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Mercury Exposures in Informal Gold Miners and Relatives in Southern Peru

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Subjects working in or living near informal gold mining and processing in southern Peru were studied to determine mercury exposures from two tasks: amalgamation and amalgam smelting. The authors collected 17 airborne and 41 urinary mercury levels. The mean urinary levels were 728 (range: 321–1,662) and 113 (45–197) μg/L for working in smelters and living near smelters, respectively. A third group working in amalgamation had a mean 18 μg/L (range 8–37). People living in the mining town but with no mining activities had 8 μg/L (5–10), while a control group outside the town had 4 μg/L (2–6). Mean airborne mercury exposure was 2,423 μg/m^3 (range 530-4,430) during smelting, 30.5 μg/m^3 (12–55) during amalgamation, and 12 μg/m^3 (3–23) in the mining town. Smelters are highly contaminated with mercury, as are the people living around smelters. *Key words*: mercury exposure; informal gold miners; urine content; environmental exposure.

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Mercury, a highly toxic metal that exists in nature, is artificially introduced into the environment by various human activities. Mercury can be readily transferred between air, water, and soils and can be transported long distances in the atmosphere.[1] Exposures occur in both occupational and environmental settings.[2,3] Mercury can cause neurobehavioral problems with even moderate exposure and severe neurologic damage with high exposure.

Mining is an important source of exposures to mercury.[4–6] Mercury (Hg) levels in urines of gold miners[3] are higher than those of people in other occupations such as dentistry or in control groups.[2]

In Peru, there are two types of gold mines: formal and informal. There are approximately 50,000 informal gold miners (self-employed). In arid zones in mid-southern Peru, gold is extracted from the ore through amalgamation with mercury in quimbaletes. (amalgamation sites). Quimbalete is a type of mortar in which the mineral is milled using water to a fine sand, then mixed with mercury in order to recover gold, in proportions of 30 kg of ore and 0.5–1 kg of mercury, depending on the kind of ore. The resulting material is discharged into a well, where the water evaporates (processing water). The amalgam at the bottom of the quimbalete is separated from tailings (Figs. 1 and 2). These amalgams are then heated (amalgam burning), giving off mercury vapors while leaving the ore as a purer gold form. This procedure represents a serious public health problem, since an estimated 10,000 informal gold miners are breathing the toxic mercury vapors produced by smelting (burning) amalgam. Sometimes the procedure is performed in small houses with insufficient ventilation where the miners and their families live. The entire family may be exposed to Hg for prolonged periods. Amalgam smelting is also commonly done in gold shops in the artisanal mining towns. The Peruvian government has proposed a system to control the mercury vapors that allows the recovery of the mercury through the use of a specially ventilated stove called a retort, but this equipment is not generally used and many of the informal miners are not even award of it.

We measured air and urinary mercury levels among informal gold miners and their relatives from mid-southern Peru, as well as soil and water levels in their environment. Eight subjects from a non-mining town were also studied.

MATERIALS AND METHODS

Participants and Location

The research was performed in the informal mining zones of Chaparra and Tulin, located in the Departments of Ica and Arequipa, respectively, in mid-southern Peru. The control group came from the Achaco region located at Ica; this group had no direct or indirect activities related to mining. Chaparra is a mining town of 1,234 inhabitants, almost all of them working in mining. Tulin has a population of 1,860, 85% of whom are dedicated to mining and 15% to agriculture. Achaco is a agricultural town, outside of Nazca city, with a population of 230.

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Figure 1—Gold amalgamation site (quimbaletes) in Tulin.

The research team visited the towns to explain the purpose of the study and ask for volunteer participation. Study participants represented a convenience sample. The only criterion for participation was to have lived at least six months in a mining or control town, although we also sought preferentially those with occupational exposures in the mining towns. In the case of smelters and people from the quimbaletes, all subjects had been working in these activities for at least six months before the sampling. Smelting usually took place ten to 12 times a day, and occurred on the days when urine and air sampling took place for this study.

All volunteering subjects signed an informed consent form approved by the IRB from the University of Cayetano Heredia,. in Lima. No financial incentive was offered, although participants received a small cooler with juice and crackers. A questionnaire was used to collect information about living conditions and occupation. Children were enrolled via agreement with their parents.

The subjects (19 from Chaparra, 16 from Tulin and eight controls from Achaco) completed the questionnaire and each provided a urinary sample. One sample was rejected because we had doubts about its validity and one was lost.

Of the final 41 participants, 20 of them were asked to participate in the airborne exposure assessment (i.e., to wear the passive sampler), but only eight agreed to participate. Nine more persons were asked just to complete the questionnaire and to wear the passive device in order to collect more air samples. We obtained 17 samples of air exposure; eight of these subjects also provided urine data. One participant agreed to wear the passive sampler on two different days two months apart.

Urine Sample Collection and Analysis

Very early in the morning the research team visited to the participants in their houses to pick up the urine samples. Each participant was asked to collect the first spot urine sample in the morning in a polypropylene container. For the total mercury analysis, a 50 mL urine sample from each participant was placed into a 200-mL polypropylene flask, preserved with glacial acetic acid, and stored in a portable refrigerator. Mercury analysis were conducted within one week. Total mercury analysis was preformed by cold atomic spectophotometry. Quality control procedures included the analysis of blank samples, and precision and accuracy measurements through the analysis of the standard reference material.

Airborne Mercury Analysis

Exposure to airborne mercury was determined by sampling the air, locating a passive device in the breathing zone of each subject. The samples were collected over periods of one hour for amalgam smelters and four hours for the other sites . The air sampling and analysis method used to determine mercury exposure was OSHA-SLTC Method No. ID-140,[7] based in the collection of airborne mercury in a passive dosimeter containing Anasorb® C300: The sorbents were digested

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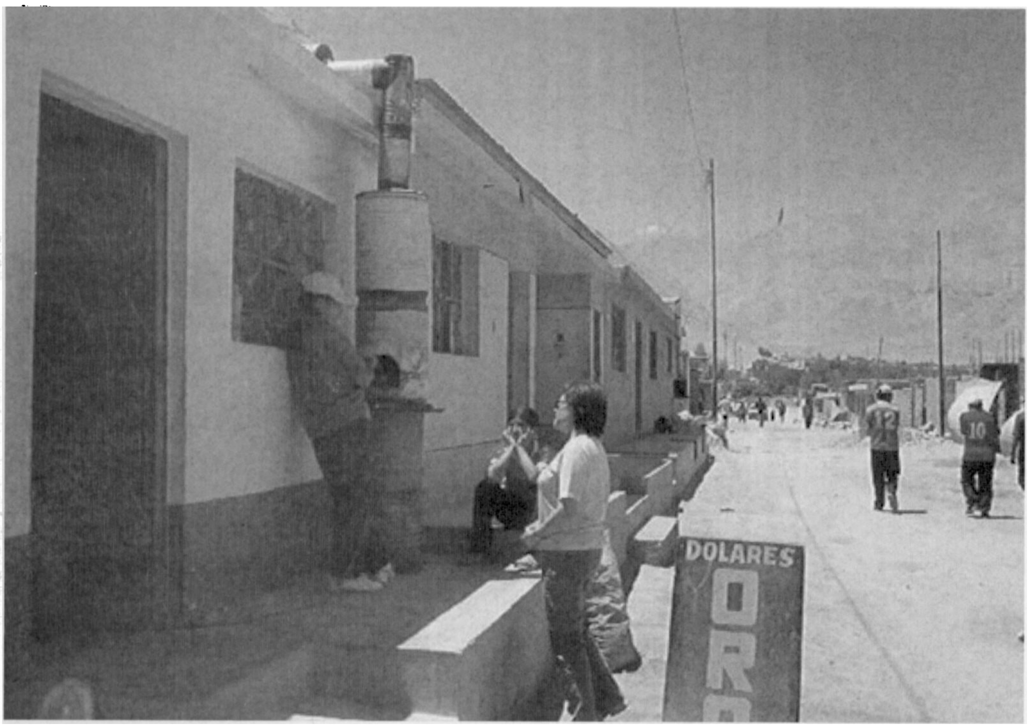

Figure 2—Gold shop in Chaparra. An amalgam smelter is burning the amalgam outside the shop.

using nitric acid and hydrochloric acid. The mercury in the sample was reduced to elemental mercury using stannous chloride and analyzed using a cold vapor-atomic absorption spectrophotometer.

Data Analysis

Statistical analysis were performed using SPSS version 13. Analyses consisted of calculation of means and t-tests of means between exposure groups, the latter using log-transformed urine values. Non-parametric Wilcoxon's rank sum tests were also conducted to compare means.

RESULTS

The 41 participants were clustered in five activity groups: 1) amalgam smelter: persons who smelted (heated/burned) the amalgam in the gold shops or were usually in the gold shops; 2) those living next to gold shops; 3) those working in and/or living next to quimbaletes (adults working in quimbaletes usually worked in mining activities three weeks a month, and in quimbaletes one week per month, and also smelted once a month at home or in gold shops. There were also subjects in this group that only worked in the quimbaletes, as well as children who played in the quimbaletes (because their parents were working there or because they lived there); 4) those living in the mining town: people from Chaparra neither involved in the mining work nor living near gold shops nor quimbaletes; 5) controls: people living in Chaco where no mining activities are performed.

Table 1 shows characteristics of the 41 participants. Their ages ranged from 3 to 60 years; 16 were female and 25 were male. They had been engaged in the described activities for periods ranging from six months to 20 years. Most of the participants consumed fish just one or twice a month and drank alcohol once a week. Most of them (72%) claimed to have no knowledge about mercury toxicity. All four activity groups had significantly higher urinary mercury levels than did the nonexposed controls (Table 2). Results were not affected by age or sex, variables that lacked significance in regression analyses.

Over all, 27% of the participants (11/41) had more than 50 µg/L mercury in their urines, which is the WHO recommended permissible level for exposed workers.[8] Forty-one percent of the subjects (17/41) exceeded 25 µg/L of mercury in urine; this concentration has been related to possible or subtle adverse health effects [9,10]. Normal urinary mercury levels among nonexposed persons are typically around 5 µg/L.[1,6,8]

The miners with the task of smelting the mercury–gold amalgam had the highest urinary mercury concentrations (mean: 728.03 µg/L), followed by people who were living close to the gold shops (mean: 113.4 µg/L).

In subjects working or living in quimbaletes, the mean urinary mercury level was 17.78 µg/L (range 8–37). The urinary mercury levels in nine adults and six children were similar ($p = 0.44$, t test of log urine) despite the fact that four of nine adults smelted amalgam once a month. The group of persons living in the mining town showed an increased urinary mercury concentration of 8.0 µg/L.

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Table 3 shows air levels of mercury. Participants from the gold shops had the highest mean mercury exposure concentrations (2,423.3 μg/m^3), followed by the six quimbaleteo workers (30 μg/m^3) and townspeople (12 μg/m^3). The current Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for mercury vapor is 100 μg/m^3 of air.[11] The National Institute for Occupational Safety and Health (NIOSH) in 1992 set the recommended exposure limit (REL) for mercury[12] at 50 μg/m^3 as TWA (time-weighted average concentration). The limit recommended for an eight-hour TWA, 40-hour week by the WHO[13] and the American Conference of Governmental Industrial Hygienists (ACGIH)[14] is 25 μg/m^3.

Eight subjects had both air and urinary mercury levels. The Pearson correlation coefficient for log air and log urinary mercury levels was 0.93 ($p = 0.0006$). However, this was driven by the two workers in smelters, who had very high air and urinary levels. The other six workers, with lower exposures, worked in quimabaleteo and showed little correlation between log air and log urinary levels. This may be partly because in the quimbaleteo there is dermal absorption of mercury and possible oral ingestion, in addition to inhalation.

It has been estimated that 50 μg/m^3 in air corresponds to about 5–150 μg/L in urine, and that 25 μg/m^3 in air corresponds to about 10-50 ug/l in the urine (ACGIH).[14] Two workers in our study group had high air levels (both about 4,400 μg/m^3) and had urinary levels of 887 and 560 μg/L, while six others had air levels ranging from 12 to 55 μg/m^3 and urinary levels ranging from 8 to 25 μg/L.

DISCUSSION

Urine provides a good measure of mercury since mercury is renally excreted with a half-life of 40–90 days.[3,15–18] It has been demonstrated that first spot samples of urine may serve as an adequate substitute for 24-hour urinary mercury exposure.[3,16,17]

Our results show that informal miners, their families, and persons living in artisanal mining towns have significantly increased mean urinary levels in relation to a control population. Workers in the amalgam smelters and persons living close to the gold shops exceeded the WHO guideline concentration of 50 μg/L for urinary mercury.[19]

Our finding of high urinary mercury levels was similar to results from Venezuela[20] for employees of a large mining company and for informal miners. In Tanzania,[19] five persons frequently exposed to amalgamation and amalgam roasting had a urinary mercury mean of 241.3 μg/L. In Santaren, Brazil,[21] managers of gold shops had a mean urinary mercury level of only 81.1 μg/L, but 78% of the gold shops in Santaren used a rudimentary fume hood to protect against Hg vapor. A more recent study in Santaren[23] demonstrated that subjects with less than two days since last exposure to mercury either in gold mining or refining industry or through proximity had a geometric mean of urinary mercury content of 75.6 μg Hg/g-cr (SD 213.4, range 6.5-759.3). In our study the urinary mercury levels among six amalgam smelter workers ranged from 300

TABLE 1 Characteristics of the Study Subjects and Urinary Mercury Concentrations, by Activity Category

Activity Category and Time in Activity	Subject		Urinary Mercury (μg/L)
	Age (Years)	Sex	
Amalgam smelter			
1 year	36	F	1662.40
1 year	7	M	426.40
8 mo.	21	F	510.03
15 years	48	F	560.32
20 years	45	F	321.45
3 years	47	M	887.62
Living close to gold shop			
13 years	49	F	112.24
3 years	17	M	86.76
6 mo.	4	M	45.80
10 years	30	F	79.12
9 years	9	M	159.50
5 years	5	M	197.00
Working and/or living in quimbaletes			
8 years	33	M	25.13
8 years	29	M	10.41
2 years	10	M	17.10
3 years	4	F	14.40
13 years	54	M	20.20
6 years	60	M	19.08
5 years	36	M	18.06
2 years	46	M	24.32
8 years	8	M	16.38
7 years	43	F	9.37
9 years	9	M	28.21
8 years	17	F	37.02
12 years	12	M	8.42
5 years	29	M	10.51
5 years	20	M	8.17
Living in artisanal mining town			
12 years	12	M	9.15
14 years	14	F	8.29
2 mo.	20	F	7.92
6 years	22	F	5.03
6 mo.	30	F	7.33
1 year	33	M	10.18
Control*			
4 years	5	F	2.67
3 years	3	M	4.45
2 years	30	F	3.30
19 years	19	M	4.30
12 years	15	M	3.12
18 years	18	F	5.46
5 years	38	M	4.95
15 years	45	M	6.46

*Time in activity indicates years living in non-mining area.

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TABLE 2 Mercury Levels in Urines of the Study Groups*

Groups	No.	Urinary Mercury (µg/L) Mean	SD	Range	p Group vs Control†
Amalgam smelter	6	728.03	496.08	321–1662	<0.0001
Living close to gold shop	6	113.40	55.80	45–197	<0.0001
Working and/or living in quimbaletes	15	17.78	8.25	8–37	<0.0001
Living in an artisanal mining town	6	7.98	1.75	5–10	0.01
Control	8	4.33	1.28	2–6	

*WHO recommended urinary limit = 50 µg/L. ACGIH estimates that 10–50 µg/L mercury in the urine corresponds to approximately 25 µg/m³ in air.
†t test for log of urinary levels of each group vs control; Wilcoxon's rank-sum test gave the same results.

TABLE 3 Mercury in Air (µg/m³)* in Three of the Exposed Groups

Groups	No.	Mean	SD	Range
Amalgam smelter	6	2423.3	1735.9	4,440–530
Working and/or living in quimbaletes	6	30.5	18.9	55–12
Living in artisanal mining town	5	11.8	11.8	23–3

*WHO/ICPS = 0.2 µg/m³ is a guidance value for long-term inhalational exposure of the general public to metallic mercury vapor. WHO and ACGIH recommend a maximum occupational exposure of 25 µg/m³ 8-H TWA (time-weighted average concentration) exposure, over a 40-hour week.

to 1,600 µg/L. These high levels were due to the lack of hoods for protection and the heavy smelter use in this population (eight to 12 times during a working day, including the day of sampling).

The mercury content of subjects in our study was therefore similar to or higher than previous published results.[3,19,21–23] A special problem in Peru's informal gold mining sector is that many children work in the quimbaletes and they are more susceptible to the effects of mercury.

Studies of workers exposed to elemental mercury vapor with mercury urinary levels between 10 and 50 µg/L (as found in subjects from quimbaleteos) have shown self-reported memory disturbances, sleep disorders, anger, fatigue, and/or hand tremors.[9] For urinary mercury levels of 50–100 µg/L (as in people living near gold shops) the likely health effects reported were effects on cognitive, sensory, personality, and motor functions, and also proteinuria, glomerular as well as tubular. Finally, urinary mercury levels of 100–1,000 µg/L (as found in smelters and people living near goldshops) are related to neurologic, renal, respiratory, cardiovascular, gastrointestinal, and immunologic effects.[1,9]

The high mercury concentrations in the gold shops could be much reduced by using well-designed stoves (retorts). Retorts are systems where mercury is evaporated and recovered by condensation, avoiding air pollution; however the recovery of mercury is low and sometimes it needs to be reactivated by using brine and electricity.[24] The main obstacles to using such stoves are: 1) it is necessary to use more energy to burn the amalgam, so the cost of gold recovery is increased; 2) the gold is recovered in a different color; and 3)lack of information about mercury toxicity.

Our study had some limitations: the ample size was small and the subjects were not selected randomly, which could have resulted in a bias, but we did accept all subjects who wanted to participate. However, our study does indicate the seriousness of mercury exposures of informal miners and their relatives in arid areas of Peru.

CONCLUSION

Smelters in this informal mining sector are strongly contaminated with mercury, and this pollution extends to areas where people are living around the gold shops. People working in the quimbaletes have elevated urinary mercury levels. Furthermore, mercury in children in mining towns may place them at risk for neurodevelopmental and learning disorders.[3,25] More studies are needed to study the health effects of these exposures and to assess intervention strategies to reduce exposures.

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