Pamela L. Drake  ·  Maritza Rojas  ·  Christopher M. Reh  
Charles A. Mueller  ·  F. Michael Jenkins

Occupational exposure to airborne mercury during gold mining operations near El Callao, Venezuela

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Abstract Objective: The National Institute for Occupational Safety and Health (NIOSH) recently conducted a cross-sectional study during gold mining operations near El Callao, Venezuela. The purpose of the study was to assess mercury exposures and mercury-related microdamage to the kidneys. The study consisted of concurrent occupational hygiene and biological monitoring, and an examination of the processing techniques employed at the different mining facilities. Mercury was used in these facilities to remove gold by forming a mercury-gold amalgam. The gold was purified either by heating the amalgam in the open with a propane torch or by using a small retort. Methods: Thirty-eight workers participated in this study. Some participants were employed by a large mining company, while others were considered “informal miners” (self-employed). Mercury exposure was monitored by sampling air from the workers’ breathing zones. These full-shift air samples were used to calculate time-weighted average (TWA) mercury exposure concentrations. A questionnaire was administered and a spot urine sample was collected. Each urine sample was analyzed for mercury, creatinine, and N-acetyl-β-D-glucosaminidase (NAG). Results: The range for the 8-h TWA airborne mercury exposure concentrations was 0.1 to 6,315 μg/m³, with a mean of 183 μg/m³. Twenty percent of the TWA airborne mercury exposure measurements were above the NIOSH recommended exposure limit (REL) of 50 μg/m³, and 26% exceeded the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) of 25 μg/m³. The mean urine mercury concentration was 101 μg/g creatinine (μg/g-Cr), and the data ranged from 2.5 to 912 μg/g-Cr. Forty-two percent of the study participants had urine mercury concentrations that exceeded the ACGIH biological exposure index (BEI) of 35 μg/g-Cr. Urinary NAG excretion is considered a biological marker of preclinical, nonspecific microdamage to the kidney’s proximal tubule cells. The mean urine NAG concentration was 3.6 International Units/g-Cr (IU/g-Cr) with a range of 0.5 to 11.5 IU/g-Cr. Three workers had urine NAG levels in excess of the reference values. Correlation analyses found statistically significant correlations between airborne mercury exposure and urine mercury level (P = 0.01), and between urine mercury level and urine NAG excretion (P = 0.01). In addition, the airborne mercury exposure data and urine mercury data were segregated by job tasks. A Wilcoxon rank sum test revealed significant correlations between tasks and mercury exposure (P = 0.03), and between tasks and urine mercury level (P = 0.02). Conclusions: The tasks with the highest mean airborne mercury exposures were “burning the mercury-gold amalgam” and “gold refining/smelting”. Recommendations were provided for improving the retort design to better contain mercury, for ventilation in the gold shops, and for medical surveillance and educational programs.

Key words  Gold mining · Mercury · Biological monitoring · NAG · Occupational exposure
Introduction

Over two decades ago, the South American countries of Venezuela, Ecuador, Peru, Columbia, and the Amazon region of Brazil saw a large increase in gold mining activities due to the rising price of gold [9, 16, 27]. Recent attention has been focused on the problem of occupational and environmental mercury contamination as it relates to the gold mining and refining industries in these countries [14, 19, 20].

A series of case studies are being conducted by the National Institute for Occupational Safety and Health (NIOSH) at gold and silver mines to characterize workers' exposures to mercury during refining operations. NIOSH recently conducted an occupational health study to determine if overexposure to mercury existed at selected mining operations in the gold mining region of Bolivar State, Venezuela. The goals of this study were to determine the extent of mercury exposures in the mining community of El Callao, and to identify exposure sources in work areas.

Precious metals, such as gold, are usually found in two types of deposits, lode or alluvial. In a lode deposit, the gold is embedded in the host rock. Since the gold is an integral part of the host rock, the ore must be crushed and processed. Alluvial deposits, also referred to as placer deposits, are formed when erosion breaks up a lode deposit over time, and deposits the gold as sediments with sand and gravel. Alluvial gold may be found in the beds of streams or lakes or in sediments that have been buried over time [9]. The gold mined in the El Callao area is primarily from lode deposits and this study focused on those types of operations.

Both large and small lode mining operations are found around El Callao, but the majority are small-scale informal mines. The small-scale mines employ from one to ten people and only the larger of these have their own milling facility at the mine site. Most small-scale miners depend on cooperative mills to process their ore. At the small mills the ore was crushed and run through a water concentrator to remove the majority of the waste rock. The concentrates were then de-greased and panned with mercury to capture the gold in a mercury-gold amalgam. Because of the inefficiencies of this process, a significant amount of mercury remained with the waste material, called tailings, resulting in mercury finding its way into the groundwater and rivers. To purify the gold, the mercury-gold amalgam was heated, resulting in vaporization of the mercury. The gold was further refined at the gold shops. Few, if any, preventative measures were taken to protect the mill or gold shop workers from hazardous mercury vapors. Mercury toxicity in gold miners, mill operators, refiners, and individuals living near these processes has been documented [5].

The two large underground mines near El Callao employed approximately 1,000 people. These large-scale mines used modern mining methods and cyanide leaching to extract the gold, therefore mercury was not generally used during processing. The large mine included as a part of this study had mercury present in the plant because the company purchased the tailings from small, nearby mills. The tailings still contained about 10 g of gold per tonne because of the inefficiencies associated with mercury separation methods at the small mills. The run-of-mine ore, which averaged 4 g of gold per tonne, was blended with the tailings to achieve an overall mill feed of 5 g of gold per tonne.

The health effects related to exposure to elemental mercury through inhalation are well documented [2, 3, 8, 10, 35]. The target organs for mercury toxicity are the central nervous system (CNS) and the kidneys. The kidneys are sensitive target organs because a large proportion of the absorbed mercury dose accumulates in the renal cortex. Chronic exposure is characterized by proteinuria (albumin, β-2-microglobulin, retinol-binding protein, etc.) and enzymuria (β-galactosidase, N-acetyl-β-d-glucosaminidase (NAG), β-glucuronidase, etc.) [4, 6, 11, 13, 22, 28, 31, 32, 34]. These manifestations can diminish the ability of proximal tubule segments to reabsorb water, proteins, and other substances, thus affecting the kidneys' ability to maintain volume and composition of body fluids within normal limits.

NAG is a large hydrolytic enzyme, and is abundant in the lysosomes of proximal tubule cells [32]. An increase in urinary NAG levels is considered an indicator of nonspecific microdamage to proximal tubule cells, that is, cell breakdown, necrosis, or increased cellular turnover [18, 24]. In fact, urinary NAG excretion is clinically used as a biological marker of disease-related renal damage in cases of diabetes mellitus, hypertension, and rheumatoid arthritis [29, 30]. NAG has also been used in cross-sectional studies as a nonspecific indicator of cadmium- and mercury-related microdamage to the kidneys' proximal tubules [4, 11, 17, 23, 28, 32].

Methods

This study was conducted in El Callao, Venezuela, a small mining area of Bolivar State, where extensive gold extraction is carried out. El Callao is a small town of approximately 5,000 people with the majority of households relying on income from mining activities. The mining-related jobs were easily classified into three employment categories: large mining company, small mining operations (informal miners), and those working in gold shops where jewelry was manufactured. The intent was to survey workers from all three employment categories. Within the employment categories there were workers who performed different tasks. In the case of the informal miner, tasks that an individual performed could change daily. In order to determine if exposures differed according to the task being performed each day, specific tasks were identified. The informal miners carried out the tasks of mining, milling, burning, and smelting. Mining consisted of excavating the ore and transporting it to the mills. Milling included operating the ore crusher and water concentrator, and panning the concentrates with mercury to form the amalgam. Burning referred to burning the amalgam to vaporize the mercury to separate the gold, and the smelting task was performed to refine the gold further. The individuals employed at the large mining company primarily worked in the plant, operating equipment, managing the cyanide leach process, handling materials, and conducting maintenance and repairs. In one