Elevated blood selenium levels in the Brazilian Amazon

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Abstract

Contaminated fish poses a difficult challenge throughout the world, on the one hand, fish is a very nutritious food source, while on the other hand it accumulates many toxic substances, including mercury (Hg). As part of our efforts in the Brazilian Amazon to maximize nutritional input from fish consumption, a dietary mainstay, and minimize toxic risk, we have been studying the role of selenium (Se), an essential element, that may influence the distribution of Hg in the body and influence Hg neurotoxicity. Se, which is naturally present in the soil, is ingested through consumption of various foods, notably fish, mammals and certain plants. The objectives of the present study were: (i) evaluate whole blood Se (B-Se) and Hg (B-Hg); (ii) characterize B-Se variations with respect to socio-demographic and dietary variables; and (iii) examine the relation between B-Se and B-Hg. A total of 236 persons from six riparian communities of the Tapajós River Basin, a tributary of the Amazon, participated in this study. Whole blood Se and Hg were measured and interview administered questionnaires were used to obtain data on socio-demographic variable, smoking and drinking habits, and fish and fruit consumption. The results show that B-Se are in the upper normal range (median = 284.3 μg/L, range = 142.1–2029.3 μg/L). No individuals presented B-Se deficiency, but 9 participants from the same extended family had relatively high B-Se levels, potentially a threat to their health. B-Se varied between communities, was significantly higher among alcohol drinkers and farmers, but not associated with age, sex or tobacco consumption. A significant positive relation between B-Se and B-Hg was noted, independently of the overall fish consumption. B-Se increased with consumption of Peacock bass (Cichla sp.), a piscivorous fish species, and coconut pulp (Cocos nucifera L.). The B-Se intercommunity variations may reflect geographic differences in local soil Se levels as well as traditional land use practices in the different ecosystems of the Tapajós River Basin. In this population with relatively high exposure to Hg, Se may play an important role. Further studies should examine, in this region, the sources of Se, its transmission through the terrestrial and aquatic ecosystem and its role with respect to human health.

Keywords: Selenium; Mercury; Blood; Geographic differences; Fish and fruit consumption

1. Introduction

The ability of selenium (Se) to alleviate mercury (Hg) toxicity has long been suggested (Parizek and...
Ostadalova, 1967; Ganther et al., 1972) and numerous animal studies have been conducted to understand the underlying mechanisms (Magos, 1991; Imura and Naganuma, 1991; Yoneda and Suzuki, 1997; Gregus et al., 2001). For human populations, Se–Hg interactions have often been presumed, and although several studies have attempted to elucidate the nature of these interactions, they are still poorly understood. Many epidemiological studies have shown a positive correlation between Se and Hg in blood (Grandjean et al., 1992; Svensson et al., 1992; Bensryd et al., 1994; Hagmar et al., 1998; Osman et al., 1998; Muckle et al., 2001; Bárány et al., 2002; Karita and Suzuki, 2002; Hansen et al., 2004; Lindberg et al., 2004), and most attribute it to the same source: fish consumption.

Several studies have shown a positive correlation between bioindicators of Hg and Se and fish and/or marine mammals intake (Svensson et al., 1992; Hagmar et al., 1998; Muckle et al., 2001; Karita and Suzuki, 2002; Hansen et al., 2004), although in some studies, the correlation between fish consumption and Se was weak (Grandjean et al., 1992; Bensryd, et al., 1994). In contrast, Se–Hg correlations have also been shown in populations with low fish intake (Osman et al., 1998; Bárány et al., 2003) and in a non fish-eating population (Lindberg et al., 2004), suggesting that, there may be an interaction between Se and Hg, independently of fish consumption.

Se is an essential element with important biological functions, and both Se deficiency and excess can lead to adverse health outcomes. Highly regulated, Se is crucial due to its incorporation into selenoproteins (WHO, 1986). Primarily, but not exclusively due to its enzymic functions, Se is believed to exert a number of beneficial health effects on immunocompetence, reproductive capacity, mood states, as well as cardio- and neuro-protective properties and prevention of cancer (Hawkes and Hornbostel, 1996; Nève, 1996; Barrington et al., 1997; Combs and Gray, 1998; Arthur et al., 2003; Brauer and Savaskan, 2004).

Diet represents, by far, the principal route of Se intake and food Se levels reflect Se concentrations in soils. Natural geophysical and bioavailability of Se in soils, sediments and waters, which vary greatly from one region to another, account for uptake by plants and subsequent levels in fish and mammals (Levander, 1987). Fish and mammal organs, such as kidney and liver, are known to accumulate significant levels of Se and are, potentially, good dietary sources of this essential element for humans. In general, fruits and vegetables contain low Se levels, however, depending on Se bioavailability within specific ecosystems and food consumption patterns, cereals may constitute an important source of Se (WHO, 1986).

Amazonian riverside populations rely mainly on fish as a primary source of animal proteins. Locally grown manioc, rice, beans, vegetables, fruits and nuts complete the prevalent diet (Passos et al., 2001). Numerous studies have reported high body burdens of organic mercury (OHg) in relation to fish consumption among these Amazonian populations (Boischio et al., 1995; Lebel et al., 1997; Dolbec et al., 2001; Harada et al., 2001; Passos et al., 2003). In the Tapajós River Basin of the Amazon, hair Hg median values vary between 10 and 15 μg/g (Lebel et al., 1997; Dolbec et al., 2001; Harada et al., 2001; Passos et al., 2003), but no studies have examined Se levels and its possible influence on Hg uptake or effects. In another region of the Amazon, Dorea and collaborators (1998) reported that certain Amazonian fish species may be good sources of Se. In addition, certain edible fruit species, such as Brazil nuts (Bertholletia excelsa Humb. and Bonpl.) and Paradise nuts (Lecythis usitata Miers) of the Lecythidaceae family are known to accumulate high levels of Se from soils (Chang et al., 1995; Andrade et al., 1999).

Because of the possible local sources of Se, we undertook a study: (i) to assess Se blood levels among riverside communities living along the Tapajós River, a major tributary of the Amazon River, (ii) to explore its variation in respect to socio-demographic data and fish and fruit consumption, and (iii) to examine its relation with blood Hg.

2. Methods

2.1. Study design

This cross-sectional epidemiological study is part of a larger project that uses an integrated approach to examine factors that modulate Hg transmission through aquatic ecosystems, human uptake and toxicity in the Lower Tapajós ecosystems, human uptake and toxicity in the Lower Tapajós River Basin. In this region, there are approximately 50 communities with diverse population size and origin, different extractive, fishing and traditional agricultural practices, religious adherence, and access to health care, education, local authorities and cities. The area is composed of several types of soils and aquatic environments, varying from floodplains to lotic ecosystems, presenting a large variety of local fish and fruit. For the present study, we selected six riverside communities to reflect the diversity of regional ecosystems and populations.

Fig. 1 presents the map of the study area, the Lower Tapajós River Valley, in the state of Pará, Brazil.
The communities of São Luís do Tapajós (SL) and Nova Canãa (NC) are located respectively on the east and west shores of the Tapajós River, south of the city, Itaituba. The riverside community of Santo Antônio (SA) is situated on the Itapacurazinho River, a tributary of the Tapajós River. Vista Alegre (VA) and Mussum (Mu) are located on the west shore of the Tapajós River, in the municipality of Aveiro. The community of Açaituba (Ac) is located on the Cupari River, another tributary of the Tapajós River. The study was carried out, from June to August 2003, during the descending-water season.

2.2. Study population

Since it was not possible to carry out random sampling, a convenience sample was used. However, we were able to verify the age and sex distribution of the study participants with respect to the underlying population, using the results from a door-to-door socio-demographic survey of the entire community in each village. During this survey, the study was explained at each household and persons were invited to participate. In addition, community meetings were organized in each community to further explain the study.

A total of 236 adults, between the ages of 15 and 89 years (116 women and 120 men), from the six villages, agreed to participate. Table 1 shows their age and sex distributions and the participation rate in relation to the underlying population. Age and sex distributions were similar to the entire population, with the exception of those over 65 years, who were under-represented.

The study received approval from the Ethics Review Board of the University of Quebec at Montreal and of the Federal University of Rio de Janeiro. All participants signed a consent form, which was read to them.

Fig. 1. Map of the study area.
2.3. Dietary assessment

An interview-administered questionnaire was used to estimate participant’s fish and fruit consumption as well as socio-demographic characteristics such as age, sex, smoking habits, alcohol consumption, years of education and occupation (e.g. fisherman and/or farmer and/or teacher and/or community agent, etc.). A food frequency questionnaire for fish and fruit eating habits covered the last 7 days. Respondents were asked to indicate for each day the number of meals containing fish, as well as the name of the fish species. For each fruit species, participants were asked to indicate the quantity consumed over the same period. Using the dietary habits of the fish species and the trophic classification proposed by Ferreira et al. (1998), fish species were classified as piscivorous or non-piscivorous.

2.4. Blood sampling and analyses

For each participant, a blood sample was collected by a nurse in a 6 ml heparinized Becton Dickinson Vacutainer® (6-ml plastic Vacutainer Lavander+K\textsubscript{2}EDTA (BD7863)) and immediately frozen on the research boat at −20 °C until analysis. Frozen blood samples were sent for analyses of whole blood selenium (B-Se), whole blood total Hg (B-THg) and whole blood IHg (B-IHg) to the Quebec Toxicology Centre (CTQ) of the National Institute for Public Health. Samples were analyzed by inductively coupled plasma–mass spectrometry (ICP–MS) for B-Se levels, according to the method described by Labat et al. (2003), and by cold vapour atomic absorption spectrometry (CV-AAS) for B-THg and B-IHg, as described by Ebbestadt et al. (1975). The organic fraction of Hg in whole blood (B-OHg) was determined as the difference between THg and IHg. Detection limits were 7.90 \mu g/L for Se and 0.20 \mu g/L for Hg analysis. The CTQ is accredited ISO 17025 and analytical performance for Hg analysis in the Interlaboratory Comparison Program for Metals in Biological Media was 36/36 for precision and 6/6 for reproducibility.

2.5. Statistical analysis

Descriptive statistical analysis were used to characterize the study population of the six villages, B-Se, B-THg, B-OHg and B-IHg levels, as well as the socio-demographic data, and fish and fruit frequency consumption over the previous 7 days. Since the distribution of B-Se, B-THg, B-IHg, B-OHg levels were not normally distributed, non-parametric analyses and logarithmic transformations were performed. In these cases, Wilkoxon/Kruskal–Wallis tests (Normal approximation) and Kendall Correlation (r) were employed. When variables were normally distributed, ANOVA (F ratio), Contingency analysis (Fisher’s Exact Test) and Pearson’s Correlation (r) were used. Stepwise Multiple Regression model, with direction ‘forward’ and rule ‘combine’ and probability \( p=0.10 \) to enter and \( p=0.05 \) to leave the model, was used to determine which variables had statistical importance to predict B-Se levels and evaluate relationships between B-Se and, B-THg, B-IHg and B-OHg levels. Only fish and fruit species consumed by more than 10% of the participants were considered in the regression analysis. Results were defined as statistically significant at \( p<0.05 \). Analyses were performed using JMP 5.0.1 software (SAS Institute Inc.).

3. Results

The socio-demographic characteristics of the study group are presented in Table 2. A total of 83.4% were born in the State of Pará, while the others came from different areas in Brazil, mainly from the Northeast (Maranhão=11.0%, Ceará=1.7%, Rio Grande do Norte=0.4%). Few (5.9%) had completed elementary school (8 years) and fewer still (2.1%) had finished high school (11 years), while 15.7% had no formal education. For the persons that did not drink river
All participants reported that they usually consumed at least one fish meal per week. The mean number of total, piscivorous and non-piscivorous fish meals during the preceding 7 days are presented in Table 3. The major piscivorous fish consumed were pescada (Plagioscion squamosissimus), peacock bass (Cichla sp.), piranha (Serrasalmus sp.), and sarda (Pellona sp.), while the major non-piscivorous fish were aracu (Schi zodon sp. and Leporinus sp.), pacu (Mylossoma sp.), caratinga (Geophagus proximus) and jaraqui (Semapro chilodus insignis). No difference in fish consumption was observed between men and women. People living in the villages directly on the Tapajós River (SL, NC, VA and AC) ate significantly more fish meals compared to those who lived on the smaller tributaries (SA and AC) (F ratio=20.2, \( p<0.0001 \)). This difference is reflected by higher consumption of piscivorous fish in the villages directly on the Tapajós compared to the others (F ratio=18.1, \( p<0.0001 \)); no difference was observed for non-piscivorous fish consumption (F ratio=2.56, \( p=0.11 \)).

A large proportion of the population (67.4%) reported eating at least one fruit/day in the preceding 7 days. Although more men reported eating this amount compared to women (70.8% vs. 63.8%), the differences were not significant (Fishers’ Exact Test, \( p=0.16 \)). Villagers from the northern portion of the Tapajós River Valley (VA, Mu and AC) reported eating significantly more fruits than those in the south (SL, NC, SA) (82.4% vs. 56.8%; Fisher’s Exact Test, \( p<0.0001 \)). The principal fruits consumed by the participants were banana (Musa spp.), oranges (Citrus spp.), coconut water and pulp (Cocos nucifera L.), papaya (Carica papaya L.), tucumã (Astrocaryum vulgare Mart.), jambo (Eugenia malaccensis L.), cacao (Theobroma cacao L.), common guava (Psidium guajava L.), avocado (Persea americana Mill.) and passion fruit (Passiflora edulis Sims.). Because of the season, only 13.1% consumed Brazil nuts (Bertholletia excelsa Humb. and Bonpl.) and no one ate Paradise nuts (Lecythis usitata Miers).

Table 4 presents the distribution of B-Se concentrations, which were not normally distributed. One hundred and fifty-five persons (65.7%) had B-Se levels between 100 and 340 \( \mu \)g/L, considered as the normal range (Ryan and Terry, 1996); of the 81 persons (34.3%) that presented levels superior to the normal range, 71 participants (30.0%) had levels varying between 340 and 1000 \( \mu \)g/L, while 9 participants from SA and 1 participant from VA had B-Se levels above the NOAEL established at 1000 \( \mu \)g/L (U.S. EPA, 2002). A tendency was observed for men to have higher levels, compared to women (median=307.9 vs. 276.4 \( \mu \)g/L; Normal approximation, \( p=0.07 \)).

Fig. 2 shows the percentile distribution of B-Se for each village. Since the village of SA presented a very wide range of B-Se levels (142.1–2029.3 \( \mu \)g/L), the distribution within the village was examined. Results showed that one extended family had very significantly higher Se levels compared to the others (Normal approximation, \( p<0.0001 \)); thus, in Fig. 2, we divided SA into 2 groups: SA-1 and SA-2. The B-Se levels of the SA-1 group were not statistically different from the northern communities of VA, Mu and AC, which in turn were higher than SL and NC (Normal approximation, \( p<0.0001 \)). Within the 2 southern villages, SL displayed significantly higher B-Se concentrations (Normal approximation, \( p=0.03 \)).

The B-THg, B-OHg and B-IHg concentrations were also not normally distributed (Table 4). B-OHg represented an elevated fraction of THg blood levels (median=87.4%, range=75.2–94.3%). Log adjusted B-Se and B-THg were positively correlated (Pearson’s \( r=0.19, p=0.03 \)). A similar correlation was observed with or without the SA-2 group with very high B-Se levels.

Table 3
Mean number of total, piscivorous and non-piscivorous fish meals during the preceding 7 days

<table>
<thead>
<tr>
<th></th>
<th>Total study population</th>
<th>Tapajós River villages</th>
<th>Tributaries villages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(mean ± S.D., ( n=236 ))</td>
<td>(mean ± S.D., ( n=169 ))</td>
<td>(mean ± S.D., ( n=67 ))</td>
</tr>
<tr>
<td>Total fish</td>
<td>7.3 ± 4.7</td>
<td>8.2 ± 4.9*</td>
<td>5.2 ± 3.4</td>
</tr>
<tr>
<td>Piscivorous fish</td>
<td>3.6 ± 3.7</td>
<td>4.2 ± 4.0*</td>
<td>2.0 ± 2.0</td>
</tr>
<tr>
<td>Non-piscivorous fish</td>
<td>3.7 ± 3.3</td>
<td>3.9 ± 3.6</td>
<td>3.2 ± 2.5</td>
</tr>
</tbody>
</table>

\( *p<0.001 \).
Results of multiple regression analysis, with all groups in the model (Table 5), showed that B-Se varied positively with B-THg, increased with frequency of consumption of peacock bass (Cichla sp.) fish, was higher among alcohol drinkers and farmers, and increased with the consumption of coconut pulp (Cocos nucifera L.). All these variables accounted for up to 66.4% of the B-Se levels variability. The following variables did not enter into the model: age, sex, years of education, state of birth, smoking, fishing and source of drinking water. Dietary items, such as total fish meal consumption, total piscivorous and non-piscivorous fish meal consumption, number of total fruits consumed and specific fish and fruit consumption frequency, other than peacock bass and coconut pulp, did not significantly enter into the model. Peacock bass and coconut pulp were eaten by 25.8% and 24.2% of the study population, respectively.

When the two different Hg fractions, B-OHg and B-IHg, were entered separately into the model, results were similar (slope = 0.098, p = 0.0002, $r^2 = 0.663$ vs. slope = 0.101, $p = 0.0001$, $r^2 = 0.665$, respectively) and, like B-THg, they entered at the third position. For both types of Hg, the significant variables that entered in the model were the same as with B-THg. No relation was observed between B-Se levels and percentage of B-OHg. All stepwise regression models were tested with and without the SA-2 high Se group.

Like B-Se, blood Hg varied by community; Fig. 3 shows the percentile distribution for B-OHg and B-IHg for each community. For B-OHg, SA-1 had significantly lower levels compared to all of the others (Normal approximation, $p < 0.001$), while Ac had significantly higher levels than SA-1 (Normal approximation, $p = 0.007$), both had significantly lower levels compared to all of the others (Normal approximation, $p < 0.05$). For B-IHg, SA-1 and Ac had significantly lower levels than the villages located directly on the Tapajós River (SL, NC, VA, Mu) (Normal approximation, $p < 0.01$). Within the 2 groups of the village of SA, SA-2 presented significant B-IHg higher levels (Normal approximation, $p = 0.02$).

Although there was a positive relation between B-Se and B-Hg with all participants individually, when one considers median concentrations of both elements within each community, there is an inverse relation between

### Table 4
Distribution of the B-Se, B-THg, B-OHg and B-IHg levels in the study population ($n = 236$)

<table>
<thead>
<tr>
<th>Variable (µg/L)</th>
<th>Mean ± S.D.</th>
<th>Median</th>
<th>25th percentile</th>
<th>75th percentile</th>
<th>Min–Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-Se</td>
<td>361.7 ± 256.0</td>
<td>284.3</td>
<td>229.0</td>
<td>390.9</td>
<td>142.1–2029.3</td>
</tr>
<tr>
<td>B-THg</td>
<td>61.8 ± 38.9</td>
<td>57.2</td>
<td>34.1</td>
<td>90.0</td>
<td>4.8–223.7</td>
</tr>
<tr>
<td>B-OHg</td>
<td>53.9 ± 34.7</td>
<td>50.1</td>
<td>29.0</td>
<td>71.2</td>
<td>4.2–199.6</td>
</tr>
<tr>
<td>B-IHg</td>
<td>7.9 ± 4.5</td>
<td>7.6</td>
<td>4.8</td>
<td>10.2</td>
<td>0.4–24.1</td>
</tr>
</tbody>
</table>

![Fig. 2. Percentile distribution of B-Se levels for each village.](image)

*Significant differences of B-Se levels between communities are shown by different types of box plots: SA-2 is significantly more elevated than SL, NC, SA-1, VA, Mu and Ac (Normal approximation, $p < 0.0001$); SA-1, VA, Mu and Ac are significantly more elevated than SL and NC (Normal approximation, $p < 0.0001$); and SL is significantly more elevated than NC (Normal approximation, $p = 0.03$). The pointed lines indicate the normal range for Se.*

### Table 5
Variables associated with B-Se levels (stepwise regression model)*

<table>
<thead>
<tr>
<th>Variable $^b$</th>
<th>Category</th>
<th>Slope</th>
<th>$r^2$ value $^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Community $^d$</td>
<td>(SL, NC, SA-1, Mu, VA, Ac) &lt; SA-2</td>
<td>0.100</td>
<td>***</td>
</tr>
<tr>
<td>2. Community (SL, NC) &lt; (SA-1, Mu, VA, Ac)</td>
<td>0.034</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>3. ln B-THg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Peacock bass consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Alcohol</td>
<td>Non-drinkers &lt; drinkers</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6. Community</td>
<td>NC &lt; SL</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>7. Agriculture</td>
<td>Non-farmers &lt; farmers</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8. Coconut pulp</td>
<td>Non-eaters &lt; eaters</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

*Variables were rank-classified (from 1 to 8) following the stepwise analysis when considered Hg exposure, fish and fruit consumption, geographic and socio-demographic data, smoking and drinking habits.

*Significance: $^p < 0.08$, $**p < 0.05$, $***p < 0.001$. 

*Each variable ‘community’ presents significant B-Se differences between singular or a group of persons from one or more villages.
median Se and median OHg and IHg (Fig. 4). The Kendall Rank Correlation is significant ($\tau = -0.77$, $p = 0.04$) for IHg, but not for OHg, although there is a tendency ($\tau = -0.60$, $p = 0.09$).

4. Discussion

Se levels are elevated in this population. No one displays blood Se deficiency; the lowest level observed was 142 μg/L. Thirty-four percent of the participants have B-Se levels above the normal range, with a group of persons from the same village, showing particularly high levels. In this area, there is no evident source of anthropogenic Se contamination. Only a few studies around the world have reported elevated B-Se levels. Most were from regions where populations consumed crops grown in seleniferous soils in specific areas of Venezuela (Jaffe et al., 1972), China (Yang et al., 1983), the United States of America (Swanson et al., 1990), India (Hira et al., 2004), or were defined by high marine fish and mammals consumption in Canada (Muckle et al., 2001) and Greenland (Hansen et al., 2004).

Even when the extended family with high Se levels is excluded, there are significant differences between villages. The two southernmost communities (SL and NC) have significantly lower levels compared to the others. These geographical differences may reflect variations in Se concentrations and/or bioavailability in soils. In regions where large variations in Se intake have been observed, it has usually been attributed to locally produced staple food, grown in soils with varying Se concentrations (WHO, 1986). The extended family that presented very high levels of Se, included husbands and wives that were not genetically related,
but lived in proximity. Their high levels of Se may reflect Se soil content in their particular geographical location. Another explanation may be that members of this family own a Brazil nut tree plantation and told us that they often ate Brazil nuts in various culinary forms: they cooked game meat and fish in Brazil nut milk, mixed local fruit with Brazil nut milk for juice and made cakes from Brazil nuts. Brazil nuts are known to accumulate significant levels of Se (Chang et al., 1995). However, they were not in season during the data collection for the present study. Among the fruits surveyed, the only association with B-Se was observed for consumption of coconut pulp, which showed a tendency. Aleixo and collaborators (2000) reported that coconut milk, which is made of grated mature coconut pulp, may be a good selenium source. The high Se levels observed in this community warrant further investigation as to the presence of symptoms of Se toxicity.

Farmers had higher B-Se levels compared to non-farmers, which may reflect Se sources within local crops. Farmers probably consume more and a larger variety of locally grown vegetables, rice, beans and manioc compared to non-farmers, but this would need to be verified. Irrigation and flooding processes in agriculture are known to hasten the liberation of Se from soils to local ecosystems. On one hand, it can favour the bioavailability of Se for bioaccumulation by terrestrial plants (Mikkelsen et al., 1989), while on the other, it can cause the redistribution of Se from soils to aquatic ecosystems and cause higher bioaccumulation in aquatic biota (Lemly, 2004). Higher B-Se levels among farmers may reflect the overall impact of “slash and burn” traditional agricultural practices and related deforestation, coupled to the high rate of precipitation in the Amazonian ecosystems.

In this study, there was no overall relationship between fish consumption and Se, even though fish consumption is very high. Only consumption of one fish species, peacock bass, was correlated with B-Se. Peacock bass is a large, sedentary predator species; previous studies in this river have reported high Hg content for this fish, varying from 0.21 to 0.75 μg/g of fresh weight (Lebel et al., 1997; Santos et al., 2000). Uptake of Se by the aquatic biota is usually consistent with fish eating habits. Some authors state that Se, like OHg, biomagnifies within piscivorous fish species (Barwick and Maher, 2003; Dorea et al., 1998), while others suggest that Se has a tendency to bioaccumulate at the base of the food webs in aquatic plants and invertebrate, thus explaining higher levels in some non-piscivorous species (Burger et al., 2001; Chen et al., 2001). Burger et al. (2001) observed that three of four fish species presenting higher Se levels were sedentary and invertebrate consumers, perhaps reflecting higher Se levels among the local foods of their inhabiting ecosystems than migratory species. Recently, in another aquatic ecosystem, Burger and Campbell (2004) reported high Se levels in a predator fish species, the white bass. The inconsistencies in Se fish concentrations suggest that Se distribution in the aquatic food chain may be fish species specific, ecosystem dependent and present different biomagnification patterns than OHg.

There are contradictory reports on gender differences with respect to Se. While some report higher levels among women (Hansen et al., 2004), others report higher levels among men from coastal fishing villages, but no differences between men and women for persons living in the interior (Pavão et al., 2003). Pavão et al. (2003) suggest that the discrepancies reported in different populations may reflect gender differences in dietary habits. The present study would tend to confirm this. When all of the factors were considered, the initial differences between men and women were no longer present. Cigarette smoking has likewise been inversely associated with Se blood levels (Swanson et al., 1990; Hansen et al., 2004), while other studies did not observe this association (Pavão et al., 2003; Borawska et al., 2004). We did not observe an association between Se and cigarette smoking in the present study, but smokers consumed relatively few cigarettes/day.

Those who reported drinking alcohol had higher Se levels compared to those who did not. In Se-deficient subjects, alcohol consumption may be responsible for selenium loss (Borawska et al., 2004) but for populations with normal Se status, alcohol intake has been positively associated with Se status among women (Kafai and Ganji, 2003). Brewer’s yeast (Saccharomyces cerevisiae), commonly used in the fabrication of Se supplements, may be rich in Se. Cereals used in alcohol production may also be a good source of dietary Se.

In this region of the Tapajós River, ‘slash and burn’ agriculture practices and deforestation are the major contributors to aquatic mercury (Roulet et al., 1999; Farella et al., 2001) and propitious conditions for methylation (Guimarães et al., 2000) explain the high levels of Hg in the fish and consequently in humans. In this study, we found a significant positive correlation between whole blood Se and THg, even when Se from fish intake is taken into account. Moreover, in this population, overall fish consumption was not related to Se levels. Studies in low or non-fish eaters populations have reported positive correlations between blood...
Se and Hg (Osman et al., 1998; Bárány et al., 2003; Lindberg et al., 2004). These results, coupled to the findings of the present study, suggest that the relationship between Se and Hg may not only be due to common fish sources, but also to a Se–Hg interaction in blood. Nonetheless, the comparison of epidemiological studies on blood Se–Hg interaction carried out with different populations is not entirely appropriate because: (1) there are different ranges of Se and Hg levels; (2) the sources of exposure to OHg and/or IHg are variable and animal studies suggest the possibility of different types of interactions with different speciation of Hg; (3) the blood compartment studied, i.e. whole blood vs. plasma or serum is not necessarily similar; (4) dietary habits within populations may modulate this interaction; and (5) usually only total fish consumption is evaluated to assess Se and Hg intake, while environmental studies clearly show that both elements vary within fish species.

Total blood Se was evaluated here and studies have shown that for populations with high Se levels, plasma tends to stabilize around 140 μg/L, while whole blood concentrations keep increasing (Hansen et al., 2004). Although whole blood may provide a measure of Se sequestered in red blood cells with a life of 120 days, blood may not be the best bioindicator to assess the relationship between dietary intake and Se, particularly in a population where there are important seasonal variations in food consumption. For example, the extended family with high Se levels may have eaten Brazil nut products prior to our data collection, which could, at least in part, account for their high levels of total blood Se. Other studies have examined Se in hair (Yang et al., 1983; Campos et al., 2002) and sequential analyses of hair Se levels over time may provide a better measure to examine with respect to seasonal food consumption.

An interesting finding is the inverse relation between blood Se and Hg on a community basis. A study in Canada likewise reported an inverse relation between mean fish muscle Se and Hg concentration in lakes; suggesting that the more there is Se in lake biota, the less fish bioaccumulate OHg (Chen et al., 2001). Biogeochemical and/or biophysiological mechanisms involved remain unclear. One mechanism proposed is the reduced bioaccumulation of OHg in fish by Se inhibition of sulphate reducing bacteria activity, responsible for methylation of IHg to OHg (Oremland and Capone, 1988). This inverse correlation between median B-Se and median B-IHg in this human population may reflect an overall integrated view, suggesting that Se can also mitigate Hg transmission through complex effects on different components of the aquatic ecosystems.

In this population with high levels of Hg exposure, Se, which is likewise high, may be playing an important role with respect to Hg toxicity. In this region, it would be useful to further study the Se cycle in order to determine the sources, transmission and effects of Se in this population, in relation to Hg.

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