Environmental Research Section A **90,** 98–103 (2002)
doi:10.1006/enrs.2002.4389

Mercury Exposure in Munduruku Indians from the Community of Sai Cinza, State of Pará, Brazil

Elisabeth C. de Oliveira Santos,* Iracina Maura de Jesus,* Volney de M. Câmara,† Edilson Brabo,* Edvaldo C. Brito Loureiro,* Artur Mascarenhas,‡ Judith Weirich,* Ronir Ragio Luiz,† David Cleary§

*Evandro Chagas Institute, Environmental Section—FUNASA/MS, Belém-Pará-Brazil, Brazil; †Executive Secretariat of Industry, Commerce and Mining, Brazil; ‡Federal University of Rio de Janeiro - NESC/UFRJ, Brazil; §European Union, Brazil

Received March 4, 2002

The objective of this cross-sectional study was to evaluate mercury exposure and health status among Munduruku Indians from the community of Sai Cinza, State of Pará, Brazil. The population studied included 330 indians, who submitted to a questionnaire, clinical exams, and collection of hair, blood, urine, and feces. Mercury was measured in hair and fish. Although no person was found to have overt mercury intoxication, the mean levels of mercury in hair were elevated (14.45 μg/g for children from 7 to 12 years old, 15.70 μg/g for women between 14 and 44 years old, and 14.1 μg/g for the remaining population). Mercury levels in fish were below levels recommended by the World Health Organization, but rates of fish consumption were high. These results place this indigenous populations as a group under risk of mercury toxicity from the gold production.

Key Words: **mercury; indians; epidemiology; gold mining; Amazon.**

INTRODUCTION

The indigenous populations living in the State of Pará, Brazil at the beginning of the 18th century was estimated at more than 54,000 individuals. However, with the passing of years this number decreased considerably. The indian groups who survived colonialism now comprise less than 16,000 persons, mostly distributed in 37 indigenous reservations, in a space of 228,280 km^2 on close to 18.31% of Pará State (Oliveira, 1983; Pará, 1997).

Indian populations declined over this time mainly due to the introduction of new diseases acquired through contact with Europeans. Also important were armed conflicts related to land and social disruption, loss of cultural identity caused by acquisition of new habits, absence of guarantees of territorial integrity, and lack of protection of natural resources (Santos *et al.*, 1992; Gonçalves, 1993; Santos, 1993).

Riverside populations including indians living near the Tapajós River basin are potentially exposed to the risk of mercury from gold mining activities developed in this area primarily via eating fish, since fish consumption is the main protein source of this population. Metallic mercury used in gold mining is known to be transformed to methylmercury in rivers and then incorporated into the food chain, especially by carnivorous fish (Aula *et al.*, 1994; Castilhos *et .al.,* 1998; Mascarenhas *et al.*, 1998; Brabo *et al.*, 2000; Santos *et al.*, 2000).

MATERIALS AND METHODS

A cross-sectional study was conducted to evaluate mercury exposure and health status among Munduruku Indians from the community of Sai Cinza, State of Pará, Brazil. This community resides on the western side of the Tapajós River, about 15 km from the Municipality of Jacareacanga, in the southwest of Pará State (Fig. 1). As observed during the field research it includes 390 indians living in 63 houses, in a space of 1205 m along the river. All age groups were included in this study.

Drinking water is drawn from small rivers close to the village and consumed without treatment. These rivers are also used for bathing and domestic purposes. Sanitary conditions are very poor and wastes are discharged into the water or buried. Only two houses are served by septic systems, one used by the government and another by a religious mission.

Munduruku Indians are popularly known in the area as "head hunters" because after the battles,

0013-9351/02 $35.00

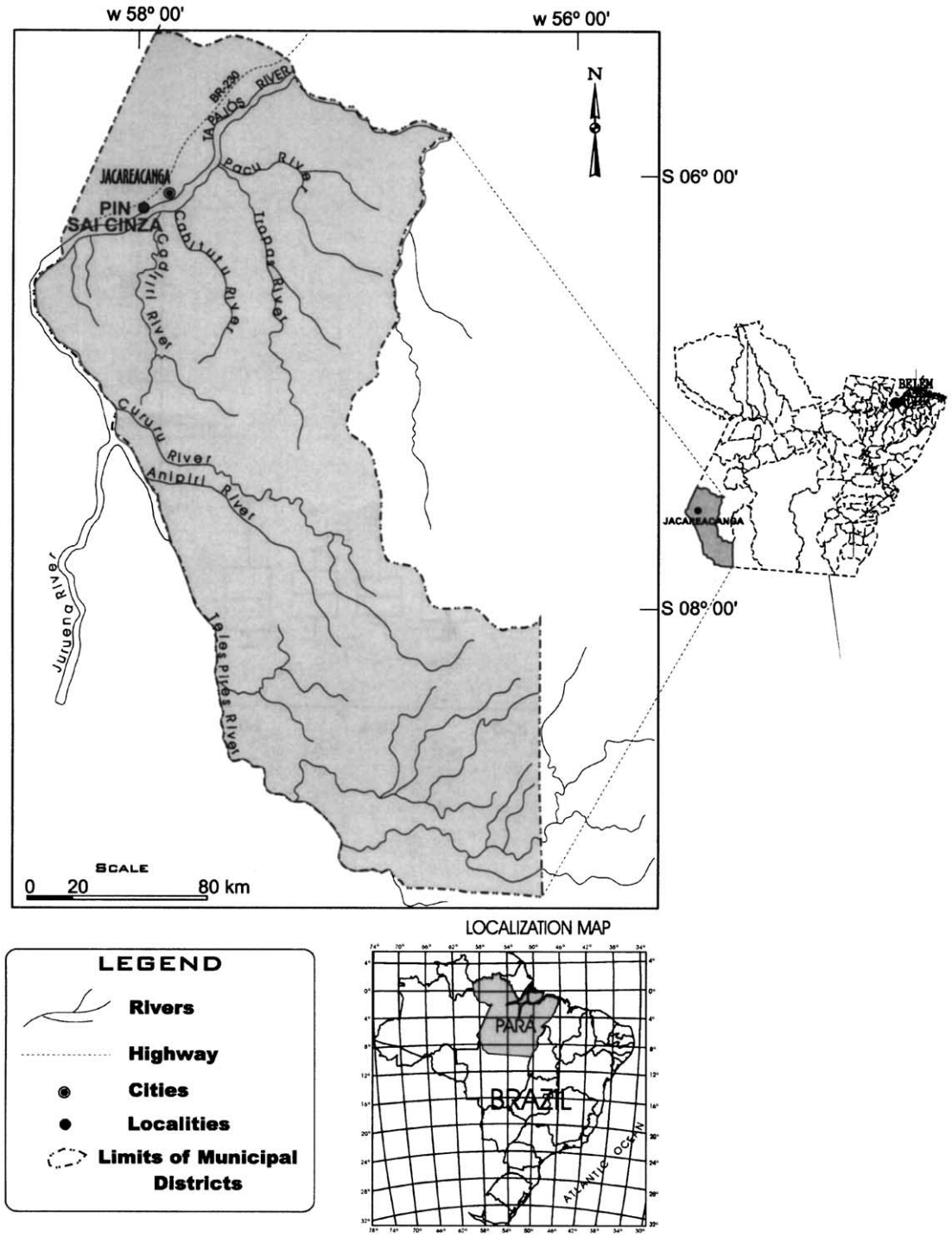

FIG. 1. Map of study area.

they used to exhibit the enemy's heads. They belong to the linguistic family of the same name and the total remaining population now lives on the margins of the Tapajós River (Silva *et al.,* 1995). The main economic activities of this community are agriculture, fishing, hunting, and gold mining. Agriculture is limited to subsistence raising of cassava. They also have some cattle and carry out a small trade in wood, chestnut and syringa (Pará, 1994).

The study procedures were developed from previous contacts with the community. From these contacts a local census was developed to visit all

residences 30 days before beginning the field research. In the study all residents were invited to participate. Each individual signed a registration giving assurance of informed consent. Information on age, gender, occupational history, dietary habits, and morbidity was obtained by a questionnaire. A small local laboratory was set up on site for collection, identification, and preservation of biological specimens. Medical exams were performed to verify signs and general symptoms with attention to the nervous system (speech and sight, static and dynamic equilibrium, motor coordination, tactile sensitivity, muscle tone and posture).

The biological samples collection included hair for total mercury, urine from 15 individuals (infection cases and pregnancy), blood for malaria prevalence and total mercury (not discussed in this paper), and feces for direct diagnosis of intestinal parasites.

The samples of hair were removed from different areas of the scalp, with at least 100 strands taken from each area, cut 1 cm from the scalp with scissors of nonoxidizable steel, and stored in white envelopes at room temperature until analysis. Fish samples commonly consumed were collected by fishing net in the Muiuçu Lake, the preferential place of fishing near the village, and stored by removing portions of edible tissue from each specimen. These were frozen individually in plastic bags for later analysis. The analytical procedures for total mercury determination were performed by the Evandro Chagas Institute according to the method proposed by Akagi *et al.,* (1995, 1996). The mercury determinations were made by flameless atomic absorption spectrophotometry using a mercury analyzer Hg-3500.

The data were entered into the dBase program. For statistical analysis, a nonparametric procedure, the Kruskall–Wallis test, comparing mercury distributions by each group was used. The Spearman coefficient (SC) was applied to evaluate correlations among variables (Armitage, 1971).

RESULTS

From the population of 390 individuals, 330 participated in the interview and clinical evaluation (others were out of town or did not want to participate). They consisted of 192 females (58.2%) and 138 males (41.8%). Of these, 324 reported a diet composed mainly of fish. The ages varied from 6 months to 81 years with an average of 19 years.

The medical examination did not reveal any person with signs or symptoms indicative of central nervous system dysfunctions that could be associated with mercury intoxication, such as problems in speech, balance, motor coordination, or tactile or pain sensibility. Some individuals were treated for other conditions found during the clinical examination. Parasitological exams to detect malaria were conducted by examination of a thick blood film in 187 individuals; among them 12 positive cases (6.4%) were detected. Fecal exams by direct preparations in 321 samples revealed prevalences of 98% of intestinal parasistism and 90% of polyparasitism.

The mean level of total mercury in hair was 16.0 μg/g (Table 1). In the individuals with ages less than or equal to 15 years the mercury levels varied from 4.50 μg/g in young children (≤ 2 years old) to 90.40 μg/g in older children (11 to 15 years old). In subjects older than 15 years the mercury concentration varied from 6.60 to 64.50 μg/g. In the general population, 204 individuals (67.0%) presented levels of Hg below the mean while 120 (33.0%) were above 16.0 μg/g. The Hg levels were shown through kurtosis and symmetry analysis to not have a normal distribution. There was no correlation between total hair mercury concentration and age ($P > 0.05$),

TABLE 1

Total Hair Mercury Concentrations (μg/g) by Age Groups from 324 Munduruku Indians, Sai Cinza, Pará, Brazil, 1996

Age group (Years)	*n*	Mean of age (Years)	Geometric mean (μg/g)	Mean Hg in hair (μg/g)	Standard deviation	Range
0–2	39	1.44	12.96	14.41	6.64	4.50–34.50
3–5	39	3.92	15.21	16.14	5.48	6.5–33.10
6–10	61	7.80	16.27	17.77	9.74	9.0–66.60
11–15	52	12.6	15.35	17.08	11.62	6.80–90.40
16–25	43	21.0	14.65	15.17	3.71	9.30–25.70
26–35	35	30.0	13.83	14.67	5.00	6.90–28.30
36–45	20	41.5	14.59	16.25	9.24	7.80–44.20
> 45	35	56.7	13.92	15.31	10.47	6.60–64.50
Total	324	18.92	14.72	16.0	18.92	4.50–90.40

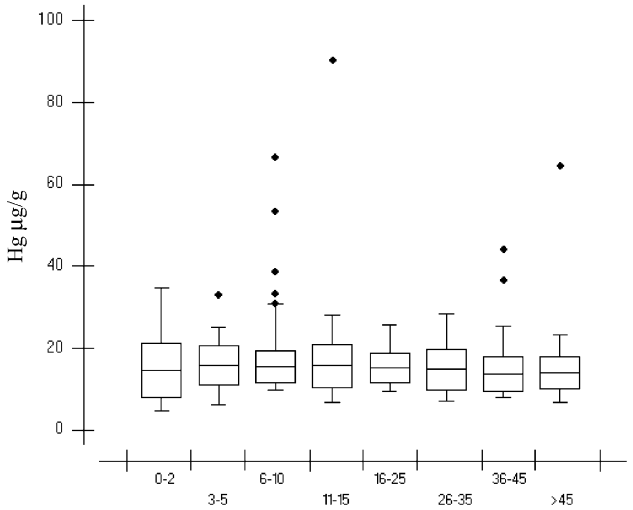

FIG. 2. Hg levels in hair in Munduruku Indians by age (Sai Cinza, Amazon, Brazil).

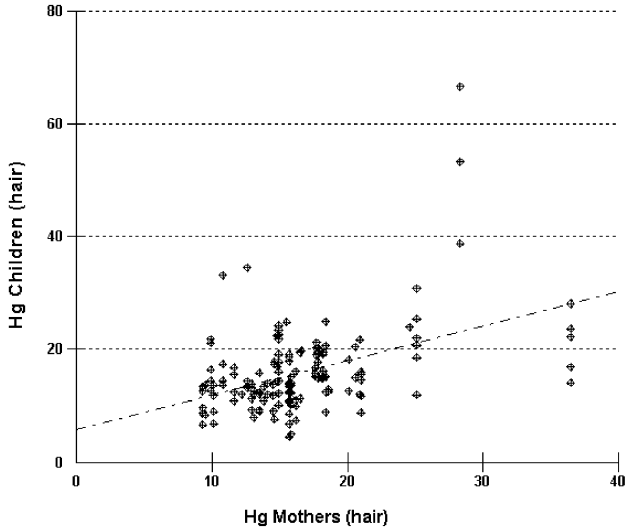

FIG. 3. Relationship between Hg levels (µg/g) in hair of mothers and their own children in Munduruku Indians, Sai Cinza, Amazon, Brazil (Spearman correlation = 0.3672, $P < 0.01$).

which distribution is demonstrated in Fig. 2. Statistical measures shown in Table 1 include the geometric mean which also showed no significant differences in the Hg levels by age group.

In the context of the World Health Organization recommendations there was no subject with mean Hg below 2.0 µg/g (unexposed population) and only two individuals were below 6.0 µg/g (Biological Tolerance Limit). It is important to emphasize that persons in all age groups had high values of mercury in hair.

Between selected groups such as individuals between 7 and 12 years old (growth and school development), women in fertile age (possibility of fetus exposure through the placental barrier), and the remaining individuals, no significant differences in Hg levels were found by Kruskall–Wallis test ($P > 0.05$). However, all these groups showed hair Hg level above 14.0 µg/g, indicating exposure over background. The mean of mercury for children from 7 to 12 years old was 14.45 µg/g, for women between 14 and 44 years old this was 15.70 µg/g, and the remaining population had Hg levels of 14.1 µg/g.

Mothers and their children were paired to evaluate the correlation among their Hg levels by the SC in Fig. 3, which shows a positive but weak correlation (SC = 0.3672, $P < 0.01$).

Table 2 presents occupational activities for the population in Sai Cinza. As expected, the majority of this indigenous population worked in agriculture. Some indians had more than one occupation, particularly agriculture and gold mining. The 31 indians working in gold mining probably had an additional source of Hg exposure, more specifically the metallic mercury used in amalgamation. This was not measured by the mercury analysis in the hair, since the appropriate indicator would be analysis of urine samples. Craft fishing is an activity commonly performed by most of the population and thus was not shown in Table 2. The other groups that show the lowest Hg means include people that work in carpentry, hunting, farmng, crafts, and syringa.

The population had a high consumption of several fish species; among them 12 species were collected for mercury analysis (Table 3). The mean of total Hg in carnivorous fish was 0.297 µg/g higher than the levels observed in noncarnivorous fish (0.095 µg/g). Although these mercury concentrations varied for each fish species, size, age, and alimentary habit,

TABLE 2
Total Mercury Concentrations in Hair (µg/g) by Occupations, Sai Cinza, Pará, Brazil, 1996

Occupation	Individuals	%	Mean	Range
Agriculture	127	39.2	17.28	6.8–90.4
Gold mining	6	1.9	13.77	10.7–18.5
Agriculture and gold mining	25	7.7	13.80	6.9–25.7
Others	11	3.4	12.27	6.6–20.6
Children up to 6 years old	93	28.7	16.83	4.5–66.6
Students	38	11.7	15.13	9.0–38.7
Without information	24	7.4	17.01	9.6–30.8
Total	324	100.0	16.01	4.5–90.4

TABLE 3
Total Mercury in Fish Species Consumed by Munduruku Indians, Sai Cinza, Pará, Brazil

Fish species	Alimentary habit	*N*	Hg Mean (μg/g)	Range
Tucunaré	Carnivorous	17	0.267	0.173–0.338
Traíra	Carnivorous	07	0.322	0.160–0.546
Piranh	Carnivorous	03	0.219	0.065–0.450
Jandiá	Carnivorous	03	0.093	0.051–0.130
Barbado	Carnivorous	03	0.419	0.349–0.474
Aruanã	Carnivorous	01	0.174	—
Surubim	Carnivorous	01	0.385	—
Jaraqui	Noncarnivorous	22	0.112	0.074–0.201
Caratinga	Noncarnivorous	18	0.120	0.067–0.201
Pacu	Noncarnivorous	02	0.042	0.026–0.057
Aracu	Noncarnivorous	02	0.108	0.097–0.120
Mandi	Noncarnivorous	01	0.095	—
Total		80		

they are all below 0.5 μg/g, the limit recommended by the World Health Organization (1990).

DISCUSSION

This population of Munduruku Indians showed high concentrations of total mercury in hair ranging from 4.50 up to 90.40 μg/g. This was observed for all persons with no statistical differences by age group, sex, occupation or diet. There was a weak and positive correlation in hair Hg among women in fertile age and their children.

The area in which this group lives is at risk of pollution by mercury from gold extraction. These high levels of mercury could be increased by cultural practices of the Mundurukus. Fish is the main food consumed, with continuous fish ingestion throughout the day for all ages. This pattern of exposure is similar to that of other riverside (non-indian) communities from the Tapajós River basin, such as São Luiz do Tapajós which is under risk of pollution by mercury from the gold mining (Santos *et al.*, 2000).

It is necessary to know the importance of other variables that could be related to the mechanisms of methylmercury absorption by humans, such as the possible influence of alimentary habits. Also important to the health conditions of this population is the high prevalence of intestinal parasitism in addition endemics such as malaria that weaken individuals, organism, affecting their imunological system and possibly their exposure to Hg.

The concentrations of total mercury in fish in Sai Cinza were below the limit recommended by the World Health Organization. However, it is important to emphasize that fish consumption is very high, such that a slow accumulation could represent risk to the health of the human population, which is at the top of the food chain.

ACKNOWLEDGMENTS

Financial support for this study was provided by National Foundation of Health, Evandro Chagas Institute, and European Union.

REFERENCES

Akagi, H., Malm, O., Branches, F. J. P., Kinjo, Y. Kashima, Y., Guimarães, J. R. D., Oliveira, R. B., Haraguchi, K., Pfeiffer, W. C., Takizawa, Y., and Kato, H. (1995). Human exposure to mercury due to gold mine in the Tapajós river basin, Amazon, Brazil: Speciation of mercury in human hair, blood and urine. *Water Air Soil Pollut*. **80,** 85–94.

Akagi, H., Malm, O., and Branches, F. J. P. (1996). Human exposure to mercury due to mining in the Amazon, Brazil—A review. *Environ. Sci.* **3,** 199–211.

Armitage, P. (1971). "Statistical Methods in Medical Research." Blackwell Sci., Oxford.

Aula, I., Braunschweiler, H., Leino, T., Malin, I., Porvari, P., Hatanaka, T., Lodenius, M., and Juras, A. (1994). Levels of mercury in the Tucuruí Reservoir and its surrounding area in Pará, Brazil. *In* "Mercury Pollution Integration and Synthesis" (C. J. Watras and J. W. Huckabee, Eds.), pp. 21–40. CRC Press, Boca Ration, FL.

Brabo, E. S., Santos, E. O., Jesus, I. M., Mascarenhas, A. F., and Faial, K. F. (2000). Mercury contamination of fish and exposure of an indigenous community in Pará state, Brazil. *Environ. Res*. **84,** 197–203.

Castilhos, Z. C., Bidone, E. D., and Lacerda, L. D. (1998). Increase of the background human exposure to mercury through fish consumption due to gold mining at the Tapajós river region, Pará state, Amazon. *Bull. Environ. Contam. Toxicol*. **61,** 202–209.

Gonçalves, A. (1993). Saúde, garimpagem e mercúrio entre os Kaiapó–Gorotire. *In* "Consequência da Garimpagem no Âmbito Social e Ambiental da Amazônia" (A. Mathis and R. Rehaag, Eds.), pp. 61–63. CEJUP, Belém.

Mascarenhas, A. F. S., Brabo, E. S., Santos, E. C. O., Jesus, I. M., and Faial, K. F. (1998). Níveis de mercúrio em peixes na Bacia higrográfica do Tapajós, Jacareacanga—Itaituba, Pará: Resultados preliminares. *In* "Revista da Sociedade Brasileira de Medicina Tropical. XXXIV Congresso da Sociedade Brasileira de Medicina Tropical." Manaus, p. 41.

Oliveira, A. E. (1983). Ocupação Humana. *In* "Amazônia: Desenvolvimento, Integração e Ecologia" (E. Salati, W. J. Junk, H. O. Shubart, and A. E. Oliveira, Eds.), pp. 144–300. Conselho de Desenvolvimento Científico e Tecnológico, Brasília.

Pará–Secretaria de Estado de Ciência, Tecnologia e Meio Ambiente. (1997). "Propostas de Diretrizes para a Política Estadual de Apoio às Sociedades Indígenas." SECTAM, Belém. [Mimeografado]

Pará–Secretaria de Estado de Indústria, Comércio e Mineração. (1994). "Estrutura Fundiária e Ocupação do Solo e Subsolo—Caracterização Geral do Município de Itaituba. SEICOM, Belém.

Santos, E.O. (1993). Garimpagem e Saúde. *In* "Consequências da Garimpagem no Âmbito Social e Ambiental da Amazônia" (A. Mathis, and R. Rehaag, Eds.), pp. 36–37, Ed. CEJUP, Belém.

Santos, E. C. O., Rosa, J. F. T., Jesus, I. M., and Loureiro, E. C. B. (1992). A Saúde das populações da Amazônia Brasileira. *In* "Enfoque Integral de la Salud Humana en la Amazonia." (L. Yarzabal, C. Espinal, and L. E. Aragon, Eds.), pp. 95–156. Associação de Universidades Amazônicas/Universidad Central de Venezuela, Imprenta UCV, Caracas.

Santos, E. C. O., Jesus, I. M., Brabo, E. S., Loureiro, E. C. B., Mascarenhas, A. F., Weirich, J., Câmara, V. M., and Cleary, D. (2000). Human health in riverside amazon communities living in exposed and not exposed areas to mercury pollution from gold mining. *Environ. Res*. **86,** 100–107.

Silva, A. L. da, Grupion, L., and Benzi, D. (1995). "A Temática Indígena nas Escolas." MEC/MARI/UNESCO, Brasília.

World Health Organization (1990). "Methylmercury. Environmental Health Criteria 101." WHO, Geneva.