Journal of Trace Elements in Medicine and Biology 44 (2017) 99–103

Contents lists available at ScienceDirect

Journal of Trace Elements in Medicine and Biology

journal homepage: www.elsevier.com/locate/jtemb

Applied methodology

Mercury in breast milk from women in the Federal District, Brazil and dietary risk assessment for breastfed infants

Fernanda M. Rebelo[a,b], Leandro R. da Cunha[b], Patrícia D. Andrade[b], Walkimar A. da Costa Junior[c], Wanderley R. Bastos[c], Eloisa D. Caldas[b,*]

[a] Brazilian Health Surveillance Agency, University of Brasilia, Brasilia, DF, Brazil
[b] Laboratory of Toxicology, Department of Pharmacy, University of Brasilia, Brasilia, DF, Brazil
[c] Laboratory of Environmental Biogeochemistry Wolfgang Christian Pfeiffer, Federal University of Rondônia, Porto Velho, RO, Brazil

ARTICLE INFO

Keywords:
Breast milk
Mercury
Methyl mercury
Risk assessment

ABSTRACT

Mercury is a toxic metal, ubiquitous in nature; it is excreted in breast milk from exposed mothers and may affect infant neuro-development. In this study, 224 breast milk samples provided by eight human milk banks in the Federal District of Brazil were analyzed for total mercury (THg), of which 183 were also analyzed for methyl mercury (MeHg), the most relevant form of this metal for the breastfed infants. Samples were acid digested in a microwave oven and THg determined by atomic fluorescence spectrometry (LOQ of 0.76 μg/L). Samples were lyophilized, ethylated and MeHg determined in a MERX automated system (LOQ of 0.10 μg/L). Inorganic mercury (IHg) levels were estimated from the THg and MeHg determined in the samples. Most of the samples were collected 1–2 months postpartum, with 38% during the first month. Over 80% of the samples had THg values above the LOQ, reaching a maximum of 8.40 μg/L, with a mean of 2.56 μg/L. On average, MeHg accounted for 11.8% of THg, with a maximum of 97.4%. Weekly intakes were estimated individually, considering the baby's age and body weight at the time of milk collection. Mean weekly intake for MeHg was 0.16 ± 0.22 μg/kg bw, which represented 10% of the PTWI; in only one case, the intake exceeded 100% of the PTWI (1.90 μg/kg bw, 119% of PTWI). Mean intake for IHg was 2.1 ± 1.5 μg/kg bw, corresponding to 53% PTWI. These results indicate no health concern for the breastfed babies, a conclusion that can be extended to the consumers of breast milk donated to the milk banks, primarily immature and low weight babies.

1. Introduction

Breast milk provides all the necessary nutrients for the baby during the first six months of life, protecting against a variety of diseases [1,2]. However, milk may contain toxic compounds to which the mother have been exposed to, including mercury. Human exposure to mercury has been an important health concern worldwide since the event of Minamata disease in the middle of the 20th century in Japan, which killed over one thousand people [3]. In a recent review, Ha et al. [4] retrieved 514 relevant papers published since 2012 covering the various aspects of mercury research, from which 75 are on its effects on child development.

Elemental mercury is derived from natural degassing of the earth's surface, and it is eventually oxidized to its inorganic form (IHg), returning to the surface and water systems through rain. Furthermore, anthropogenic sources, including mining, industrial activities and deforestation, can significantly increase the human burden of this metal [5,6]. Methyl mercury (MeHg) is found in the aquatic environment and sediment, formed through the methylation of inorganic mercury, mainly by reducing bacteria [7]; the main source of human exposure to MeHg is through fish consumption [8]. The main source of IHg for the general population is food, in addition to amalgam fillings [9,10]. Rice has been shown to contain both the organic and inorganic forms [11–13]. However, while less than 15% of IHg is absorbed by the gastrointestinal tract, over 95% of ingested MeHg is absorbed, and diffuses in various body tissues, including the brain [14].

MeHg crosses the blood-brain and placental barriers and may compromise neurological development of fetuses, causing irreversible damage [15]. At its 61st Meeting, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) concluded that neurodevelopmental toxicity is the sensitive health outcome to the exposure to MeHg, and the fetus is the most critical population group [16]. The Meeting established a Provisional Tolerable Weekly Intake (PTWI) of 1.6 μg/kg bw for fetuses and children. Al-Saleh et al. [17] reported significant

* Corresponding author at: Department of Pharmacy, University of Brasilia, Campus Darci Ribeiro, 70910-900 Brasilia, DF, Brazil.
E-mail address: eloisa@unb.br (E.D. Caldas).

http://dx.doi.org/10.1016/j.jtemb.2017.06.009
Received 10 April 2017; Received in revised form 15 June 2017; Accepted 24 June 2017
0946-672X/

associations between MeHg levels of the mother and infant hair and infant neurodevelopment delay assessed by the Denver Developmental Screening Test II, possibly involving an oxidative stress mechanism [18].

The levels of total mercury (THg) in breast milk vary substantially worldwide, with the highest levels found in Brazil [19]. In a study conducted by our research group in the Federal District of Brazil, THg intake by the infants during lactation exceeded the PTWI of 5 μg/kg bw in most cases, which raised a health concern for this population, although the benefits of breast milk were highlighted by the authors [20]. This PTWI was withdraw by the 72nd JECFA Meeting and replaced by a PTWI for IHg of 4 μg/kg bw [8]

As the Federal District is a region of low fish consumption [21], the hypothesis of the present study was that most of the mercury present in milk from the Federal District mothers is in inorganic form, which is of less health concern to the fetus and less absorbed by the lactating baby than the organic form. To test this hypothesis, breast milk samples collected from milk banks were analyzed for the content of THg and MeHg. Furthermore, the risk of the lactating babies associated with the exposure to mercury was assessed.

2. Materials and methods

2.1. Breast milk samples

The samples analyzed in this study were provided by eight human milk banks or directly from the milk bank donors in the Federal District from May 2011 to February 2012, as described by Andrade et al. [22]. To be included in the milk bank, a volunteer should be breast-feeding or expressing milk for her own child, be healthy, not smoking more than 10 cigarettes per day, not use alcohol or illegal drugs, and provide medical and laboratory exams. Information on the mother's age and the infant's date of birth was also provided by the milk banks. Months of lactation/infant age was estimated from the infant date of birth and the day the sample was taken from the milk bank or provided directly by the donor, rounding up to the month. The project was approved by the Ethics Committee of the University of Brasilia (CEP n° 27/11). The collected samples were kept at −18 °C until analyzed. All the glassware used in the analyses were previously acid washed.

2.2. Total mercury analysis

THg was determined using a previously validated method described by Cunha et al. [20]. In summary, 1 mL aliquot of the homogenized milk sample was digested with 2 mL of Suprapur nitric acid (65%; Merck, USA) in a microwave (DGT-100 Provecto Systems, Brazil), the digest diluted to 25-mL with nanopure water and THg quantified by atomic fluorescence spectrometry (PSA 10.023 Merlin system; PS Analytical, Kemsig, Sevenoaks, UK) using a 2% stannous chloride solution as a reduction agent. The performance of the method was confirmed with certified skim milk powder reference material containing 9.4 ± 1.7 ng/g THg (BCR®-150; Institute for Reference Material and Measurements, Belgium) with recoveries between 95% and 105%. The limits of detection (LOD) and quantification (LOQ), estimated based on the instrument response of a blank solution, were 0.26 and 0.76 μg/L, respectively.

2.3. Methyl mercury analysis

An aliquot of the breast milk samples (5 mL) was lyophilized (Liotop − K105), and samples were analyzed following the validated method described by Vieira et al. [23]. In summary, 5 mL of 25% KOH methanolic solution was added to a known amount of lyophilized milk sample (0.2 g) in a teflon tube and left at 70 °C for 6 h, with gentle stirring every hour. The samples were kept for 48 h in the dark, centrifuged, and 50 μL taken for ethylation with 50 μL of tetra ethyl sodium borate (1%, from Brooks Rand Labs; Seattle, USA) and 200 μL of acetate buffer (pH 4.5; 2 mol/L). The mixture was diluted up to 40 mL with ultra-pure water (milli-Q, Millipore, Cambridge, MA, USA). MeHg was analyzed on a MERX automated MeHg system (Brooks Rand Labs) equipped with an auto-sampler, a purge and trap unit, a packed column GC/pyrolysis unit, and a Model III atomic fluorescence spectrophotometer. A certified material was analyzed with each batch for quality control (IAEA Biological Reference Materials of Terrestrial Origin for Determination of Trace and Minor Elements; Human hair, IAEA 085), with recoveries between 85% and 105%. The LOQ was established based on the lowest level of the calibration curve and corresponded to 0.1 μg/L MeHg.

2.4. Mercury intake by infants and risk characterization

Consumption of human milk by the infants at the age the milk was collected was obtained from Costa et al. [24], and body weight from the WHO Child Growth Standards [25]. As no information about the sex of the babies was provided by the mothers, a mean milk consumption and body weight between boys and girls was assumed. MeHg and IHg intakes, in μg/kg bw/week, were calculated for each breast milk sample and child according to Eq. (1).

$$Weekly\ \ intake = \frac{Weekly\ \ milk\ \ consumption(L)\ \ x\ \ concentration\ \ (\mu g/L)}{body\ \ weight(kg)} \quad (1)$$

The risks from exposure to MeHg and IHg were assessed according to Eq. (2), and expressed as % PTWI (1.6 μg/kg bw for MeHg [16] and 4 μg/kg bw for IHg [8]). Risk may exist when the % is higher than 100:

$$\%PTWI = \frac{Weekly\ \ intake \times 100}{PTWI} \quad (2)$$

2.5. Statistical analysis

The data obtained were analyzed using SPSS version 22, IBM software. Kolmogorov-Smirnov and Shapiro-Wilk were used to test for normality of the distributions, and Spearman's rank correlation coefficient determined for not normal distributions, with significance at $p \leq 0.05$.

3. Results

3.1. Studied population

The 224 breast milk samples analyzed in this study were provided by 213 donors of the Federal District milk banks. Eleven donors provided samples in two different occasions (up to 6 months apart). On average, the donors were 28.6 ± 6.6 years (15–47 years), and the mean body weight of the newborn babies was 3.2 ± 0.56 kg (1.2–5.3 kg). Most of the samples were collected 1–2 months postpartum, with 38.3% of them during the first month. All samples were analyzed for THg, but due to limitations of sample volume, only 183 samples were analyzed for MeHg.

3.2. Mercury levels in breast milk

Table 1 summarizes the results of mercury levels in the breast milk samples. Over 80% of the samples had THg values above the LOQ (0.76 μg/L), reaching a maximum of 8.40 μg/L, with average of 2.56 μg/L. Levels of MeHg were much lower, with most of the 183 samples analyzed containing levels below the LOQ (0.10 μg/L), with a maximum of 2.82 μg/L. On average, MeHg accounted for 11.8% of THg. Estimated mean levels for IHg (= [THg − MeHg]) were 2.37 μg/L, with a maximum of 8.18 μg/L.

A weak but significant Spearman correlation was found between

Table 1
Mercury levels in breast milk samples provided by the bank milk samples of the Federal District, Brazil.

	N (% ≥ LOQ)	Mean ± sd	Median	Min.	Max
THg (μg/L)	224 (84.1)	2.56 ± 1.7[a]	2.32	< 0.76	8.40
MeHg (μg/L)	183 (45.6)	0.19 ± 0.28[b]	0.05	< 0.10	2.82
% as MeHg	183	11.8 ± 16.8	4.73	0.85	97.4
IHg (μg/L)[c]	183	2.37 ± 1.66	2.07	0.01	8.18

[a] Samples < LOQ (0.76 μg/L) were considered at 1/2 LOQ; samples < LOD (0.26 μg/L) were considered at 1/2 LOD.
[b] Samples < LOQ were considered at 1/2 LOQ (0.10 μg/L).
[c] [THg − MeHg]; sd: standard deviation.

Table 2
Intake and risk characterization for MeHg and IHg in breast milk samples.

Months of lactation (# of samples)[a]	Intake, μg/kg bw/week		%PTWI[b]	
	MeHg	IHg	MeHg	IHg
1 (75)	0.13	2.38	7.84	59.4
2 (37)	0.13	2.31	7.89	57.8
3 (28)	0.21	2.20	13.0	54.9
4 (14)	0.26	1.65	16.4	41.3
5 (7)	0.16	0.91	10.3	22.8
6 (9)	0.17	1.48	10.6	37.0
> 6 (12)	0.11	1.58	6.72	39.4
Mean ± sd	0.16 ± 0.22	2.1 ± 1.5	10.0 ± 13.7	52.9 ± 38.0
Median	0.05	1.8	2.96	46.2
Maximum	1.9	7.3	119	183

[a] Months of lactation information not available for one sample, but the sample was included to estimate the total means; sd: standard deviation.
[b] 1.6 and 4 μg/kg bw/week, for MeHg and IHg, respectively.

concentrations of THg and MeHg (r_s = 0.157; p = 0.034), as well as between MeHg and months of breastfeeding/age of the child (r_s = 0.234; p = 0.001) and mother's age (r_s = 0.168; p = 0.024).

3.3. Intake of mercury by infants and risk characterization

Table 2 shows the mean intakes of MeHg and IHg by each infant/mother pair and the % of the respective PTWIs, according to the months of lactation by the time the sample collected by the donor. For MeHg, the risk was higher during the 4th month (16% PTWI), while for IHg it decreased up to the 5th month, down to 22.8% PTWI. Mean weekly MeHg intake of all samples was 0.16 μg/kg bw, reaching a maximum of 1.90 μg/kg bw, corresponding to 119% of the PTWI (Table 2). IHg intakes were much higher, reaching 7.3 μg/kg bw and 183% of the PTWI.

Fig. 1 shows the dispersion plot of % PTWI and months of lactation. While the intake of only one sample exceeded the MeHg PTWI (by a 7-month old child), 25 samples exceeded the IHg PTWI, all from the first 4 months of lactation, with the number of samples decreasing from 16 in the first month to only 1 in the 4th month. No significant correlation

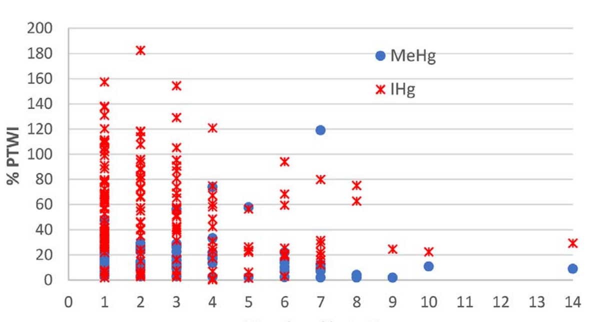

Fig. 1. Dispersion plot of % PTWI for MeHg and IHg, according to months of lactation.

was found between the%PTWI of MeHg and months of lactation, but a significant correlation was found for IHg (r_s = −0.232, p = 0.045).

4. Discussion

The THg values in breast milk found in this study were lower than those obtained in two previous studies conducted in the Federal District. Costa et al. [26] analyzed milk samples collected from 23 donors (7–30 days postpartum), finding a mean THg level of 5.73 μg/L (max. of 23.1 μg/L). Cunha et al. [20] found similar THg levels in 142 breast milk samples provided in 2002–2005 by 18 mothers from 15 to 90 days postpartum (6.47 μg/L; max. of 22.7 μg/L). Furthermore, Costa et al. [26] found a significant correlation (r = 0.6087, p = 0.0057) between breast milk THg and the mother's number of amalgam fillings, which are an important source of mercury, especially IHg [10,27].

No significant dietary or environmental changes have occurred in the Federal District since those two studies were conducted. Hence, it is possible to hypothesize that the lower levels of THg found in the present study (samples collected in 2011/2012) were mainly due to the partial replacement of amalgam fillings with other dental materials by the dentists in recent years. This replacement has been occurring mainly for esthetic purposes [28], but also following the United Nations Environment Programme recommendation to decrease dental amalgam use worldwide [29].

Studies conducted in the Brazilian Amazon found levels of THg in breast milk similar [23] or higher [30,31] than those reported in the present study. Overall, the total mercury levels in breast milk from Brazilian mothers are higher than those found in most other regions of the world (see review by Rebelo & Caldas [19] and Table 3), probably due to the high levels of this metal naturally present in Brazilian soil and water [32–34].

Cunha et al. [20] found a significant correlation between THg levels in breast milk and consumption frequency of fat, grains and vegetable servings (p < 0.02). Rice is a staple food in Brazil, with a mean consumption of 186 g/day in the Federal District [21], and can be an important source of mercury exposure, primarily in the inorganic form [11,12].

Costa et al. [26] and Cunha et al. [20] reported a very low frequency of fish consumption among the study participants. Indeed, in the last Brazilian consumption survey [21], only 6.3% of the Federal District women aged 15–47 years old reported the consumption of fish (2 non-consecutive days reporting), with an estimated mean consumption of 8.73 g/day (consumers and non-consumers). Cunha et al. [20] did not find a significant correlation between fish consumption and THg in breast milk during the 90-day period, but providing a fish meal for the mothers on the 75th day had a significant positive impact on the THg level.

Due to the relevance of MeHg for the neurological effects of mercury on the fetus and on infants [8], and the much higher gastrointestinal absorption rate of MeHg compared to IHg [14], it is imperative that speciation of the mercury present in breast milk be performed to evaluate the actual risks that breastfed infants are exposed to. Very few studies have analyzed MeHg in breast milk worldwide, and a summary of these studies is shown in Table 3. The studies are discussed further.

In the study conducted by Vieira et al. [23] in the Amazonian region, a significantly higher level of THg, MeHg and %MeHg (p < 0.001) was found in breast milk collected among the riverine population (54% consume at least 3 fish meals/week) compared to the urban population, which has a much lower fish consumption (44% consume less than one fish meal/week). The median contribution of MeHg to the total mercury was 36% in the riverine population, while in the urban population this was 12%, higher to what was found in the present study for the low fish-consuming Federal District population (median of 4.73%).

Gundacker et al. [10] reported that the mercury present in all 21 breast milk samples collected from Austrian women was in the

Table 3
Studies that evaluated total mercury and methylmercury in breast milk from 2000 to 2016.

Reference	Country	N THg (MeHg)	THg µg/L* (range)	MeHg µg/L* (range)	% MeHg* (range)	Observation
Vieira et al. [23]	Brazil, Amazonia State	82 (45)	0.36 (0.09–3.7)	0.12 (0.01–0.47)	12 (1–98)	Urban population
		75 (46)	2.3 (0.12–6.48)	0.87 (0.11–3.4)	37 (12–71)	Riveirine population
Gundacker et al. [10]	Austria	21	IHg = 0.2 (0.1–2)	not detected	–	2–8 weeks pp
Valent et al. [34]	Italy	492 (182)	0.18 (0–28.3)	0.14 (0.01–1.9)	60 (1–100)	Mature milk
Miklavcic et al. [27]*	Italy	605 (224)	0.2 (< LOD − 28)		60 (16–100)**	MeHg values are in percentage of THg
	Slovenia	284 (7)	0.2 (< LOD − 2.9)		47 (3–71)**	
	Croacia	125 (26)	0.2 (< LOD − 2.4)		56 (23–100)**	
	Greece	44 (21)	0.6 (< LOD − 12)		7 (2–96)**	
Iwai-Shimada et al. [37]	Japan	27 (27)	0.81 (0.14–1.87)	0.45 (0.06–1.2)	54 (17–87)	30 days pp

N = number of samples analyzed; pp = post-partum; * median; ** (P5-P95).

inorganic form. The authors also found that the number of maternal amalgam fillings was associated with THg in meconium and with IHg in placenta. In a multinational study conducted in Europe [27], the median %MeHg in Greece (276 g fish/week) was 7%, the lowest ratio among the countries (Table 3). Although Slovenian women consume the lowest fish amount among the populations (178 g/week), MeHg accounted for 47% of THg (median), in the same range as Croatia and Italy, who were higher fish consumers (280–300 g/week) [27,34]. This apparently contradictory result may be related to the type and origin of the fish consumed by each population, as mercury concentration in fish depends on the trophic level, with piscivorous fish containing the highest THg concentrations and% MeHg [35,36].

In Japan, which has a high fish-consuming population, 54% of mercury found in breast milk was in the organic form (Table 3), and a significant correlation was found between the lipid-adjusted MeHg in breast milk and eicosapentaenoic acid *plus* docosahexaenoic acid in maternal plasma, markers for fish consumption [37].

Cunha et al. [20] found that the intake of THg by Federal District babies during breastfeeding exceeded the PTWI (5 µg/kg bw/week) in most cases (up to 800%), which could indicate a health concern. This THg PTWI was withdrawn by the JECFA, as it was agreed that MeHg is the relevant toxicological form of mercury for neural adverse effects for the fetus and babies [8]. The present study showed mean/median weekly intakes of MeHg contributing to 10/3% of its PTWI, with only one exceedance among the 183 infant/mother cases evaluated; most of the intakes accounted for less than 10% of the PTWI. These results indicate that the risks of neuro effects due to the MeHg intake through breastfeeding for this population can be excluded. Considering the median level of MeHg reported by Vieira et al. ([23]; Table 2) and a milk consumption of 750 mL for a 5.5 kg 2–3 month baby [24], the estimated median intake of MeHg for the Amazonian urban population was 0.83 µg/kg bw/week, accounting for 7% of the PTWI. For the high fish-consuming riverine, the median intake corresponded to 51% of the MeHg PTWI (max. of 200%). Iwai-Shimada et al. [37] estimated that the median MeHg weekly intake by one–month-old Japanese infants (4 kg bw and 800 mL milk) represented 39% of the PTWI, with only one case exceeding the PTWI. These results altogether indicate that babies breastfeeding from mothers with high fish consumption does have higher MeHg intake. However, the benefits of fish consumption and of breast feeding for the mother and babies outweigh any potential risks that may exist when the intake exceeds the toxicological safety level [38,39].

Although MeHg is the mercury form relevant for breastfeeding infants [16], we also estimated the IHg levels in the samples, and the exposure and risk for the infants. The exposure exceeded the IHg PTWI in about 14% of the cases, mostly during the first two months of lactation (up to 183% PTWI), with a week, but significant negative correlation with months of lactation. However, IHg is poorly diffused through the brain [14], and the exposure is unlikely to have significant neurotoxic effects for the infants.

Brazil has probably the largest network of milk banks in the world, with over 200 banks in hospitals across the country, and it is an international reference for similar programs worldwide [40]. Milk banks provide breast milk to immature newborn babies and low weight babies that, for some reason, cannot be breastfed. Hence, the data provided by the samples analyzed (Table 1) can be extended to this population as well. Considering a daily milk consumption of 200 mL by 2 kg bw for immature newborn or low weight babies, the mean and median intakes represented 8.3 and 2.2% of the MeHg PTWI, with only one exceedance at 123% of the PTWI.

One key strength of this study was the number of mothers involved and of samples analyzed (provided by milk banks), higher than previous studies conducted in the Federal District or other Brazilian regions (provided by the mothers). However, the study had some limitations that should be addressed. One limitation was the lack of body weight of the infants and milk consumption at the time the sample was collected, which were estimated based on published data for each estimated infant age/months of lactation. Another limitation was the lack of food consumption information, especially on fish, rice and vegetables, and the number of amalgams of the breast milk donors. This information would allow correlation analysis that could explain the large variation among the mercury levels found in the samples. This information is not available in the milk banks and could not be obtained from the mothers.

5. Conclusions

To the best of our knowledge, this is first study conducted in the Federal District region that analyzed MeHg in breast milk, and the second conducted in Brazil. The levels of MeHg found in the samples confirmed our hypothesis that most of the mercury present in milk from the low fish-consuming Federal District mothers was in the inorganic form, probably due to the IHg mercury present in rice and vegetables, and the use of amalgam fillings by the mothers. The weekly intake of MeHg represented, on average, 10% of the PTWI, with only one exceedance, indicating no health concern for the breastfed babies. Consumers of breast milk donated to the milk banks are also not exposed to MeHg levels that could represent a health risk. This conclusion is very important in the context of breast milk banks, in which the quality of the milk is a constant concern. Nevertheless, it is always important to emphasize the importance of monitoring the levels of environmental contaminants in breast milk, an essential food for the baby, mainly in the first 6 months of life.

Conflict of interest statement

The authors declare no conflict of interest

References

[1] S. Haroon, J.K. Das, R.A. Salam, A. Imdad, Z. Bhutta, Breastfeeding promotion interventions and breastfeeding practices: a systematic review, BMC Public Health 13 (Suppl. 3) (2013) S20.

[2] T. Grzelak, U. Wozniak, K. Czyzewska, The influence of natural feeding on human health: short and long-term perspectives, Prz. Gastroenterol. 9 (1) (2014) 4–10.
[3] J. Watts, Mercury poisoning victims could increase by 20,000, Lancet 358 (2001) 1349.
[4] E. Ha, N. Basu, S. Bose-O'Reilly, J.G. Dórea, E. McSorley, M. Sakamoto, H.M. Chan, Current progress on understanding the impact of mercury on human health, Environ. Res. 152 (2017) 419–433.
[5] E.J. Tokar, W.A. Boyd, J.H. Freedman, M.P. Maalkes, Toxic effects of metals, in: Curtis D. Klaassen (Ed.), Toxicology. The Basic Science of Poisons, 8th edition, MacGraw-Hill Education, 2013, pp. 981–1030.
[6] A. Carpi, A.H. Fostier, O.R. Orta, J.C. Santos, M. Gittings, Gaseous mercury emissions from soil following forest loss and land use changes: field experiments in the United States and Brazil, Atmos. Environ. 96 (2014) 423–429.
[7] R.R.S. Correia, J.M.D. Guimarães, Mercury methylation and sulfate reduction rates in mangrove sediments, Rio de Janeiro, Brazil: the role of different microorganism consortia, Chemosphere 167 (2017) 438–443.
[8] Joint FAO/WHO Expert Committee on Food Additives, Evaluation of certain contaminants in food (Seventy-second report). WHO Technical Report Series, No. 959, (2011).
[9] K. Ask, A. Akesson, M. Berglund, M. Vahter, Inorganic mercury and methylmercury in placentas of Swedish women, Environ. Health Perspect. 110 (5) (2002) 523–526.
[10] C. Gundacker, S. Fröhlich, K. Graf-Rohrmeister, B. Eibenberger, V. Jessening, D. Gicic, S. Prinz, J. Wittmann, H. Zeisler, B. Vallant, A. Pollak, P. Husslein, Perinatal lead and mercury exposure in Austria, Sci. Total Environ. 408 (2010) 5744–5749.
[11] B. Meng, X. Feng, G. Qiu, Y. Cai, D. Wang, P. Li, L. Shang, J. Sommar, Distribution patterns of inorganic mercury and methylmercury in tissues of rice (*Oryza sativa* L.) plants and possible bioaccumulation pathways, J. Agric. Food Chem. 58 (2010) 4951–4958.
[12] S.E. Rothenberg, L. Windham-Myers, J.E. Creswell, Rice methylmercury exposure and mitigation: a comprehensive review, Environ. Res. 133 (2014) 407–423.
[13] C.C. Brombach, P. Manorut, P.P. Kolambage-Dona, M.F. Ezzeldin, B. Chen, W.T. Corns, J. Feldmann, E.M. Krupp, Methylmercury varies more than one order of magnitude in commercial European rice, Food Chem. 2017 (214) (2017) 360–365.
[14] Centers for Disease Control and Prevention, Fourth Report on Human Exposure to Environmental Chemicals, US Department of Health and Human Services, Atlanta, GA, 2009.
[15] World Health Organization, Children's exposure to mercury compounds. Geneva, 2010.
[16] Joint FAO/WHO Expert Committee on Food Additives, Evaluation of certain food additives and contaminants (Sixty-first report). WHO Technical Report Series, No. 922, (2004).
[17] I. Al-Saleh, M. Nester, M. Abduljabbar, R. Al-Rouqi, C. Eltabache, T. Al-Rajudi, R. Elkhatib, Mercury (Hg) exposure and its effects on Saudi breastfed infant's neurodevelopment, Int. J. Hyg. Environ. Health 219 (1) (2016) 129–141.
[18] I. Al-Saleh, R. Elkhatib, R. Al-Rouqi, M. Abduljabbar, C. Eltabache, T. Al-Rajudi, M. Nester, Alterations in biochemical markers due to mercury (Hg) exposure and its influence on infant's neurodevelopment, Int. J. Hyg. Environ. Health 219 (8) (2016) 898–914.
[19] F.M. Rebelo, E.D. Caldas, Arsenic, lead, mercury and cadmium: toxicity, levels in breast milk and the risks for breastfed infants, Environ. Res. 151 (2016) 671–688.
[20] L.R. Cunha, T.H.M. Costa, E.D. Caldas, Mercury concentration in breast milk and infant exposure assessment during the first 90 days of lactation in mild western region of Brazil, Biol. Trace Elem. Res. 151 (2013) 30–37.
[21] Brazilian Institute of Geography and Statistics, Aquisição alimentar per capta Brasil e grandes regiões. Pesquisa de Orçamentos Familiares 2008–2009, (2012).
[22] P.D. Andrade, J.L.G. da Silva, E.D. Caldas, Simultaneous analysis of aflatoxins B1, B2, G1, G2, M1 and ochratoxin A in breast milk by high-performance liquid chromatography/fluorescence after liquid-liquid extraction with low temperature purification (LLE-LTP), J. Chromatogr. A 1304 (2013) 61–68.
[23] S.M. Vieira, R. Almeida, I.B.B. Holanda, M.H. Mussy, R.C.F. Galvão, P.T.B. Crispim, J.G. Dorea, W.R. Bastos, Total and methyl Mercury in hair and milk of mothers living in the city of Porto Velho and villages along the Rio Madeira, Amazon Brazil, Int. J. Hyg. Environ. Health 216 (2013) 682–689.
[24] T.H.M. Costa, H. Haisma, C.K. Wells, A.P. Mander, R.G. Whitehead, L.J.C. Bluck, How much milk do infants consume? Data from 12 countries using a standardized stable isotope methodology, J. Nutr. 140 (2010) 2227–2232.
[25] World Health Organization, WHO child growth standards based on length/height, weight and age. WHO multicentre growth reference study group, Acta Pædiatrica (Suppl. 450) (2006) 76–85.
[26] S.L. Costa, O. Malm, J.G. Dorea, Breast-milk Mercury concentrations and amalgam surface in mothers from Brasilia, Brazil, Biol. Trace Elem. Res. 106 (2005) 145–151.
[27] A. Miklavcic, A. Casetta, J.S. Tratnik, D. Mazej, M. Krsnik, M. Mariuz, K. Sofianou, Z. Spiric, F. Barbone, M. Horvat, Mercury, arsenic and selenium exposure levels in relation to fish consumption in the Mediterranean area, Environ. Res. 120 (2013) 7–17.
[28] D.T. Santos, K.R.H.C. Dias, M.P. Alves dos Santos, Dental amalgam and its role in current dentistry, Rev. Bras. Odontol. 73 (2016) 64–68.
[29] United Nations Environment Programme, Minamata convention on mercury, (2013) http://www.mercuryconvention.org/Convention (Acessed 5 July 2017).
[30] A.A.P. Boischio, D.S. Henshel, Linear regression models of methyl mercury exposure during prenatal and early postnatal life among riverside people along the upper madeira river, Amazon, Environ. Res. A 83 (2000) 150–161.
[31] F.A. Santos, B. Cavecci, J.C. Vieira, V.P. Franzini, A. Santos, A. de Lima Leite, M.A. Buzalaf, L.F. Zara, P. de Magalhães Padilha, A metalloproteomics study on the association of mercury with breast milk in samples from lactating women in the Amazon region of Brazil, Arch. Environ. Contam. Toxicol. 69 (2) (2015) 223–229.
[32] L.D. Lacerda, G.O. Gonçalves, Mercury distribution and speciation in waters of the coastal lagoons of Rio de Janeiro, SE, Brazil, Mar. Chem. 76 (1) (2001) 47–58.
[33] P.S. Fadini, W.F. Jardim, Is the Negro River Basin (Amazon) impacted by naturally occurring mercury? Sci. Total Environ. 275 (2001) 71–82.
[34] F. Valent, M. Mariuz, M. Bin, A. Little, D. Mazej, V. Tognin, J. Tratnik, A.J. McAfee, M.S. Mulhern, M. Parpinel, M. Carrozzi, M. Horvat, G. Tamburlini, F. Barbone, Associations of prenatal mercury exposure from maternal fish consumption and polyunsaturated fatty acids with neurodevelopment: a prospective cohort study in Italy, Int. J. Epidemiol. 23 (5) (2013) 360–370.
[35] J.J. Berzas Nevado, R.C. Rodriguez Martin-Doimeadios, F.J. Guzman Bernardo Jimenez, M. Moreno, A.M. Herculano, J.L. Nascimento, M.E. Créspo-Lopez, Mercury in the Tapajós River basin, Brazilian Amazon: a review, Environ. Int. 36 (6) (2010) 593–608.
[36] A.L. Maulvault, P. Anacleto, V. Barbosa, J.J. Sloth, R.R. Rasmussen, A. Tediosi, Toxic elements and speciation in seafood samples from different contaminated sites in Europe, Environ. Res. 143 (2015) 72–81.
[37] M. Iwai-Shimada, H. Satoh, K. Nakai, N. Tatsuta, K. Murata, Methylmercury in the breast milk of Japanese mothers and lactation exposure of their infants, Chemosphere 126 (2015) 67–72.
[38] J.L. Daniels, M.P. Longnecker, A.S. Rowland, J. Golding, ALSPAC Study Team, University of Bristol Institute of Child Health (2004) Fish intake during pregnancy and early cognitive development of offspring, Epidemiology 15 (2004) 394–402.
[39] M.N. Mead, Contaminants in human milk: weighing the risks against the benefits of breastfeeding, Environ. Health Perspect. 116 (2008) A427–A434.
[40] RBLH, Rede Global de Bancos de Leite Humano. http://rblh.fiocruz.br/pt-br/pagina-inicial-rede-blh (Accessed 5 July 2017).