Maternal and environmental determinants of breast-milk mercury concentrations

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We aimed to evaluate the maternal factors [including dietary habits, dental care, smoking, anemia, levels of breast-milk zinc (Zn) and iron (Fe), and levels of serum selenium (Se), Zn and copper (Cu)] that influence breast-milk mercury (Hg) concentrations and to investigate whether there is any relation between Hg concentrations and infant growth and development during the exclusive breastfeeding period and in the second year of life. Forty-four healthy mother-infant pairs in the 10-20-day postpartum period were enrolled in the study. Maternal history and blood samples for hemoglobin, Fe, Fe binding capacity, ferritin, Se, Zn, and Cu and breast-milk samples for Fe, Zn and Hg were taken. Infant growth and development during the exclusive breastfeeding period and in the second year of life were followed. The mean concentration of breast-milk Hg was 3.42±1.66 µg/L. Serum Se levels were negatively correlated with milk Hg levels. Multivariate analysis revealed that active/passive smoking and offal intake during pregnancy and presence of maternal anemia had an impact on increased milk Hg concentrations. Preventive strategies for mercury exposure should include management of iron deficiency anemia, cessation of smoking exposure and proper nutrition during the pregnancy period.

Key words: mercury, zinc, iron, selenium, breast-milk, anemia, nutrition, offal, smoking.

Mercury (Hg) is a public health concern due to its toxic effects on infants and its widespread occurrence in the environment.[1,2] Infants may be exposed to Hg via breast-milk.[2-4] There is a wide variation in the reported data from different countries on the concentrations of heavy metals in human milk.[2-9] Generally, there is a low transfer of toxic metals through milk when maternal exposure levels are low.[2-6] To diminish maternal and infant exposure to Hg, it is necessary to establish guidelines based on an understanding of the environmental occurrence of these metals and the manner in which they reach the developing human organism.[8,10] In spite of this, knowledge is limited about the sources of maternal exposure, the influence of a mother's lifestyle on her breast-milk metal concentrations and the transfer of Hg through breast-milk in relation to other trace elements.[11,12] In addition, the concentration of Hg in breast-milk and its relation with the infant's development during the exclusive breastfeeding period are not clear.[8,13-17] However, community-based information on how Hg is obtained by mothers is fundamental in establishing guidelines to diminish exposure and toxicity during early human development.[10,12,18,19] In this regard, an overview of the public health implications of exposure to Hg via breast-milk for nursing infants and health-based guidance could be provided. Therefore, the goals of this study were (a) to detect the concentrations of milk Hg in healthy mothers, (b) to evaluate maternal factors that influence breast-milk Hg level [including dietary habits, dental care, smoking, maternal anemia, levels of breast-milk iron (Fe) and zinc (Zn), and levels of serum

selenium (Se), Zn and copper (Cu)], and (c) to investigate whether there is any relation between Hg levels and infant growth and development during the exclusive breastfeeding period and in the second year of life.

Material and Methods

This prospective study was conducted between January 1, 2003 and September 31, 2005 in Ankara, Turkey. Healthy mothers in the 10-20-day postpartum period, who were admitted to Hacettepe University İhsan Doğramacı Children's Hospital for well-baby follow-up, were enrolled in the study, if the babies were exclusively breastfeeding and mothers were willing to continue with exclusive breastfeeding up to at least five months. Preterm (gestational age <37 weeks) or low birth weight babies (birth weight <2500 g) and twin babies were not taken into the study. Only infants who were exclusively breastfed at the 5th month of age were included for further analysis with breast-milk and blood sample analysis. An infant was considered to be exclusively breastfed when he or she had received only breast-milk with no other liquids or solids, as defined by the World Health Organization (WHO 1991).[20]

Mothers were informed about the purpose of the study, and a written consent was obtained. The Ethical Committee of the Faculty of Medicine, Hacettepe University, approved the study protocol (TBK 01/4-5).

Mothers completed a questionnaire with respect to weight prior to pregnancy, weight gain during pregnancy, height, gestational age, environmental factors, maternal nutrition (fish consumption, viscera of hen, sheep and cow [offal]), smoking habits, alcohol consumption, and amalgam fillings and dental care during the pregnancy and lactation period, and birth weight of the infant. Infants were examined, their weight, height and head circumferences were recorded, and Denver II test was given to investigate their development at the enrollment (10-20 days postpartum), and at the 5th month and the 2nd year.

Denver II test was performed by the certificated investigator (DEK). Denver II includes 125 items. The test is based on observation and the caretaker's reporting of the child's skills in personal–social, fine motor, language, and gross motor areas using a standard test form and kit. Denver II results were interpreted as: two or more delayed items were scored as "abnormal", one delay and one caution as "questionable", and no delays or one caution as "normal". The standardization of Denver II was done in Ankara, Turkey.[21]

Maternal blood samples (8 ml) for hemoglobin (Hb), Fe, Fe binding capacity, ferritin, Zn, Cu, Se and breast-milk samples (5-to-10 ml) for Fe, Zn and Hg were taken in the 10-20-day postpartum period in the morning. Part of the blood sample was collected in an EDTA-treated test tube and immediately analyzed for Hb (Coulter Counter-S model, Coulter ®; STKS, Coulter Corp., Hialeah, FL, USA). The other part of the sample was collected in a tube, free of trace elements, and after centrifugation, serum was stored frozen at -20°C until analyzed for Fe, Fe binding capacity, ferritin, Zn, Cu, and Se. Serum Fe and Fe binding capacity were measured by colorimetric methods (Sigma) and serum ferritin by a commercial kit (Tina quant® a ferritin(e), Lot no: 62159101-62376101, Preciset ferritin(e), Lot no: 61043462, Roche, USA) with Modular Analytic System (ROCHE Diagnostics/HITACHI (Modular DP), Japan) at the Hacettepe University Laboratory of Biochemistry. Transferrin saturation (TS) was calculated as: (serum Fe / serum Fe binding capacity) X 100.

Serum Zn and Cu concentrations were determined by atomic absorption spectrophotometer on Varian Techtron model 1200 (Varian Techtron, Melbourne, Victoria, Australia), and serum Se levels were measured using the fluorometric procedure defined by Lalonde et al.[22] carried out at Hacettepe University Ihsan Doğramacı Children's Hospital, Nutrition and Metabolism Unit.

Milk samples were collected in the morning before feeding the infant from the left or right breast. In order to avoid contamination to the extent possible, milk was expressed by hand, directly into polyethylene bottles and stored at –20°C until analysis. Atomic absorption spectrophotometry was used to detect the content of milk Hg [Perkin-Elmer FI-AAS (Flow Injection Hydride System)], Fe [Perkin-Elmer SIMAA-6000 (Graphite Furnace, Zeeman-effect background correction] and Zn (Perkin-Elmer AAnalyst 100, Überlingen, Bundesrepublik, Germany) at Duzen Laboratories, in Ankara.

Statistical analyses were conducted with SPSS (version 10.0 for Windows; SPSS Inc., Chicago, IL, USA). The normality of data distribution was checked using the Kolmogorov-Smirnov test. Serum Fe and milk Fe concentrations were log-transformed for the analysis and presented as the geometric means because the distributions of raw data values were skewed. Student's t test was used for comparing means, chi-square test for comparing proportions, and Pearson correlation coefficients for studying correlations. Fisher's exact test was used when applicable. Due to the limited serum samples, serum Se, Zn and Cu levels were studied only in 27 cases and not taken into multivariate analysis. Multiple linear regression analysis (stepwise model) was used to determine which factors among maternal age, parity (1^{st} vs $\geq 2^{nd}$), viscera and fish intake, active/passive cigarette smoking, number of amalgam fillings, birth weight of infant, maternal Hb concentrations at 10-20 days postpartum, logarithmic concentration of milk Fe, and milk Zn status best predicted milk Hg concentrations. Statistical significance level was set to $p < 0.05$.

Results

During the study period, 67 mother-infant pairs were enrolled in the study; however, only 44 infants were still exclusively breastfed at the 5^{th} month of age and these mother-infant pairs formed the study group. The mothers had normal and healthy pregnancies. Maternal blood pressure was normal and there was no history of gestational hypertension. Three women had cesarean deliveries. Maternal and infant characteristics are summarized in Table I. The mean maternal age was 27.8 years (range: 18-38). None of the mothers had occupational exposure to Hg as it was known. The mean concentration for Hg was 3.42 ± 1.66 µg/L (min-max: 0.35-6.90 µg/L, Table I). 47.7% of the breast-milk samples ($n = 21$) marginally exceeded the concentration of 3.5 µg/L for Hg. Milk samples in cases with Hg concentrations of more than 3.5 µg/L at 10-20 days postpartum were taken again at the 8^{th} week postpartum and new milk samples were found to be below 3.5 µg/L.

Maternal nutritional status (weight, height, body mass index [BMI], weight gain during pregnancy), parity, interval from previous pregnancy, gestational anemia and Fe usage during pregnancy, and Fe and Zn contents of breast-milk did not affect the breast-milk Hg content (Tables II, III). Overall, 30 mothers took Fe supplementation more than one month, while 6 mothers had no supplementation during pregnancy. Overall, 14 mothers had anemia (Hb < 12 g/dl) at 10-20 days postpartum. Anemic mothers had significantly higher milk Hg ($p = 0.026$, Table III).

Of all, 14 mothers had eaten viscera (liver, kidney or brain) of cows or sheep during pregnancy (1-3 meals). These mothers had high levels of the mean milk Hg levels compared to those who had not consumed offal; however, this was not found to be statistically significant. None of the mothers had eaten fish more than 3 meals/week, and 12 mothers (27.3%) reported no fish intake. Fish consumption was ≥3 meals/month in 36.4% of mothers. The three most popular fish (in descending order of intake) were anchovy, cod and bonito. No woman reported intake of freshwater fish during pregnancy or breastfeeding. The women's total fish intake was similar in pregnancy and during the breast-feeding period. Fish consumption did not affect breast-milk Hg content significantly ($p > 0.05$, Table III).

No woman reported consumption of alcohol, and 8 women reported smoking, 5 of whom quit during pregnancy. High Hg content (≥3.5 µg/L) in milk sample was seen more frequently in mothers who had active or passive cigarette smoking exposure than in the absence of maternal smoking exposure (70.6% for smokers, 33.3% for nonsmokers, $p = 0.016$; Table III).

The women had a mean number of 2.2 ± 1.5 (range: 0–5) amalgam surfaces (Table I). Seven (15.9%) mothers had no amalgam-filled teeth. No woman reported amalgam teeth filling or restoration during pregnancy. Hg in breast-milk did not correlate with the number of amalgam-filled teeth ($r = 0.092$; $p > 0.05$).

Serum Se levels were negatively correlated with milk Hg levels ($n = 21$, $r = -0.462$, $p = 0.015$, Table II). This relation also continued after controlling for maternal age, parity, gestation week, birth weight, and infant sex ($n = 21$, $r = -0.503$, $p = 0.017$). However, neither serum Zn nor Cu levels affected milk Hg level. Serum

Table I. Maternal and Infant Characteristics (n=44)

Maternal characteristics	mean ± SD	range
Maternal age, years	27.8 ± 5.2	18-38
Maternal weight, prior to pregnancy, kg	58.6 ± 7.7	48-83
Body mass index, kg/m^2	22.9 ± 3.2	18.3 -31.1
Weight gain during pregnancy, kg	14.2 ± 6.4	0-30
Number of amalgam fillings	2.2 ± 1.5	0 – 5
Fish intake, meals/month	2.0 ± 1.9	0-8
Hemoglobin, g/dl	13.1 ± 1.3	11.0-16.9
Serum iron, µg/dl (GMT)	48.9	12.0-147.0
Serum iron binding capacity, µg/dl	379 ± 74	262-599
Transferrin saturation, %	15.9 ± 9.2	2.7-44.8
Serum ferritin, µg/L	47.9 ± 25.0	5.5-123.7
Serum zinc, µg/dl (n=27)	129 ± 32	66-189
Serum copper, µg/dl (n=27)	130 ± 37	34-191
Serum selenium, µg/L (n=27)	62.8 ± 8.7	42.6-76.7
Breast-milk iron, mg/L (GMT)	0.51	0.29-1.27
Breast-milk zinc, mg/L	4.78 ± 1.83	1.5-9.0
Breast-milk Hg, µg/L	3.42 ± 1.66	0.35-6.90
Infant characteristics		
Gestational age, week	39.4 ± 1.1	37-42
Birth weight, kg	3.35 ± 0.40	2.70-4.32
Weight at 10-20-days postpartum, kg	3.72 ± 0.38	2.75-4.45
Weight at 5 months of age, kg	7.23 ± 0.85	5.80–8.90
Length at 5 months of age, cm	65.9 ± 2.0	62.5-71.0
Head circumference at 5 months of age, cm	41.8 ± 1.6	38.1–46.0
Weight at 2 years of age, kg (n=21)	13.3 ± 1.3	11.5-16.5
Height at 2 years of age, cm (n=21)	86.6 ± 3.5	81.0-94.5
Head circumference at 2 years of age, cm (n=21)	48.6 ± 1.5	46.0-53.0

GMT: Geometric mean titer.

Table II. The Correlations Between Breast-Milk Mercury Levels and Maternal-Infant Parameters at 10-20 Days Postpartum (n=44)

Maternal characteristics	Correlation coefficients
Maternal age	0.011
Weight prior to pregnancy	0.138
Body mass index	0.051
Weight gain during pregnancy (n=34)	0.316
Number of amalgam-filled teeth	0.092
Hemoglobin, g/dl	-0.357*
Serum iron, µg/dl	-0.331*
Serum iron binding capacity, µg/dl	0.113
Transferrin saturation, %	-0.254
Serum ferritin, µg/L	-0.117
Serum zinc, µg/dl (n=27)	-0.074
Serum copper, µg/dl (n=27)	0.051
Serum selenium, µg/L (n=27)	-0.462*
Breast-milk iron, mg/L	-0.112
Breast-milk zinc, mg/L	0.086
Infant characteristics	
Birth weight	-0.032
Infant weight at 10-20 days postpartum	-0.171
Infant height at 10-20 days postpartum	0.013
Infant head circumference at 10-20 days postpartum	-0.121

*$p < 0.05$.

Table III. Influence of Selected Factors on the Mean Mercury Levels and the Frequency of High Mercury Level in Human Milk

		N	Milk Hg levels#	Milk Hg≥ 3.5 µg/L&
Maternal hemoglobin concentration	<12 g/dl	14	4.23±1.34	10 (71.4)
	≥12 g/dl	30	3.05±1.67*	11 (36.7)*
Iron supplementation during pregnancy	≤1 month	14	3.93±1.69	8 (57.1)
	>1 month	30	3.19±1.61	13 (43.3)
Gestational anemia	No	20	3.67±1.71	12 (50.0)
	Yes	24	3.22±1.61	9 (45.0)
Interval from previous pregnancy	<48 months	11	2.85±1.26	4 (36.4)
	≥48 months and primiparous	33	3.61±1.74	17 (51.5)
Parity	Primiparous	27	3.63±1.78	14 (51.9)
	Multiparous	17	3.10±1.42	7 (41.2)
Active/passive smoking	Absent	27	3.05±1.58	9 (33.3)
	Present	17	4.02±1.63	12 (70.6)*
Consumption of viscera	Absent	30	3.04±1.32	13 (43.3)
	Present	14	4.23±2.03	8 (57.1)
Fish consumption	<3 meals/month	28	3.06±1.63	11 (39.3)
	≥3 meals/month	16	4.05±1.54	10 (62.5)
Sex of infant	Male	24	3.43±1.63	12 (50.0)
	Female	20	3.41±1.73	9 (45.0)
Total		44	3.42±1.66	21 (47.7)

#comparison between groups with Student's t test or Mann-Whitney U test where appropriate. &: row percentage, differences in the frequency of groups with chi-square test.
*$p < 0.05$.

Se, Zn and Cu levels were not taken into multivariate analysis due to the limited number of cases. A multiple regression model (stepwise) for breast- milk Hg concentration as a function of maternal age, parity (1^{st} vs $\geq 2^{nd}$), viscera and fish intake, active/passive cigarette smoking, number of amalgam fillings, birth weight of infant, maternal Hb concentrations at 10-20 days postpartum, logarithmic concentration of breast-milk Fe, and breast milk Zn status revealed that presence of maternal anemia, active/passive cigarette smoking and offal intake had an impact on increased breast-milk Hg concentrations (R square = 0.427, $F = 9.704$, $p < 0.001$).

Breast-milk Hg concentrations at 10-20 days postpartum had no effect on infant's weight, height and head circumference at 5 months' postpartum during the exclusive breastfeeding period. Of the 44 mother-infant pairs recruited at 10-20 days postpartum, 21 remained in the study for anthropometric measurements at 2 years' postpartum. Milk Hg levels at 10-20 days postpartum did not affect weight, length, head circumference or blood pressure of the infant at the 2^{nd} year of age ($p > 0.05$). All children had normal Denver test at 5 months' and 2 years' postpartum.

Discussion

The mean concentration of breast-milk Hg was 3.42 µg/L in our study. Concentrations of mean Hg vary widely in human milk samples around the world: 2.02-9.50 µg/L.[2-7,18] Milk Hg concentrations may differ depending on sampling day and time during each feeding session and exposure concentrations of the mothers.[2,3,6,19] Median Hg in breast-milk was reported to be decreased significantly ($p < 0.001$) from day 4 to 6 weeks' postpartum but remained unchanged thereafter.[6] Similarly, in the present study, when milk samples with high Hg concentrations were reanalyzed at the 8^{th} week postpartum, milk Hg concentrations were found to be below 3.5 µg/L. Bjornberg et al.[6] also found that the median concentrations were 0.12 µg/L in the first milk, 0.15 µg/L about halfway through the feeding session, and 0.18 µg/L at the end of the feeding session at 6 weeks ($n = 15$; $p < 0.001$). In the present study, to prevent sampling error, we took the first milk as a standard protocol.

Regarding the selected parameters studied in this work (mother's age, weight, parity, number of mother's teeth fillings, newborn's gender and birth weight, smoking habits in the family), maternal anemia and active/passive smoking

were the only statistically significant parameters in univariate analysis. In addition, the mothers with higher fish and viscera consumption had somewhat higher concentration of Hg in milk in univariate analysis. However, multivariate analysis showed that maternal Fe deficiency anemia, consumption of viscera and active/passive smoking during pregnancy had a role in milk Hg concentrations in our study population. Ünüvar et al.[8] also reported that smoking during pregnancy and the number of cigarettes significantly increased the Hg levels. Gundacker et al.[4] reported elevated milk Hg in cases with maternal weight of <60 kg, prematurity (<37 weeks gestation), frequent consumption of cereals, maternal use of vitamins, and residence in either urban or industrial areas of Austria. In our study, the contribution of maternal vitamin intake (n=7) and pica (n=3) to milk Hg was not investigated due to the limited number of suitable cases. As a limitation, no information was taken about the cereal consumption habits of the subjects. Premature infants were also not taken into the study because of difficulty in being exclusively breastfed.

The number of maternal dental amalgam fillings and amalgam placements or removals during pregnancy and the lactation period were reported to determine the concentration of milk Hg.[9,11,23] However, in our study, the number of amalgam fillings had no effect on milk Hg concentrations. This might be due to the limited number of amalgam fillings (<6) in mothers and no placements or removals of amalgam during the pregnancy period. The amount of Hg released from dental amalgam has been shown to be inversely correlated with the number of days post-delivery.[19,23] In addition to the limited number of amalgam fillings, milk sampling day (10-20 days postpartum) might have had an effect on our results.

There have been some controversial results about the effect of fish consumption on breast-milk Hg concentrations.[4,11,19] Some studies observed a positive association between breast-milk Hg concentration and fish consumption in mature milk.[11,19] In contrast, Gundacker et al.[4] observed no correlation between total Hg and the frequency of fish consumption in 165 Austrian women 2-14 days' postpartum. In our study, frequency of fish consumption showed no significant correlation in multivariate analysis. However, in our study, none of the mothers had eaten fish in more than three meals in one week during pregnancy.

In the present study, for the first time, viscera consumption (liver, brain of bovine, sheep) was taken into consideration, and the presence of viscera consumption was shown to influence milk Hg concentrations positively in multivariate analysis. Dorea[2] mentioned that farming practices in industrialized countries increasingly utilized animal by-products as ingredients fed to animals used as food for human consumers. Hg can thus also pass to eggs, milk, meat, and farmed fish fed fishmeal-containing diets. Therefore, fish may not be the endpoint of Hg contamination in the human food chain. Kacmar et al.[24] reported that the long-term ingestion of Hg with feed leads to a pronounced Hg accumulation in the viscerals (kidneys and liver) of sheep. Similarly, Feng et al.[25] reported that the percentage of Hg accumulations found in the kidney, liver and brain of maternal rats were approximately 52.7%, 38.7%, and 1.66%, respectively, while these rates were 23.7%, 48.9% and 15.6% in infant rats after exposure to low-dose inorganic Hg. As a limitation of this study, we had a limited number of cases and of mothers who consumed a significant amount of viscera, and they may have had some other demographic characteristic placing them more at risk for increased Hg concentrations. However, none of the mothers had occupational exposure to Hg as known from work history.

Micronutrients may interact with toxic metals at several points in the body: absorption and excretion of toxic metals; transport of metals in the body; binding to target proteins; metabolism and sequestration of toxic metals; and finally, in secondary mechanisms of toxicity such as oxidative stress.[26,27] Feng et al.[25] studied the effect of Hg on the homeostasis of Cu, Fe, Se, and Zn in maternal–infant rat pairs after pregnant rat *in utero* and weaning exposure to low-dose inorganic Hg, and they found that the concentrations of the essential trace elements were quite stable in comparison with the two groups of maternal and infant rats after low-level Hg2+ *in utero* and weaning exposure; however, the levels of Cu in the infant rat heart, kidneys, brainstem, and hippocampus of the Hg-exposed rats were slightly higher

than in the control rats. Additionally, they reported positive correlations between Hg and Cu and Hg and Zn in all the samples; between Hg and Se in all samples except the liver in maternal rat samples; and between Hg and Cu and Hg and Zn in the samples except the liver, and between Hg and Se in the samples except the spleen, hippocampus and thalamus in infant rat samples.[25] However, to date, the impact of trace elements on the concentrations of Hg in breast-milk remains unclear. There was a negative correlation between breast-milk Hg concentration and serum Se levels in the present study. The possible mechanisms may include redistribution of Hg, competition for binding sites or formation of a Hg-Se complex.[17,28,29] Additionally, the risk of Hg exposure to infants was shown to be primarily influenced by maternal anemia in the present study. Therefore, people eating a diet deficient in micronutrients will be predisposed to toxicity from nonessential metals. Peraza et al.[30] reported that Fe deficiency leads to pica and complications of pica included lead poisoning and Hg poisoning. These suggest that the dietary presence of the essential elements may contribute to the protection of mother and fetus from the effects of heavy metal exposure, while their deficiency may increase toxicity. Therefore, appropriate dietary manipulation and prevention of Fe deficiency anemia may thus be valuable in the prevention and treatment of heavy metal toxicity.

In the present study, milk Hg content had no effect on the weight and height of five-month-old children during the exclusive breastfeeding period and of two-year-old children. Furthermore, all children showed normal development regardless of the concentration of milk Hg. Similarly, regardless of type of exposure (*in utero* or *ex utero*), no major neurologic signs were reported in children 9 months to 2 years of age in relation to maternal milk Hg content.[13] Grandjean et al.[15] examined 583 infants for three developmental milestones that are usually reached between 5 and 12 months of age, i.e., sitting, crawling and standing, and reported that infants who reached milestone criteria early had significantly higher Hg concentrations in the hair at 12 months of age. Several explanations might be given for these controversial results. The first is that Hg could possess adverse effects on the central nervous system, but environmental and metabolic differences could modulate their toxicity and neurobehavioral outcome in infant exposure during fetal development.[14,16] The second is that although metals and other pollutants are excreted into breast-milk in accordance with the environmental contamination and diet of the mothers, the advantages of breastfeeding outweigh the risks under normal conditions.[2,3,6] The third explanation is that breast-milk is not the primary pathway of exposure for infants, and that prenatal transplacental exposure is a much greater concern.[6] It should be noted that the trans-lactational barrier is more effective than the transplacental barrier in preventing the transfer of these toxic metals to infants.[12] Grandjean et al.[31] found a negative correlation between the Hg concentration in cord blood and nutritional status (weight and height) at 18 months, which was irrespective of duration of breastfeeding. A fourth explanation is that neurological consequences of Hg have been detected only by neurobehavioral tests; however, they do not separate prenatal insults or postnatal exposure in breast-milk.[12] Indeed, cow's milk-based formulas and tap water pose a greater risk of infant exposure to neurotoxic substances.[2] As a result, the possibility of chemical contamination of breast-milk must not mean that mothers give up this vital nutrient for their children.

The transfer of Hg from the mother to the fetus is through the placenta and breastfeeding and occurs at different rates, depending on the source of Hg.[6] The United States (US) Food and Drug Administration and the US Environmental Protection Agency (EPA) are advising pregnant women, nursing mothers, and young children to avoid eating fish that contain high concentrations of Hg such as shark, swordfish, king mackerel, and tile fish, and to eat instead up to 340 g/week of a variety of fish and shellfish that are lower in Hg (EPA 2004).[32] Some traditional dietary practices of eating raw fish and shellfish such as in sashimi and sushi might affect toxicological burden.[18] At the community level, public-based information and risk factors should be investigated and at the individual level, the physician could provide advice on reducing the toxicological burden to the expectant mothers and their children. Interestingly, Passos et al.[10] reported an association between fruit

consumption and lower Hg levels in Amazonian riparians, thus showing the protective effect of fruit consumption against Hg exposure via dietary intake of fish. In the present study, breast-milk Hg concentrations depended on viscera consumption during the pregnancy period and Fe deficiency anemia at 10-20 days postpartum. Offal is usually given as a traditional therapy for prevention and treatment of anemia in Turkey. In addition to decreasing fish consumption, traditional foods should be taken into consideration in effective guidelines to diminish Hg body load.[10] Reduction in maternal Hg contamination may occur with Fe prophylaxis during pregnancy and with screening and treatment of Fe deficiency anemia in the early postpartum days.

In conclusion, prevention strategies should include management of iron deficiency anemia and proper nutrition (reduced ingestion of offal) during the pregnancy period considering traditional foods and treatment. Smoking exposure during pregnancy should be prevented. Further studies are necessary to detect the changes in milk mercury concentrations with treatment of iron-deficient mothers and in countries with high viscera consumption.

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REFERENCES

1. Counter SA, Buchanan LH. Mercury exposure in children: a review. Toxicol Appl Pharmacol 2004; 198: 209–230.
2. Dorea JG. Mercury and lead during breast-feeding. Br J Nutr 2004; 92: 21-40.
3. Abadi HG, Hibbs BF, Pohl HR. Breast-feeding exposure of infants to cadmium, lead, and mercury: a public health viewpoint. Toxicol Ind Health 1997; 13: 495-517.
4. Gundacker C, Pietschnig B, Wittmann KJ, et al. Lead and mercury in breast milk. Pediatrics 2002; 110: 873-878.
5. Al-Saleh I, Shinwari N, Mashhour A. Heavy metal concentrations in the breast milk of Saudi women. Biol Trace Elem Res 2003; 96: 21-37.
6. Bjornberg KA, Vahter M, Berglund B, et al. Transport of methylmercury and inorganic mercury to the fetus and breast-fed infant. Environ Health Perspect 2005; 113: 1381-1385.
7. da Costa SL, Malm O, Dorea JG. Breast-milk mercury concentrations and amalgam surface in mothers from Brasilia, Brazil. Biol Trace Elem Res 2005; 106: 145-151.
8. Ünüvar E, Ahmadov H, Kızıler AR, et al. Mercury levels in cord blood and meconium of healthy newborns and venous blood of their mothers: clinical, prospective cohort study. Sci Total Environ 2007; 374: 60–70.
9. Ursinyova M, Masanova V. Cadmium, lead and mercury in human milk from Slovakia. Food Addit Contam 2005; 22: 579-589.
10. Passos CJ, Mergler D, Fillion M, et al. Epidemiologic confirmation that fruit consumption influences mercury exposure in riparian communities in the Brazilian Amazon. Environ Res 2007; 105: 183-193.
11. Oskarsson A, Schultz A, Skerfving S, et al. Total and inorganic mercury in breast milk and blood in relation to fish consumption and amalgam fillings in lactating women. Arch Environ Health 1996; 51: 234–241.
12. Sharma R, Pervez S. Toxic metals status in human blood and breast milk samples in an integrated steel plant environment in Central India. Environ Geochem Health 2005; 27: 39-45.
13. Cordier S, Garel M, Mandereau L, et al. Neuro-developmental investigations among methylmercury-exposed children in French Guiana. Environ Res 2002; 89: 1-11.
14. Davidson PW, Myers GJ, Weiss B. Mercury exposure and child development outcomes. Pediatrics 2004; 113: 1023-1029.
15. Grandjean P, Weihe P, White RF. Milestone development in infants exposed to methylmercury from human milk. Neurotoxicology 1995; 16: 27-33.
16. Marques RC, Garrofe Dórea J, Rodrigues Bastos W, et al. Maternal mercury exposure and neuro-motor development in breastfed infants from Porto Velho (Amazon), Brazil. Int J Hyg Environ Health 2007; 210: 51-60.
17. Passos CJ, Mergler D. Human mercury exposure and adverse health effects in the Amazon: a review. Cad Saude Publica 2008; 24 (Suppl): 503-520.
18. Chien LC, Han BC, Hsu CS, et al. Analysis of the health risk of exposure to breast milk mercury in infants in Taiwan. Chemosphere 2006; 64: 79-85.
19. Drexler H, Schaller KH. The mercury concentration in breast milk resulting from amalgam fillings and dietary habits. Environ Res 1998; 77: 124-129.
20. World Health Organization. Indicators for Assessing Breastfeeding Practices. 1991. Geneva, Switzerland: WHO/CDD/SER91.

21. Durmazlar N, Öztürk C, Ural B, Karagaoglu E, Anlar B. Turkish children's performance on Denver II: effect of sex and mother's education. Dev Med Child Neurol 1998; 40: 411–416.

22. Lalonde L, Jean Y, Roberts KD, et al. Fluorometry of selenium in serum or urine. Clin Chem 1982; 28: 172-174.

23. Drasch G, Aigner S, Roider G, et al. Mercury in human colostrums and early breast milk. Its dependence on dental amalgam and other factors. J Trace Elem Med Biol 1998; 12: 23-27.

24. Kacmar P, Legath J, Neuschl J. [Levels of mercury in the organs and tissues of sheep after administration of very low doses]. Vet Med (Praha) 1992; 37: 231-235. [Article in Slovak].

25. Feng W, Wang M, Li B, et al. Mercury and trace element distribution in organic tissues and regional brain of fetal rat after in utero and weaning exposure to low dose of inorganic mercury. Toxicol Lett 2004; 152: 223-234.

26. Goyer RA. Toxic and essential metal interactions. Annu Rev Nutr 1997; 17: 37-50.

27. Iturri S, Nuñez MT. Effect of copper, cadmium, mercury, manganese and lead on Fe2+ and Fe3+ absorption in perfused mouse intestine. Digestion 1998; 59: 671-675.

28. Leonzio C, Focardi S, Bacci E. Complementary accumulation of selenium and mercury in fish muscle. Sci Total Environ 1982; 24: 249-254.

29. Magos L, Clarkson TW, Sparrow S, et al. Comparison of the protection given by selenite, selenomethionine and biological selenium against the renotoxicity of mercury. Arch Toxicol 1987; 60: 422-426.

30. Peraza MA, Ayala-Fierro F, Barber DS, et al. Effects of micronutrients on metal toxicity. Environ Health Perspect 1998; 106 (Suppl): 203-216.

31. Grandjean P, Budtz-Jorgensen E, Steuerwald U, et al. Attenuated growth of breast-fed children exposed to increased concentrations of methylmercury and polychlorinated biphenyls. FASEB J 2003; 17: 699-701.

32. U.S. Department of Health and Human Services, U.S. Environmental Protection Agency. 2004. What You Need to Know About Mercury in Fish and Shellfish. EPA-823-R-04-005. http://www.cfsan.fda.gov/~dms/admehg3b.html. (Accessed February 17, 2008)