al. (17) found average 24-hour values ranging from 0.010 to 0.053 µg per cubic meter. And in Stockholm, Piscator (2) reported finding an average weekly value of 0.005 µg per cubic meter.

As is evident, all these values are far below those found by the Safety Department of Centromin Perú for La Oroya, where the average value was 18 µg per cubic meter in 24 hours, within a range of 9.1 µg per cubic meter 10 kilometers from the foundry and 26.7 µg per cubic meter one kilometer from the foundry.

In addition, the Table 1 data show that the level of cadmium in urine (which is the indicator generally used to assess the accumulation of cadmium in people) exceeded the levels found in other cities with cadmium pollution problems. Specifically, the average level found in the La Oroya test subjects (4 µg per liter of urine, with a standard deviation of ±4.95 and a standard error of
0.71) was considerably higher than that found in the Federal Republic of Germany (1 \( \mu g \) per liter—3), the United States (1.6 \( \mu g \) per liter—4), Sweden (0.25 \( \mu g \) per liter—9), and Japan (0.47 \( \mu g \) per liter—18). It should be noted that we have referred here exclusively to those researchers who calculated the level of cadmium in urine by means of the same method (atomic absorption after extraction) that we employed. Therefore, the results appear to demonstrate that the average cadmium concentration in urine was considerably higher in our study group than it was in the study populations of the countries cited.

Regarding beta-2-microglobulin (an indicator of nephrotoxicity), the average value obtained in our study (0.7 mg per liter with a standard deviation of \( \pm 5.95 \) and a standard error of 0.72) was nearly double the 0.4 mg per liter considered normal. To date it has not been possible to show the existence of proteinuria specific for cadmium exposure. However, all researchers appear to agree that beta-2-microglobulin, without being specific, is always found at higher levels in the urine of cadmium-exposed workers. This suggests tubular-type proteinuria caused by reduced resorption of protein in the renal tubules (9). Vigliani (19) has suggested that cadmium acts at the renal level by altering the catabolism of the microglobulins. Whatever the case, and despite the fact that our study subjects were found to have normal levels of urea in their blood (15–29 mg %), the relatively high levels of beta-2-microglobulin clearly demonstrated the chronic subclinical renal aggression to which this study group was exposed.

With respect to the pulmonary ventilatory function (PVF), cases of acute edema in the lungs have been recorded among people subjected to sudden and accidental exposure to cadmium vapors or fumes, while subjects exposed occupationally (i.e., in a chronic manner) show emphysematous alterations (20, 21). However, none of these alterations have been found in subjects who were not occupationally exposed (22). It is therefore not surprising that our study failed to show PVF alterations, the findings obtained being in keeping with values found for normal, nonsmoking subjects residing at high altitude (23).

**CONCLUSIONS**

These results lead to several conclusions. In the first place, it seems clear that the La Oroya population is exposed to quite high levels of cadmium oxide vapors and/or fumes. The subjects tested had a normal pulmonary ventilatory function and yielded no evidence of nephrotoxicity or osteomalacia. However, the levels of cadmium found in their urine indicated an accumulation of this element in their bodies, and beta-2-microglobulin levels were above “normal” limits.

Overall, these findings show that a more extensive epidemiologic study is needed in the city of La Oroya, one that will include different age groups. In addition, it is felt that studies should be performed on the farmlands that use water from the Mantaro River for irrigation, as well as on the agricultural products coming from this valley that are used for human and animal consumption.
SUMMARY

The city of La Oroya is a Peruvian mining and metals refining center with a population of about 40,000 inhabitants situated about 3,800 meters above sea level in the Andes Mountains. The smokestack at its foundry, rated the highest industrial smokestack in the world, emits some 10 tons of polluting vapors, fumes, and particulates per day. The plant also discharges additional pollutants into the Mantaro River that flows around the city.

The study described here, conducted by medical personnel at the Central Peru Mining Enterprise that operates the foundry, was designed to assess levels of cadmium in workers residing in La Oroya who were not occupationally exposed to that element. Past health measures directed at keeping environmental pollution in check had not involved cadmium specifically, being directed instead at other potentially hazardous materials.

Air sampled at four sites located one to 10 kilometers from the smokestack was found to contain unusually high levels of cadmium oxide. The 40 workers included in the study population did not show obvious signs of cadmium poisoning, exhibiting pulmonary ventilatory functions in the normal range for nonsmoking high-altitude residents and having normal levels of urea in the blood. However, abnormally high levels of cadmium in their urine pointed to accumulation of the element in their bodies; and high levels of beta-2-microglobulin in their urine demonstrated exposure to chronic subclinical renal aggression. All in all, these findings appear to justify more extensive epidemiologic study of the cadmium problem in La Oroya, study that should include screening of different age groups and testing for possible contamination of nearby crops.

REFERENCES


