Longitudinal assessment of mercury exposure in schoolchildren in an urban area of the Brazilian Amazon

Avaliação longitudinal da exposição ao mercúrio em crianças de uma área urbana na Amazônia brasileira

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Abstract

This study was a longitudinal assessment of mercury exposure in schoolchildren in an urban area of the Brazilian Amazon. The study population consisted of 90 children whose exposure levels were assessed by testing mercury levels in the umbilical cord blood and mothers' blood samples in 2000-2001, and in the children's hair and blood samples. The study also used a questionnaire on demographic and socioeconomic data, fish consumption, and self-reported disease history. Mean mercury level in hair in 2010 was approximately 1μg/g, ranging up to 8.22μg/g, similar to 2004 and 2006. These figures can be explained by low fish consumption. Mean blood mercury levels at birth exceeded 10μg/L, ranging up to nearly 60μg/L, which indicates mercury transfer across the placenta. There was a significant increase in blood mercury from 2004 to 2006 ($p < 0.001$), suggesting exposure through air pollution. The main exposure to mercury was during pregnancy.

Mercury; Poisoning; Environmental Exposure; Child

Introduction

Epidemiological studies in the Brazilian Amazon should consider that both working and non-working individuals may be exposed to metallic mercury (Hg) emissions caused by mining operations that use mercury as an amalgam in gold extraction, during the resmelting of gold for sale in shops usually located in urban areas, and from emissions resulting from the burning and destruction of forests [1].

Another more toxic form of exposure involves the absorption of methylmercury (MeHg) present in fish, a staple in the diet of riverine and indigenous communities, making these population groups more vulnerable [1,2]. Depending on specific environmental conditions like the presence of certain aquatic microorganisms, metallic mercury accumulated in the environment can be transformed into MeHg and biomagnify in fish along the biological chain [3].

Children can be subject to mercury exposure through: prenatal transfer across the placenta; breastfeeding, by ingesting breast milk containing mercury; and a diet rich in fish [1,3,4,5]. Recent studies have also raised the possibility of mercury exposure through vaccines [6]. According to a study by the U.S. Agency for Toxic Substances and Disease Registry [7], as compared to adults, children are more exposed and susceptible to situations involving health risks due to: their rapid

growth and development; higher levels of gastrointestinal, transdermal, and respiratory absorption based on body weight for the same concentrations of toxic substances; the incomplete development of their detoxifying mechanisms; and their immature blood-brain barrier [8,9].

Mercury can have systemic effects, reaching nearly all of the body's organs and systems. The effects are predominantly on the nervous system, causing, among others, alterations in the child's development; decreased motor coordination; alterations in hearing, speech, gait, and balance; tremors; decreased visual field; and blindness. Mercury can also have mutagenic and teratogenic effects [9,10,11,12].

Children's exposure to methylmercury has been proven by various studies, generally cross-sectional, conducted in small riverine communities in the Amazon [1,2]. As a contribution to future research on this theme, the aim of the current study was to conduct a longitudinal evaluation of mercury exposure in schoolchildren in an urban area of the Amazon, specifically Itaituba, a municipality (county) in the State of Pará which is the largest gold producer in Brazil, and whose socioeconomic and nutritional profile differs from that of the rural riverine communities [2,13].

Methods

The gold-mining boom in the Brazilian Amazon lasted until the early 1990s, but the city of Itaituba, situated in the southwest region of the State of Pará, is still the main gold marketing center in Brazil [13]. According to estimates by Souza et al. [13], based on data from the Central Bank of Brazil, from the 1990s to 2004, 3,585kg of mercury used in gold production in Itaituba were launched into the atmosphere.

The study population included children from the urban area of the municipality of Itaituba with prior information on mercury levels at birth (cord blood samples from 2000 and 2001) and analysis of mercury levels in hair samples taken later from the same children at 8 to 10 years of age in 2010. Hair and blood mercury levels were also analyzed in these children in 2004 (n = 90) and 2006 (n = 47) in samples stored at the Evandro Chagas Institute, thus providing a study with repeated measurements over time. No mercury results are available for 43 children in 2006, since they were not visited that year due to changes of address or because they were not present when the field research team visited.

The sample (n = 90) was based on the existence of a study [2] at the Evandro Chagas Institute (Instituto Evandro Chagas) with 1,510 children born in 2000 and 2001 at the maternity hospitals in Itaituba. Of these, a group of 239 children from the urban and rural areas were monitored from birth until 4 and 6 years of age. Losses to follow-up from birth to 6 years can be explained by the fact that the municipality of Itaituba has the largest infrastructure in the Tapajós Basin, offering better birthing conditions for women as compared to other municipalities in the region, so that the mothers return to their home towns and villages after childbirth (in addition to changes of address). Later, based on this list of 239 children that were followed and which included those residing in urban and rural areas, the study selected only those that studied and lived in the city limits of Itaituba, leading to the identification of the 90 children that participated in this study with the help of the Itaituba Municipal Department of Education (Secretaria Municipal de Educação de Itaituba) for children not located in 2006.

In 2010, the procedures included the use of a questionnaire on demographic and socioeconomic data, fish consumption, and self-reported disease history, similar to that used by the institution since 2000. Blood and hair samples were taken by the team from the Evandro Chagas Institute according to international procedures. Determination of total mercury in blood and hair samples used a cold vapor atomic absorption spectrometer (CV-AAS), model Automatic Mercury Analyzer HG-201 (Sanso Seisakusho Corp., Tokyo, Japan) and quality control used analysis of certified hair samples (IAEA-086), with analytical recovery of 99.65% (n = 27), and blood samples (Whole Blood II), with analytical recovery of 98.14% (n = 9).

In the exploratory data analysis, descriptive statistics were calculated for mercury levels and the appropriate graphs and tables were constructed. The Wilcoxon test was used to check variation in mercury levels from birth to 4 years and from 4 to 6 years. The McNemar chi-square test was used to test the proportions of elevated mercury in the blood of newborns, children, and mothers, using the cutoff for blood mercury recommended by the World Health Organization (≥ 8µg/L) for unexposed individuals [9]. For mercury levels in hair, the study used the reference value of 2.0µg/g for unexposed individuals, also recommended by the WHO [9].

In compliance with the ethical procedures of the *Declaration of Helsinki* and *Ruling 196/96* of the Brazilian National Health Council (Conselho Nacional de Saúde) on Research Involving Humans, the project was approved by the Institutional Review Board (case 105/2009). Study participants and their parents or guardians were informed verbally and by means of a written document concerning the study objectives and pro-

cedures, and the parents or guardians signed a free and informed consent form before the study began.

Results

The study sample of 90 children showed an even sex distribution, with 48 boys and 42 girls. As for age, the majority were 8 years old (69%), and only one child was 10. All lived in Itaituba, and 65 (70%) of the families had residential or mobile telephones.

According to the disease history reported in 2010, 67 (74.4%) of the children had a lifetime history of one to three diseases, the most common being chicken pox (17), dengue (14), intestinal infections (13), and pneumonia (12). A separate question on illnesses in the previous month showed that 48 (53.3%) had experienced one or more disease events, mainly influenza (20), fever (13), and headache (6).

Table 1 shows figures on the children's fish consumption. Only 5 children showed zero fish consumption in the previous year, while consumption once a week was reported by 44 children and twice a week by an additional 27. In 2004 and 2006, the majority of the children consumed fish a maximum of twice a week. Consumption of fish meal was reported for 21 children in 2010, but only two children consumed fish meal more than once a month. This dietary pattern was similar for both years (2004 and 2006).

Mean mercury level in hair in 2010 was close to 1µg/g, ranging up to 8.22µg/g, similar to previous years (Table 1).

The highest blood mercury level was at birth (Table 2), using cord blood and exceeding 8µg/L for both the mean and median, ranging up to nearly 60µg/L. There was a significant decrease in 2004 ($p < 0.001$, Wilcoxon test) and a subsequent increase, also significant, in 2006 ($p < 0.001$, Wilcoxon test). At birth, a significant correlation was observed (Spearman correlation coefficient = 0.315; $p = 0.002$) between cord blood and maternal venous blood levels.

As shown in Figure 1, more than 50% of the children (median line) were "positive" for blood mercury levels above the WHO limit for unexposed individuals [9] (≥ 8µg/L), decreasing to fewer than 25% in 2006. Table 3 compares the proportion of mercury levels greater than or equal to 8µg/L in the blood of mothers and their newborns at birth. The proportion of levels above the cutoff in mothers was 31.1%, statistically lower ($p < 0.001$, McNemar chi-square) than the proportion in the newborns (63.3%). Importantly, of the 28 positive results in mothers, nearly all (25) were also positive in the children, and of the 62 negative results in mothers, 32 converted to positive in the children.

Table 1

Fish consumption and descriptive measures of total mercury levels in hair samples from 90 schoolchildren in the urban area of Itaituba, Pará State, Brazil, according to year of sample collection.

Fish consumption and total mercury in hair	2004 (N = 90)	2006 (N = 47)	2010 (N = 90)
Weekly fish consumption			
Zero	22	1	5
Once	33	26	44
Twice	21	16	27
3 times or more	14	4	14
Fish meal consumption			
Yes	9	3	21
No	81	44	69
Total mercury in hair (µg/g)			
N	90	47	90
Median	0.79	0.76	1.01
Mean	1.01	1.18	1.18
Standard deviation	0.83	1.35	1.02
Maximum	4.13	8.22	8.31

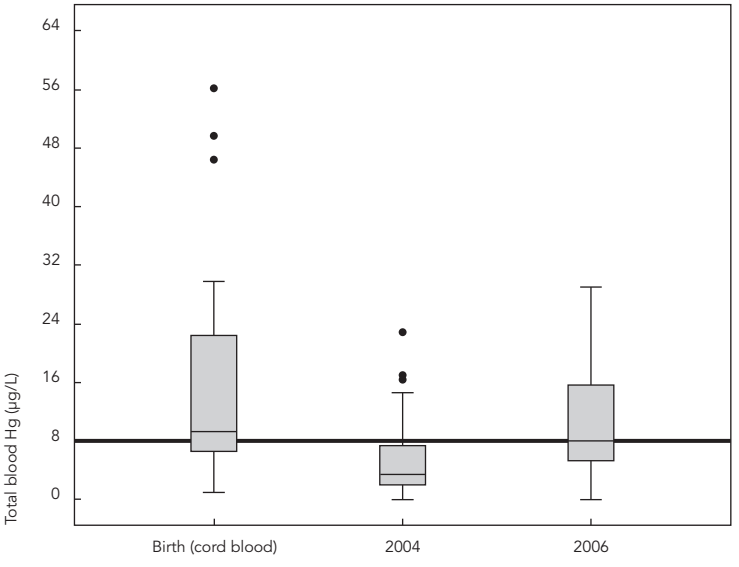
Table 2

Descriptive statistics of blood mercury levels (µg/L) and variations according to year of sample collection, urban area of Itaituba, Pará State, Brazil.

Statistics	Blood sample collection			Variations	
	Birth (cord blood)	2004	2006	Birth to 2004	2004 to 2006
N	90	90	47	90	47
Mean	14.0	5.4	10.5	8.6	-5.2
Standard deviation	12.2	4.7	7.4	12.8	7.6
Minimum	0.0	0.0	0.0	-15.5	-24.1
Median	10.0	4.0	8.0	6.4	-4.1
Maximum	57.7	22.9	29.1	53.0	18.5
p-value, Wilcoxon test				< 0.001	< 0.001

Figure 1

Blood mercury levels in children according to age. Itaituba, Pará State, Brazil.



Discussion

This was an urban population sample, thus displaying different socioeconomic conditions from the riverine communities in the same municipality. Factors emphasizing this difference included the fact that 70% of the children's families had telephones in 2010, in contrast to the riverine communities, which usually lack even basic electricity [2,14]. Using the criteria suggested by Mahaffey [15], another striking difference with the riverine communities was the low consumption of fish and fish meal in this urban sample. Due to this low weekly fish consumption, it was unnecessary to analyze other information obtained from the questionnaire such as total weekly fish consumption (weekly consumption multiplied by the number of daily servings of fish), types

Table 3

Comparisons of the proportions of mercury greater than or equal to 8µg/L in maternal blood and cord blood. Itaituba, Pará State, Brazil.

Cord blood mercury	Maternal blood mercury				Total		p-value *
	Negative (< 8µg/L)		Positive (≥ 8µg /L)				
	n	%	n	%	n	%	
Negative (< 8µg/L)	30	33.3	3	3.3	33	36.7	< 0.001
Positive (≥ 8µg/L)	32	35.6	25	27.8	57	63.3	
Total	62	68.9	28	31.1	90	100.0	

* McNemar χ^2 test.

or species of fish consumed, and approximate amount in grams.

The unexpected result of mercury level in hair, below the WHO reference of 2.0µg/g for unexposed individuals [7] , may be a consequence of the low fish consumption, showing that exposure to methylmercury after birth was negligible. In exposed communities and even in populations not directly impacted by gold-mining areas in the State of Pará, Santos et al. [14] found mercury levels in hair that exceeded what are considered safe limits for unexposed populations, such as 8.58µg/g in 203 individuals from Caxiuanã, a national conservation area.

The high mercury levels in cord blood samples indicate that the most significant exposure to mercury occurred during pregnancy. According to some authors, cord blood mercury levels reflect exposure during the first trimester of pregnancy and can decrease tenfold by the end of pregnancy and after birth [16,17]. In this sense, a decrease in these indicators would be expected during the first year of life, especially after the conclusion of breastfeeding.

In an analysis of total mercury levels in cord blood and maternal blood samples in 28 international studies, Murata et al. [18] cited levels ranging from 0.96µg/L in 1,109 individuals in Canada in a study by Rhainds et al. [19] to 22.35µg/L reported by Grandjean et al. [20] in 996 subjects in the Faroe Islands. Taking the previously cited values as the reference, or 8.0µg/L for total blood mercury in unexposed individuals or up to 5.8µg/L as suggested by Mahaffey et al. [21] , the cord blood levels detected in the current study were high.

Although the mercury levels in the children's venous blood were close to the reference values used in the international literature (8.0µg/L and 5.8µg/L), the increase in the blood mercury levels from 2004 to 2006, along with the marginally significant results for hair mercury, suggest the possibility of exposure to metallic mercury in the city of Itaituba. A plausible explanation would be mercury emissions from gold shops.

According to a study by the National Department of Mine Production in the State of Pará (Departamento Nacional de Produção Mineral do Estado do Pará) and the Foundation of the Federal University in Rondônia (Fundação Universidade Federal de Rondônia), from 2002 to 2006 [22], gold resmelting in 17 shops caused indoor and outdoor air pollution with mercury. Among others, mercury levels were analyzed in 30 soil samples and 68 dust samples collected from the streets around the gold shops. In 2002, these shops produced an average of 18.7kg of gold per month. Mercury levels varied from 71 to 1,067µg.kg^{-1} in the soil samples and from 59 to 21,943µg.kg^{-1} in the dust samples. The authors concluded that there was air pollution from mercury, especially in areas close to these gold shops [22]. The pollution increased over time, and in 2006 the mercury levels in the soil varied from 40 to 1,390µg.kg^{-1}, while the dust samples ranged from 25 to 60,778µg.kg^{-1} [22]. The authors also identified an increase in gold production, and showed that the areas with the highest mercury levels were located close to the gold shops, decreasing in proportion to the distance from these sources.

A similar result, corroborating the possibility of exposure from the gold shops, was obtained in Poconé, Mato Grosso State, in a study [23] of mercury concentrations in dust samples from houses up to 200 meters from gold shops, showing levels up to 21.29ppm, while 10% of the 158 individuals without occupational exposure living in these homes showed urine mercury levels above the WHO references, reaching 102.40µg/L [23].

Conclusion

This longitudinal evaluation of mercury exposure in children in the urban area of Itaituba from 2000 to 2010 indicates that the main exposure to the metal was prenatal. Mercury levels in the hair of these children did not exceed the reference values for unexposed individuals, while there was an increase in exposure to metallic mercury, probably from emissions by local gold shops. Health teams from the Brazilian Unified National Health System (SUS) should thus conduct joint interventions with the appropriate environmental agencies, besides special measures for more exposed individuals, particularly children and childbearing-age women.

These results also demonstrate the usefulness of assessing mercury in different types of biological samples in order to elucidate human exposure. Epidemiological studies should prioritize blood samples in urban areas with gold shops, as in Itaituba.

Resumo

O objetivo deste estudo foi realizar avaliação longitudinal da exposição de crianças de uma área urbana da Amazônia brasileira ao mercúrio (Hg). A população foi composta por 90 crianças, cuja exposição foi avaliada desde o nascimento por meio das análises dos teores de Hg no sangue do cordão umbilical e no sangue das mães em 2000/2001, e em amostras de cabelo e sangue das crianças. Os procedimentos incluíram também um questionário com informações demográficas, socioeconômicas, sobre consumo de peixes e morbidade referida. A média dos teores de Hg no cabelo em 2010 foi próxima a 1µg/g e sua amplitude 8,22µg/g, semelhantes aos anos 2004 e 2006, podendo ser explicada pela baixa ingestão de peixes. A média dos teores de Hg no sangue das crianças ao nascer ultrapassou 10µg/L e sua amplitude atingiu quase 60µg/L, indicando transferência do Hg através da barreira placentária. Ocorreu aumento significativo dos teores de Hg no sangue entre 2004 e 2006 ($p < 0,001$), sugerindo a possibilidade de exposição atmosférica ao Hg. O principal período de exposição ao Hg ocorreu durante a gestação.

Mercúrio; Envenenamento; Exposição Ambiental; Criança

Contributors

M. D. S. Dutra, I. M. Jesus, E. C. O. Santos, M. O. Lima, R. L. F. Medeiros, M. Cavadas, R. R. Luiz, and V. M. Câmara collaborated in all stages of the study.

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