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Selenium status and hair mercury levels in riverine children from Rondônia, Amazonia

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ABSTRACT

Objective: Riverine communities in Rondônia State are exposed to high selenium (Se) content in their diet because of the high-selenium soils identified in the Amazon. However, the Amazonian population has a high mercury (Hg) exposure because this metal accumulates in the soil. Because children are more vulnerable to Hg toxicity, the aim of this study was to evaluate and correlate Se status and hair Hg levels in riverine children (aged 3–9 y) living in two different locations in Rondônia State: Demarcação area (DA) and Gleba do Rio Preto (GRP).

Methods: Se levels were assessed using hydride generation quartz tube atomic absorption spectroscopy; total hair Hg levels were assessed using cold vapor atomic absorption spectrometry. Dietary intake was evaluated through a 24-h food record and a food frequency questionnaire.

Results: Forty-two children participated in this study. Eighty-four percent of the children from DA showed low plasma Se. Conversely, all children from GRP presented plasma Se levels above the reference values. Forty-five percent of the children from DA presented low erythrocyte levels, and 55% of the children from GRP showed concentration in erythrocyte above the reference values. The mean Se intake was 41.8 μg/d in DA and 179.0 μg/d in GRP. High hair Hg levels were observed in children from both the DA and GRP (3.57 ± 1.86 and 6.24 ± 5.89, respectively).

Conclusions: Children from both riverine communities are likely to present altered Se status according to their dietary intake. Additionally, these children are highly exposed to Hg, mainly through fish consumption, and the toxicity of this metal may cause metabolic damage.

Introduction

Selenium (Se) is an essential nutrient in the diet because it is necessary to make the selenocysteine found in some selenoproteins. Several physiological functions are attributed to Se, such as antioxidant properties, immune system potentiation, and heavy metal detoxification [1–3]. It is believed that Se is able to delay mercury (Hg) intoxication symptoms by forming an inert complex with Hg [4].

The northern and northeastern regions of Brazil are considered to be the most selenium-rich in the country [5,6], and they are among the leading producers of the richest Se food source, the Brazil nut *(Bertholletia excelsa, HBK)* [7,8]. Studies show that the Se status of riverine populations ranges from normal to very high and is directly related to the consumption of large amounts of Brazil nuts [9,10].

However, Amazonian populations also have the highest reported Hg exposure in the world. This metal is accumulated and

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trapped in the soils along the geological foundation of the basin, and it also comes from exogenous sources related to gold mining or industrial uses [11,12]. In this way, Amazonian people who consume local fish as their main dietary protein source may be seriously threatened by Hg contamination [13]. Several studies have shown that Se may protect against the toxic effects of Hg, as the interactions between Hg and Se are normally antagonistic [14,15].

The levels of Se and Hg in children are of particular interest because an adequate intake of Se is important for the proper development and functioning of the body throughout childhood and because children have greater vulnerability to Hg, which has important toxic effects on developing systems (particularly the cardiovascular, neurodevelopmental, and immune systems) that may persist throughout later life [16].

Given the expected variation in Se intake and Hg exposition between the two populations, we aimed to characterize the Se status in children who live in two riverine communities in Rondônia State, Brazil and to correlate this data with Hg status.

Material and methods

This study included children living in the Demarcação area (DA) and in Gleba do Rio Preto (GRP). DA is located within the municipality of Porto Velho on the right border of Machado River, approximately 30 km upstream of its confluence with the Madeira River, geographically located at S 8° 10 ’16:20′ W 62° 46 ’45.30′, 140 km from the city of Porto Velho, Rondônia State. GRP is formed by approximately 20 families of approximately 100 people who do not form a housing project because they are spread throughout an approximately 30-km space along the Preto River. The targeted communities were selected to represent different characteristics of lifestyle. DA is closer to the most developed community in the region and has easy access to products coming from outside the community. GRP presents a typical subsistence lifestyle because it is isolated from other communities, which limits the access to industrialized foods.

All of the children between the ages of 3 and 9 y who were living in these communities and were followed in our hospital boat between December 2006 and March 2007 were included in the study. We excluded children who were receiving or had received vitamin and mineral supplementation and those who presented acute inflammation, infection, fever, diarrhea, cancer, diabetes, or autoimmune disease.

Blood and hair samples and a 24-h food record were collected, and anthropometric evaluations were conducted. These assessments were performed in an outpatient clinic on a hospital boat.

This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving humans/patients were approved by the Ethics Committee of the Faculty of Pharmaceutical Sciences at the University of São Paulo. Written informed consent was obtained from the children’s parents.

Anthropometric evaluation

The children were measured while wearing light clothing and no shoes. Body weight was measured with a Filizola weighing scale to the nearest 0.1 kg, while height was measured with a portable stadiometer Sanny (São Paulo, SP, Brazil) to the nearest 0.1 cm.

Anthropometric status was classified according to World Health Organization growth standards for weight-for-age (WA), height-for-age (HA), and weight-for-height (WH). The software Anthro v3.2.2 (Geneva, Switzerland) and AnthroPlus v1.0.4 (Geneva, Switzerland) were used to determine z scores. Cutoff values for wasting, stunting, and thinness were −2 SD; cutoff values for overweight and obesity were 2 SD.

Dietary intake

Se intake was evaluated using 24-h dietary recall. The dietary recall interview was conducted on the day of blood collection, and it collected detailed information about the entire dietary intake on the previous day. The dietary intake was also assessed using a food frequency questionnaire (FFQ). Because fish, peach palm (*Bactris gasipaes HBK*) and Brazil nuts (*Bertholletia excelsa*) were the main foods consumed in the regions of study, we analyzed the Se concentrations in these foods using hydride generation quartz tube atomic absorption spectroscopy (HGQTAAS) [17]. Additionally, the fish were analyzed in relation to Hg concentration using cold vapor atomic absorption spectrometry (CV AAS) [18,19].

Table 1
The characteristics of the participants

Parameters	Demarcação area (n = 31)	Gleba do Rio Preto (n = 11)
Age (y)	5.5 ± 1.6	6.0 ± 2.1
Weight (kg)	21.0 ± 5.4	19.9 ± 5.4
Height (m)	1.14 ± 0.1	1.13 ± 0.1
Male (%)	55	70
Female (%)	45	30

All data are given as mean ± SD

To evaluate the micronutrients in the fish, they were fried with soy oil according to the manner in which they are prepared and consumed in the studied communities.

The 24-h recall data were analyzed using the software NutWin (Escola Paulista de Medicina/UNIFESP/Brazil), which was supplemented with the data obtained by analysis.

Biochemical assays

Fasting morning blood samples were collected by venipuncture in EDTA evacuated tubes to determine the Se concentration in plasma and erythrocytes. Plasma was separated by centrifugation at 3000*g* for 15 min at 4°C. The erythrocyte pellet that was obtained from the whole blood by centrifugation was washed three times with 5 mL of sterile 9 g/L NaCl solution, slowly homogenized by inversion and centrifuged at 10 000*g* for 10 min at 4°C, and the supernatant was discarded. Se determination in biologic material was performed using HGQTAAS [17]. The method reproductivity was achieved by analyzing the samples in triplicate (technical replicates to average out the technical variation) and performing readings in triplicate (nine readings per person), and *SERONORM* (*SERO*®)-certified material was adopted as a reference to serve as a control for the methodology. All reagents received analytical grade or higher purity from Merck. Nanopure water was used to prepare all of the solutions and to dilute the samples.

Hair Hg level was determined in a sample of 10 children from each locality. In these children, a hair sample was cut from the back of the head (occipital area) close to the scalp. The hairs of each sample were bundled together and placed in a labeled envelope. The total Hg level was determined using CV AAS [18,19]. The methodology validation for total hair Hg was performed by analyzing reference material with a certified value (*Human Hair*–IAEA 085).

Statistical analysis

A descriptive analysis was performed, and the results are shown as the mean ± SD for continuous variables. The Shapiro-Wilk W test was performed to verify data normality. When normal distribution was present, data from both communities were compared using the unpaired Student’s t test; the Mann-Whitney U test was used when the data were skewed.

Se intake was adjusted for energy to describe the relationship between aspects of food consumption and biochemical characteristics independent of energy intake. This procedure was performed according to the residual method [20].

Analyses were performed using the statistical software package GraphPad Prism Version 5.0. The level of significance was established at $P < 0.05$ for all tests.

Results

All 34 children living in the DA and all 15 living in GRP met the inclusion criteria; however, the parents of 3 children from the DA

Table 2
Nutritional status of children from the Demarcação area and Gleba do Rio Preto according to z score

z score	Demarcação (n = 31)			Gleba do Rio Preto (n = 11)		
	WA	WH	HA	WA	WH	HA
$z < -2$	3	0	2	0	0	0
z −2 a +2	27	27	29	10	10	10
$z > 2$	1	4	0	1	1	1

HA, height-for-age; WA, weight-for-age; WH, weight-for height

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Table 3
Centesimal composition and selenium content (μg/g) of food samples collected in the Demarcação area and Gleba do Rio Preto

Foods	Energy (kcal/100 g)	Protein (g/100 g)	Lipid (g/100 g)	Carbohydrates (g/100 g)	Selenium (μg/g)
Brazil nuts	692.49	15.94	65.33	10.19	5.83
Peach palm	302.10	19.10	69.00	214.10	0.03
Fish					
Pacu *(Piaractus brachypomus)**	490.10	36.80	38.10	0.00	0.31
Traíra *(Hoplias malabaricus)**	449.90	33.50	35.10	0.00	0.62
Jatuarana *(Bricon cephalus)*†	504.40	38.80	38.80	0.00	0.12
Cachorro *(Hydrolycus scomberoídes)*†	478.40	35.90	37.20	0.00	0.83
Piau *(Leporinus steindachneri)*†	435.00	32.70	33.80	0.00	0.48
Pacu *(Piaractus brachypomus)*†	493.30	42.10	36.10	0.00	0.65

* Machado River.
† Preto River.

and 4 from GRP did not allow them to participate in the study. Nonetheless, the scope of the study was significant, because 91% of the children from the DA and 73% from GRP were included. The mean age of the participants from the DA was 5.5 ± 1.6 y, and the mean age of those from GRP was 6 ± 2.1 y; there was no significant difference between the communities (Table 1).

No differences regarding weight or height between communities were observed (Table 1). Our data showed that regarding WA, HA, and WH, most of the children were eutrophic. WH reflects body weight in proportion to attained growth in height, and in our study we observed that although most of children were eutrophic, 12% had a WH ≥2 *z* score, which indicated overweight (Table 2). The FFQ and 24-h dietary recall showed that children from both communities experienced food monotony, and the main foods they consumed were fish, rice, manioc flour, coffee, and sugar. Children from the DA reported higher consumption of sweets, popcorn, snacks, chewing gum, biscuits, artificial juices, and soft drinks. We also observed that 36% of the children from GRP ate Brazil nuts weekly, whereas 41% of children from the DA rarely ate Brazil nuts. Together with fish, Brazil nuts are a good source of Se, while the peach palm has a low concentration of this mineral (Table 3).

Regarding Se intake, the children from GRP showed a higher Se intake compared with those from the DA (Table 4). In general, most of the children from both areas showed Se intakes varying between the recommended dietary allowance (RDA) (20 μg/d for 1–3 y; 30 μg/d for 4–8 y; 40 μg/d for 9–13 y) and the tolerable upper intake levels (UL) (90 μg/d for 1–3 y; 150 μg/d for 4–8 y; 280 μg/d for 9–13 y) [21]. Twenty-one percent of the children from the DA had Se intake lower than the estimated average requirement and 18% of the children from GRP showed an intake higher than the UL.

Table 4 illustrates the Se levels (μg/L) in the plasma and erythrocytes of riverine children from the DA and GRP. All of the children from GRP presented high-plasma Se levels that surpassed reference values (>84–100 μg/L) [22]. The children from the DA presented mean plasma Se levels within the reference range; however, 84% of them showed deficient levels. Regarding erythrocyte Se level, 55% of children from DA presented adequate concentration and 45% were deficient, whereas 55% of children from GRP showed concentrations that exceeded the reference values (90–190 μg/L) and none presented deficient levels [1].

Table 5 shows the Hg levels in the main consumed fish and in the hair of the children from both communities. Children living in GRP showed significantly higher Hg levels compared with those from the DA. Only one child from the DA (10%) and three from GRP (27%) showed Hg values <2 mg/kg, which is the reference value [23]. The remaining children presented high hair Hg levels, with the highest concentrations found in the children living in GRP (6.2 ± 5.9 mg/kg) compared with the DA participants (3.6 ± 1.9 mg/kg). There was a positive correlation between erythrocyte Se levels and hair Hg levels in the children from GRP and no other significant correlations were observed (Fig. 1).

Discussion

To our knowledge, this is the first study to analyze Se nutritional status and Hg levels in riverine children in this specific Amazonian region. We showed that these children face a threatening nutritional risk from either deficiency or excess of Se and from high Hg levels.

The FFQ and 24-h dietary recall revealed that children from both communities consume a monotonous diet containing few vegetables and fruits, as observed previously [24]. Children from the DA consumed more processed foods, a finding that can be explained by the fact that DA is closer to Calama, the most developed community in the region, which gives the DA population easy access to beverages and processed foods. The presence of processed foods in the diet of children from DA may be responsible for the presence of some overweight children, as shown by WH. In contrast, GRP is located far from other communities and has limited access to them. Although the Amazon has a huge diversity of fish, fruits, and vegetables, we observed that this abundance does not define the nutritional reality of the

Table 4
Biochemical parameters and intake of selenium among participants

Parameters	Demarcação (n = 31) mean ± SD (min-max)	Gleba do Rio Preto (n = 11) mean ± SD (min-max)
Plasma Se (μg/L)	41.9 ± 18.7 (16.1–84.4)	189.1 ± 58.7* (96.3–278.5)
Erythrocyte Se (μg/L)	97.6 ± 26.3 (58.8–165.4)	235 ± 105.6† (117.4–474.4)
Se dietary intake (μg/d)	41.8 ± 33.4 (0.0–146.0)	179 ± 207† (27.5–767.0)

DA, Demarcação area; Se, selenium
* Significantly different from DA, $P < 0.05$ (Student's *t* test).
† Significantly different from DA, $P < 0.05$ (Mann-Whitney *U* test).

Table 5
Mercury concentration in fish and children from the Demarcação area and Gleba do Rio Preto

	Mercury concentration (mg/kg)
Demarcação–Machado River	
Pacu *(Piaractus brachypomus)*	0.02
Traíra (*Hoplias malabaricus*)	2.61
Children's hair (n = 10)	3.57 ± 1.86
Gleba do Rio Preto–Preto River	
Jatuarana *(Bricon cephalus)*	1.73
Cachorro *(Hydrolycus scomberoídes)*	0.42
Piau *(Leporinus steindachneri)*	0.11
Pacu *(Piaractus brachypomus)*	0.03
Children's hair (n = 10)	6.24 ± 5.89

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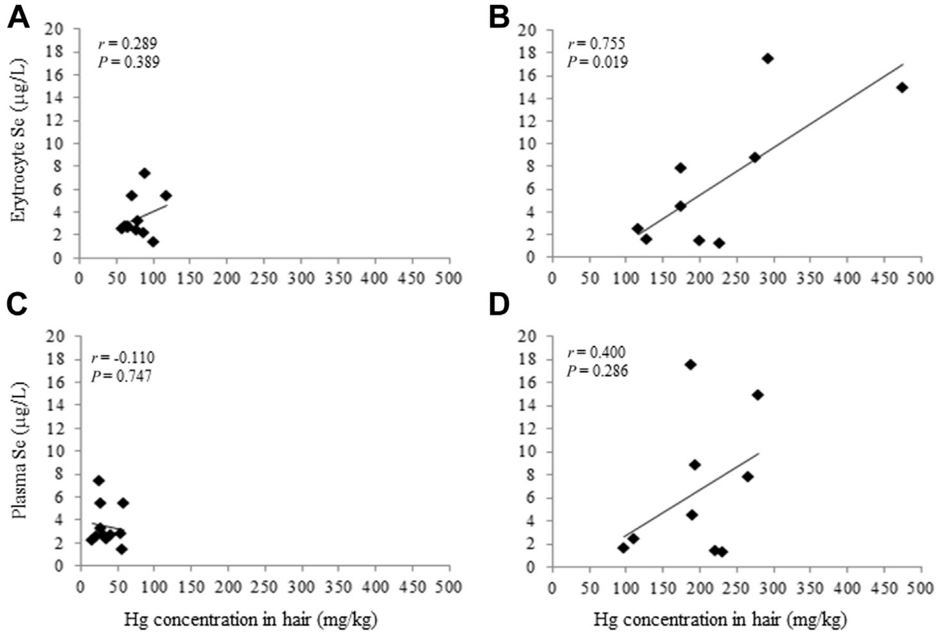

Fig. 1. Correlations between selenium levels in plasma and erythrocyte and mercury hair concentration in children from DA and GRP. (A) and (C), children from DA; (B) and (D), children from GRP. DA, Demarcação; GRP, Gleba do Rio Preto; Hg, mercury; Se, selenium.

people in these communities because they have no knowledge of the importance of a healthy diet [25,26].

The assessment of Se intake from the diet presents many difficulties, namely the absence of specific Brazilian food composition tables [27,28]. This is the main reason we have analyzed the Se concentration in the main foods consumed in these communities, including fish, Brazil nuts, and the peach palm. These foods were the main sources of Se for these communities, particularly for GRP, because the children living in this community had a high intake of Brazil nuts, the main food source of this mineral [29]. Limited data have been published about Se intake in groups of individuals from different Brazilian states. However, results of one study [18] revealed that the daily Se intake of riverine children living in Amazonia varied from 8.9 to 54 μg/d, and only 42% of the diets provided satisfactory Se amounts. Although our data are not sufficient to allow a more accurate interpretation, they suggest a particularly inadequate intake of Se from the diet, with a significant risk for deficiency for children from the DA and a significant toxicity risk for children from GRP.

The fact that children from GRP used to consume more natural foods can explain the higher levels of Se in their plasma and erythrocytes compared with DA children. Some authors suggest that to assess nutritional Se status, it is important to evaluate at least two biomarkers. In our case, plasma was used as a marker of current exposure, whereas erythrocytes reflect longer-term nutritional status because of the incorporation of Se in erythrocyte synthesis [22,30].

Malnutrition resulting from the lack of specific micronutrients does not result in short-term clinical symptoms because it is not strictly related to poverty and deficient caloric intake. Micronutrient deficiency is not associated with visible health impairments; however, it can lead to long-term consequences, increasing the risks for developing severe disease and exerting harmful effects on quality of life [31]. This observation can be applied to the children from the DA, who presented adequate levels of growth and development based on anthropometric data despite presenting some level of Se deficiency. The children from GRP also presented adequate levels of growth and development; however, we encourage the monitoring of Se levels in this population to avoid possible risks for adverse effects. It is important to mention that Se toxicity does not usually cause dermal signs or sentinel symptoms, but is related to cardiometabolic perturbations (insulin resistance, hyperglycemia, hypertension, hypercholesterolemia, and cardiovascular diseases) [32].

Blood Hg levels reflect Hg exposure in both organic and inorganic forms, which can be biased by Hg-contaminated food intake. Hg remains in the bloodstream for only a few days after exposure. Therefore, analyses must be performed quickly to detect recent exposure. In contrast, hair Hg levels are proportional to blood Hg concentrations. Because this metal is incorporated into the hair, its level is not modified [23]. Consequently, hair analysis reflects sustained exposure to Hg, which enables the assessment of Hg levels over longer periods of time [33]. A limitation of this study was that we did not measure Hg in all children and, in our case, recruitment was based on a convenience sampling procedure.

One explanation for the high Hg hair levels found in our study could be frequent fish consumption, most notably by the children from GRP. However, despite high fish consumption by the population from Manaus, Amazonia, researchers found children in this area to present hair Hg levels below the recommended values (2 mg/kg) [23]. Hair Hg and methylmercury (MeHg) levels were <10 mg/kg in all evaluated districts, which indicated a low risk for Hg adverse effects on child development [18,33]. Children from Jaú National Park (Amazon Region) had values ranging from 0.60 to 42.2 mg/kg [18]. Likewise, children from two communities in Pará state (Brasília Legal and São Luiz do Tapajós) had high Hg hair levels. In the first community, mean levels were 5.84 ± 4.91 mg/kg; in the second one, mean Hg hair levels were even higher (21.06 ± 14.38 mg/kg) [28]. Children age <15 y from Rio Negro in Amazonia also showed high mean hair Hg levels (18.52 ± 10.04 mg/kg) [34].

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Researchers have been trying to find an explanation for the absence of evident clinical symptoms in Amazonian populations who present high Hg levels. The presence of natural Se in the region has been considered a possible contributor to the apparent tolerance for chronic Hg intoxication [35–38]. Some studies suggested that adequate Se intake might provide effective protection against Hg and its toxic compounds [39]. It is believed that when Se is combined with other metals, it can produce inert compounds [40,41]. The interaction between Se and Hg forms the selenite–dimethylmercury complex, which is unstable in blood and in other tissues [42]. The protective effect of Se has been associated with higher Hg retention rather than higher Hg excretion [43]. In comparison, in vitro and in vivo studies have shown that Hg compounds inhibit the activity of some selenoenzymes, such as thioredoxin reductases and glutathione peroxidases. These enzymes have an essential antioxidant role, and decreases in their activity are related to metabolic diseases [44–46].

Although there were some limitations, such as the small sample size and the collection of only one 24-h diet record, this research allowed us to conclude that our results are considerably relevant. Certainly, studies including larger populations are necessary to confirm our results.

Conclusion

Children from both of the studied riverine communities are likely to present an altered Se status, represented either by a deficiency or excess of blood Se levels and dietary Se intake. Environmental factors, such as Hg contamination, may influence Se levels and present serious health risks to this population. It is urgent that public policies be adopted to improve the living conditions of these populations, which also includes dietary interventions to improve the nutritional Se status.

References

[1] Ortuño J, Ros G, Periago MJ, Martinez C, Lopez G, Rodrigo J. Importância nutricional del selenio. Arch Latinoam Nutr 1997;47:6–13.

[2] Romero DC, Blanco LF, Sánchez PH, Rodríguez E, Majem L. Serum selenium concentration in a representative sample of the canarian population. Sci Total Environ 2001;269:65–73.

[3] Davis CD, Uthus EO. Dietary selenite and azadeoxycytidine treatments affect dimethilhidrazine-induced aberrant crypt formation in rat colon and DNA methylation in HT–29 cells. J Nutr 2002;132:292–7.

[4] Muntau AC, Streiter M, Kappler M, Roschinger W, Schmid I, Rehnert A, et al. Age-related reference values for serum selenium concentrations in infants and children. Clin Chem 2002;48:555–60.

[5] Cintra RMGC, Cozzolino SMF. Selenium bioavailability in a regional diet of São Paulo. Int J Food Sci Nutr 1993;44:167–73.

[6] Fávaro DIT, Hui MLT, Maihara VA, Armelin MJA, Vasconcellos MB, Yuyama LK, et al. Determination of various nutrients and toxic elements in different Brazilian regional diets by neutron activation analysis. J Trace Elem Med Biol 1997;11:129–36.

[7] Müller CH, Figueiredo FJC, Kato AK, Carvalho JEU. A cultura da castanha-do-Brasil, Coleção Plantar, 23. Brasília: EMBRAPA/SPI; 1995.

[8] Souza ML, Menezes HC. Processamentos de amêndoa e torta de castanha–do–Brasil e farinha de mandioca: parâmetros de qualidade. Ciênc Tecnol Aliment 2004;24:120–8.

[9] Lemire M, Mergler D, Fillion M, Passos CJS, Guimarães JRD, Davidson R, et al. Elevated blood selenium levels in the Brazilian Amazon. Sci Total Environ 2006;366:101–11.

[10] Lemire M, Mergler D, Huel G, Passos CJS, Fillion M, Philibert A, et al. Biomarkers of selenium status in the amazonian context: blood, urine and sequential hair segments. J Exposure Sci Environ Epidemiol 2009;19:213–22.

[11] Miretzky P, Bisinoti MC, Jardim WF. Absorption of mercury (II) in Amazon soils from column studies. Chemosphere 2005;60:1583–9.

[12] Pouilly M, Rejas D, Pérez T, Duprey JL, Molina CI, Hubas C, et al. Trophic structure and mercury biomagnification in tropical fish assemblages, Iténez River, Bolivia. PLoS One 2013;31:65054.

[13] Boischio AAP, Barbosa A. Exposure to organic mercury in riparin populations on the upper Madeira river, Rondônia, Brazil, 1991: preliminary results. Cad Saude Publica 1993;9:155–60.

[14] Raymond LJ, Ralston NVC. Selenium's importance in regulatory issues regarding mercury. Fuel Process Technol 2009;90:1333–8.

[15] Dang F, Wang WX. Antagonistic interaction of mercury and selenium in a marine fish is dependent on their chemical species. Environ Sci Technol 2011;45:3116.

[16] World Health Organization. Children's exposure to mercury compounds. Geneva, Switzerland: WHO; 2010.

[17] Hao D, Xie G, Zhang Y, Tian G. Determination of serum selenium by hydride generation flame atomic absorption spectrometry. Talanta 1996;43:595–600.

[18] Farias LA, Fávaro DIT, Maihara VA, Vasconcelos MBA, Yuyama LK, Aguiar JPL, et al. Assessment of daily dietary intake of Hg and some essential elements in diets of children from the Amazon region. J Radioanal Nucl Chem 2006;270:217–23.

[19] Farias LA, Santos NR, Favaro DI, Braga ES. Mercúrio total em cabelo de crianças de uma população costeira, Cananéia, São Paulo, Brasil. Cad Saude Publica 2008;24:2249–56.

[20] Willet WC. Issues in analysis and presentation of dietary data (Monographs in epidemiology and biostatistics, 30). Nutritional epidemiology. 2nd ed. New York: Oxford University Press; 1998.

[21] Food and Nutrition Board of the Institute of Medicine. Dietary reference intakes for vitamin C, vitamin E, selenium and carotenoids. Washington, DC: National Academy Press; 2000.

[22] Thomson CD. Assessment of requirements for selenium and adequacy of selenium status: a review. Eur J Clin Nutr 2004;58:391–402.

[23] World Health Organization. Methylmercury in environmental health criteria. Geneva, Switzerland: WHO; 1990.

[24] Araújo R. Estudo de parasitoses, anemia, ingestão de ferro e desnutrição em população escolar de Tabajara. Rondônia: Federal Universty of Rondonia; 2005.

[25] Rodrigues AF, Escobar AL. Santos RS Análise espacial e determinação de áreas para o controle da malária no Estado de Rondônia. Revista da Sociedade Brasileira de Medicina Tropical 2008;41:55–64.

[26] BRASILMinistério da SaúdeSecretaria de Vigilância em SaúdeDepartamento de Análise da Situação de Saúde. Saúde Brasil. Uma análise da situação de saúde. Brasília: Ministério da Saúde; 2004.

[27] Combs GF. Selenium in global food systems. Br J Nutr 2007;85:517–47.

[28] Al-Saleh I, El-Doush I, Billedo G, Mohamed Gel-D, Yosef G. Status of selenium, vitamin E, and vitamin A among saudi adults: potential links with common endemic diseases. J Environ Pathol Toxicol Oncol 2007;26:221–43.

[29] Lemire M, Fillion M, Barbosa F Jr, Guimarães JR, Mergler D. Elevated levels of selenium in the typical diet of Amazonian riverside populations. Sci Total Environ 2010;408:4076–84.

[30] Navarro-Alarcon M, Cabrera-Vique C. Selenium in food and the human body: a review. Sci Total Environ 2008;400:115–41.

[31] Fisberg M. Sedentarismo e hábitos alimentares inadequados aumentam o risco de obesidade infantil em São Paulo. Nutrição em Pauta 2005;74:6–10.

[32] Lemire M, Philibert A, Fillion M, Passos CJ, Guimarães JR, Barbosa F Jr, et al. No evidence of selenosis from a selenium-rich diet in the Brazilian Amazon. Environment International 2012;40:128–36.

[33] Pascalicchio AAE. Contaminação por metais pesados: Saúde pública e medicina ortomolecular. São Paulo: Annablume; 2002.

[34] Barbosa AC, Souza J, Dórea JG, Jardim WR, Fadini PS. Mercury biomagnification in a tropical black water, Rio Negro, Brazil. Environ Contam Toxicol 2003;45:235–46.

[35] Campos MS, Sarkis JES, Muller RCS, Brabo ES, Santos EO. Correlation between mercury and selenium concentrations in Indian hair from Rondônia State, Amazon region, Brazil. Sci Total Environ 2002;287:155–61.

[36] Watanabe C. Modification of mercury toxicity by selenium: Practical importance? Tohoku J Exp Med 2002;196:71–7.

[37] Passos CJ, Mergler D, Gaspar E, Morais S, Lucott M, Larribe F, et al. Eating tropical fruit reduces mercury exposure from fish consumption in the Brazilian Amazon. Environ Res 2003;93:123–30.

[38] Raymond LJ, Ralston NVC. Mercury: selenium interactions and health implications. SMDJ Seychelles Med Dental J 2004;7:72–7.

[39] Pinheiro MCN, Muller RCS, Sarkis JE, Vieira JLF, Oikawa T, Gomes MSV, et al. Mercury and selenium concentrations in hair samples of women in fertile age from Amazon riverside communities. Sci Total Environ 2005;349:284–8.

[40] Yoneda AS, Suzuky KT. Detoxication of mercury by selenium by binding of equimolar Hg-Se complex to a specific plasma protein. Toxicol Appl Pharmacol 1997;143:274–80.

[41] Carvalho CML, Lu J, Zhang X, Arnér ES, Holmgren A. Effects of selenite and chelating agents on mammalian thioredoxin reductase inhibited by mercury: Implications for treatment of mercury poisoning. FASEB J 2011;25:370–81.

[42] Naganuma AA, Imura N. Mode of interaction of mercury with selenite to from high-molecular weight substance in rabbitt blood in vitro. Chem Biol Interact 1983;43:271.

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[43] U.S. Department of Health and Human Services. Toxicological profile for mercury. Atlanta, GA: Agency for Toxic Substances and Disease Registry (ATSDR); 1999.

[44] Carvalho CML, Chew E, Hashemy SI, Lu J, Holmgren A. Inhibition of human thioredoxin system: a molecular mechanism of mercury toxicity. J Biol Chem 2008;283:11913–23.

[45] Branco V, Canário J, Holmgren A, Carvalho C. Inhibition of the thioredoxin system in the brain and liver of zebra-seabreams exposed to waterborne methylmercury. Toxicol Appl Pharmacol 2011;251:95–103.

[46] Branco V, Canário J, Lu J, Holmgren A, Carvalho C. Mercury and selenium interactionin vivo: effects on thioredoxin reductase and glutathione peroxidase. Free Radic Bio Med 2012;52:781–93.