Original Article

Factors associated with total mercury concentrations in maternal blood, cord blood, and breast milk among pregnant women in Busan, Korea

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This study investigated the concentration of total mercury (THg) in maternal blood, cord blood, and breast milk, and its association with dietary factors. A total of 127 pregnant women in Busan, Korea were recruited. Maternal blood, cord blood, and breast milk were collected at 36 weeks of gestation, at delivery, and at one week after birth, respectively. Information about dietary habits and other factors were obtained from each subject. The mean THg concentrations in maternal blood, cord blood, and breast milk were 3.12±1.36 μg/L, 5.46±2.41 μg/L, and 0.91±2.08 μg/L, respectively. Positive correlations were found between log-transformed THg concentrations in maternal blood and cord blood (r=0.829, p<0.001), and between maternal blood and breast milk (r=0.296, p=0.001). Multiple linear regression analysis showed that the log-transformed concentration of THg in maternal blood was positively correlated with fish consumption (β=0.345, p<0.0001) and negatively correlated with bean consumption (β=−0.055, p=0.048). Fish consumption (β=0.482, p<0.0001) and maternal age (β=0.025, p=0.033) were positively associated with the concentration of THg in cord blood, while negative correlations were found for bean consumption (β=−0.134, p=0.027) and parity (β=−0.172, p=0.015). Beef consumption (β=0.031, p=0.007) was positively associated with log-transformed THg concentrations in breast milk, while negative correlations were found for bean consumption (β=−0.019, p=0.003) and maternal age (β=−0.083, p=0.004). Our study found that both the dietary and demographic factors differently affected to THg concentrations among samples of maternal blood, cord blood, and breast milk.

Key Words: breast milk, cord blood, diet, maternal blood, mercury concentration

INTRODUCTION

It has been well established that exposure to mercury causes serious health problems, including neurotoxicity, reproductive toxicity, and immunotoxicity. As fetuses and infants have a high susceptibility to mercury, neurobehavioral alterations may occur after exposure to relatively low doses of organic mercury compounds.[1] The health effects of mercury on fetuses and infants include preterm birth,[2] low birth weight,[3] developmental disabilities,[4] impaired brain development,[5] and other neurological impairments, such as visual and hearing impairments and speech impediments.[6]

Pregnant women are exposed to mercury in different ways. Human exposure to metallic and inorganic mercury stems mainly from occupational and industrial processes. Human exposure to organic mercury occurs primarily through non-occupational sources such as food intake. In particular, fish consumption is the most common source of chronic low-dose mercury exposure in the general population.[7,8] The biological half-life of methylmercury has been observed to be between 45 to 70 days in adult.[8-10]

Mercury absorbed in the maternal body can be transferred via cord blood and breast milk to the fetus and infant, respectively. Mercury can cross the placenta easily, and the concentration of mercury in cord blood is therefore higher than that in maternal blood.[11,12] In general, little transfer of toxic metals through breast milk occurs when maternal exposure levels are low.[13] Breast milk is defined to have three distinct stages: colostrum (days 1-5), transitional milk (days 6-14), and mature milk. The

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composition of breast milk changes across these stages, and consequently the factors that affect mercury binding also change. Two major forms of mercury are present in breast milk: inorganic mercury and methylmercury. Mercury exposure through early breast milk is associated with inorganic mercury, which results from maternal exposure to sources such as dental amalgams.[14] In contrast, mercury exposure during breastfeeding after two months of lactation mainly involves methylmercury, which is associated with fish consumption.[15] Since methylmercury has been associated with several health hazards, many countries suggest annual limits of mercury intake and limits on fish in the diet.

The 2010 Korean National Health and Nutritional Examination Survey found that the mean blood mercury concentration in the general Korean population was 3.95 μg/L, while in women, the mean blood mercury concentrations were 2.98 μg/L in women between 20 and 29 years of age, 3.24 μg/L in women between 30 and 39 years of age, and 3.48 μg/L in women between 40 and 49 years of age.[16] Few studies have been performed to assess blood mercury concentrations in pregnant Korean women. One study has shown that the mean blood mercury concentrations in pregnant Korean women were 3.27 μg/L at midpregnancy (12-28 week of gestation) and 3.08 μg/L at late pregnancy (28-42 week of gestation).[17] No studies have been performed in Korea to assess mercury concentrations in breast milk.

The objective of this study was to determine mercury concentrations in the maternal blood, cord blood, and breast milk of pregnant women in Busan, Korea, as well as to investigate dietary and demographic factors that may affect mercury concentration.

METHODS

Subjects

A total of 127 healthy pregnant women in the thirty-sixth week of gestation were recruited from January 2009 to May 2010 in one general hospital in Busan, Republic of Korea. Busan is a coastal metropolitan city in the southeastern region of the Republic of Korea. None of the subjects had any occupational exposure to mercury. All subjects were informed about the goals of the study, and gave their informed consent. This study was approved by the Institutional Review Board of Inje University, Korea.

Questionnaire

The questionnaire was administered during the thirty-sixth week of gestation. A structured questionnaire including age, maternal weight and height before pregnancy, past disease history, parity, job history, alcohol consumption, smoking habits, frequency of exercise, dietary habits, and type of drinking water, was administered via a one-on-one interview by a trained interviewer.

The dietary habits of each subject one year before the interview were assessed using a detailed questionnaire. Dietary portion size and dietary frequency were classified using a semi-quantitative food frequency questionnaire based on the Korean National Health and Nutritional Examination Survey.[18] The portion size of each item was classified as small, medium, or large. For each food, the medium size reflected the portion sizes commonly sold in the market. A small portion was taken to be one half of the median portion size and a large portion was considered to be one and a half times the median portion size. Dietary frequency was classified into the following nine categories: (1) never or seldom, (2) once a month, (3) two to three times a month, (4) one to two times a week, (5) three to four times a week, (6) five to six times a week, (7) once a day, (8) twice a day, and (9) three times or more a day. Food items were categorized into meat (pork, beef, chicken, and miscellaneous meats such as duck and processed meat), egg, milk, vegetables (root vegetables, leaf vegetables, mushrooms, fruits, nuts, and beans), seafood and seaweed (fish, seaweed, crustaceans, shellfish, processed seafood), and instant food items (instant foods, snacks, beverages).

The consumption frequency of each food was multiplied by the usual portion size (0.5 for small portions, 1.0 for medium portions, and 1.5 for large portions) to calculate servings per week for each of the items on the food frequency questionnaire. The amount of intake of each food ranged from zero servings per week (if a given subject never or seldom ate a particular food) to 31.5 servings per week (if a given subject ate a large portion size of a particular food three times or more per day).

Sample collection and analysis of mercury concentration

Maternal blood was collected in the thirty-sixth week of gestation. A sample of cord blood was collected at delivery, and breast milk sampling was carried out within a week after birth. All samples were collected in containers labeled with an identification number and the sample date. From each subject, 5 mL of maternal blood and 5 mL of cord blood were collected. All blood samples were collected in heparin-treated vacutainers® (Becton Dickinson, Franklin Lakes, NJ, USA). Breast milk was collected four to seven days after delivery in a 50-mL Falcon tube (Becton Dickinson, Franklin Lakes, NJ, USA). All samples were stored at −20°C before analysis. Total mercury (THg) concentration was analyzed by the gold-amalgam collection method, using a direct mercury analyzer (DMA-80, Milestone, Sorisole, Italy). Blood mercury concentrations were measured under strict internal and external quality control precautions. The certified reference materials used for quality control in the mercury quantification procedure were obtained by the Institute and Outpatient Clinic for Occupational, Social and Environmental Medicine of the University of Erlangen-Nuremberg (Erlangen, Germany), and the sensitivity of mercury detection was 90.9%. The detection limit was 0.18 μg/L.

Statistical analysis

The arithmetic means of the variables relating to THg concentrations in maternal blood, cord blood, and maternal milk were compared using the independent sample *t*-test and the Kruskal-Wallis test. The Kolmogorov-Smirnov test was performed to check the normality of the data distribution. As the distribution of the raw data values of the maternal blood THg and breast milk THg concentrations were skewed to the right, the data were normalized by logarithmic transformation for parametric analysis.

The relationship between log-transformed maternal blood THg concentrations and log-transformed cord blood THg concentrations was analyzed, as well as the relationship between log-transformed cord blood THg concentrations and log-transformed breast milk THg concentrations. The relationships between food consumption, other related factors (age, maternal weight, parity, exercise frequency, amount of alcohol and cigarette consumption), and log-transformed THg concentrations were evaluated. Food consumption variables and other factors that were significant determinants of mercury concentrations in maternal blood, cord blood, and breast milk were determined by Pearson's correlation analysis. Multiple linear regression analysis was used to assess the association between factors that were found to be significant in univariate analysis and log-transformed THg concentrations in maternal blood, cord blood, and breast milk. Log-transformed maternal blood, cord blood, and breast milk THg concentrations were set as dependent variables. Independent variables included the amount of consumption of the types of food that which showed significant correlations in Pearson's correlation analysis. Maternal age and parity were also entered into all multiple linear regression analyses as predictor variables. β-coefficients are presented as estimates of effect, and adjusted R^2 values are presented as a measure of model fit. Variation inflation factors are presented as a measure of multicollinearity. All statistical analyses were performed with IBM SPSS Statistics version 21.0 (IBM Corp., Armonk, NY, USA). The statistical significance level was set to $p<0.05$.

RESULTS

The arithmetic mean (±standard deviation) THg concentrations in maternal blood, cord blood, and breast milk were 3.12 μg/L (±1.36 μg/L), 5.46 μg/L (±2.41 μg/L), and 0.91 μg/L (±2.08 μg/L), respectively (Table 1). The THg concentration in cord blood was 1.75 times higher than the THg concentration in maternal blood. The main characteristics of the study subjects are shown in Table 1. The THg concentration in breast milk tended to be lower among women over 30 years of age, whereas the THg concentration in maternal blood and cord blood was relatively high in this group; however, no statistically significant differences were observed between women younger and older than 30 years of age. A significant positive correlation was found between the log-transformed THg concentrations in maternal blood and cord blood ($r=0.829$, $p<0.001$). A significant correlation was also found between the log-transformed THg concentrations in maternal blood and breast milk ($r=0.296$, $p=0.001$) (Figure 1).

In univariate analyses, no significant association was found between the log-transformed THg concentration in

Table 1. Total mercury concentrations in the maternal blood, cord blood, and breast milk of 127 pregnant women in Busan, Korea

Variables	Number (%)	Maternal blood (μg/L)		Cord blood (μg/L)		Breast milk (μg/L)	
		Mean±SD	*p* value	Mean±SD	*p* value	Mean±SD	*p* value
Total	127 (100)	3.12±1.36		5.46±2.41		0.91±2.08	
Age							
20-29 years	46 (36.2)	3.08±1.29	0.774‡	5.35±2.27	0.705‡	1.19±2.81	0.246‡
30-39 years	81 (63.8)	3.14±1.41		5.52±2.50		0.74±1.53	
Weight (kg)							
<50	40 (31.5)	3.02±1.49	0.376§	5.60±2.78	0.491§	0.67±1.20	0.246§
50-60	65 (51.2)	3.16±1.26		5.46±2.24		1.20±2.73	
60-70	16 (12.6)	3.43±1.49		5.57±2.29		0.44±0.29	
>70	6 (4.7)	2.59±1.31		4.14±1.97		0.59±0.47	
BMI (kg/m^2)†							
<18.5	17 (13.4)	3.09±1.21	0.947§	6.10±3.28	0.596§	0.85±1.75	0.495§
18.5-23.9	97 (76.4)	3.15±1.40		5.45±2.30		0.98±2.27	
24-26.9	9 (7.1)	3.03±1.45		4.75±1.69		0.49±0.40	
>27	4 (3.1)	2.79±1.28		4.44±2.11		0.36±0.14	
Previous pregnancies							
None	87 (68.5)	3.14±1.32	0.814§	5.61±2.56	0.703§	0.88±1.61	0.302§
1	36 (28.3)	3.08±1.50		5.13±2.05		0.99±3.08	
>2	4 (3.2)	3.11±1.27		4.90±2.09		0.64±0.31	
Smoking status							
Never smoker	123 (96.9)	3.11±1.35	0.424§	5.49±2.43	0.409§	0.92±2.11	0.767§
Former smoker	3 (2.4)	3.87±2.11		5.10±1.67		0.67±0.55	
Current smoker	1 (0.8)	1.99		3.07		0.55	
Alcohol drinking status							
Never	58 (45.7)	3.07±1.17	0.283§	5.53±2.60	0.369§	1.06±2.59	0.463§
Former drinker	68 (53.5)	3.13±1.48		5.36±2.24		0.78±1.55	
Current drinker	1 (0.8)	6.03		8.38		0.4	
Regular physical exercise							
No	112 (88.2)	3.07±1.28	0.206‡	5.38±2.37	0.341‡	0.85±1.94	0.419‡
Yes	15 (11.8)	3.54±1.87		6.01±2.70		1.32±2.98	

BMI: body mass index; SD: standard deviation.
†Classification from Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies.[19]
‡Calculated with the independent-sample *t*-test.
§Calculated with the Kruskal-Wallis test.

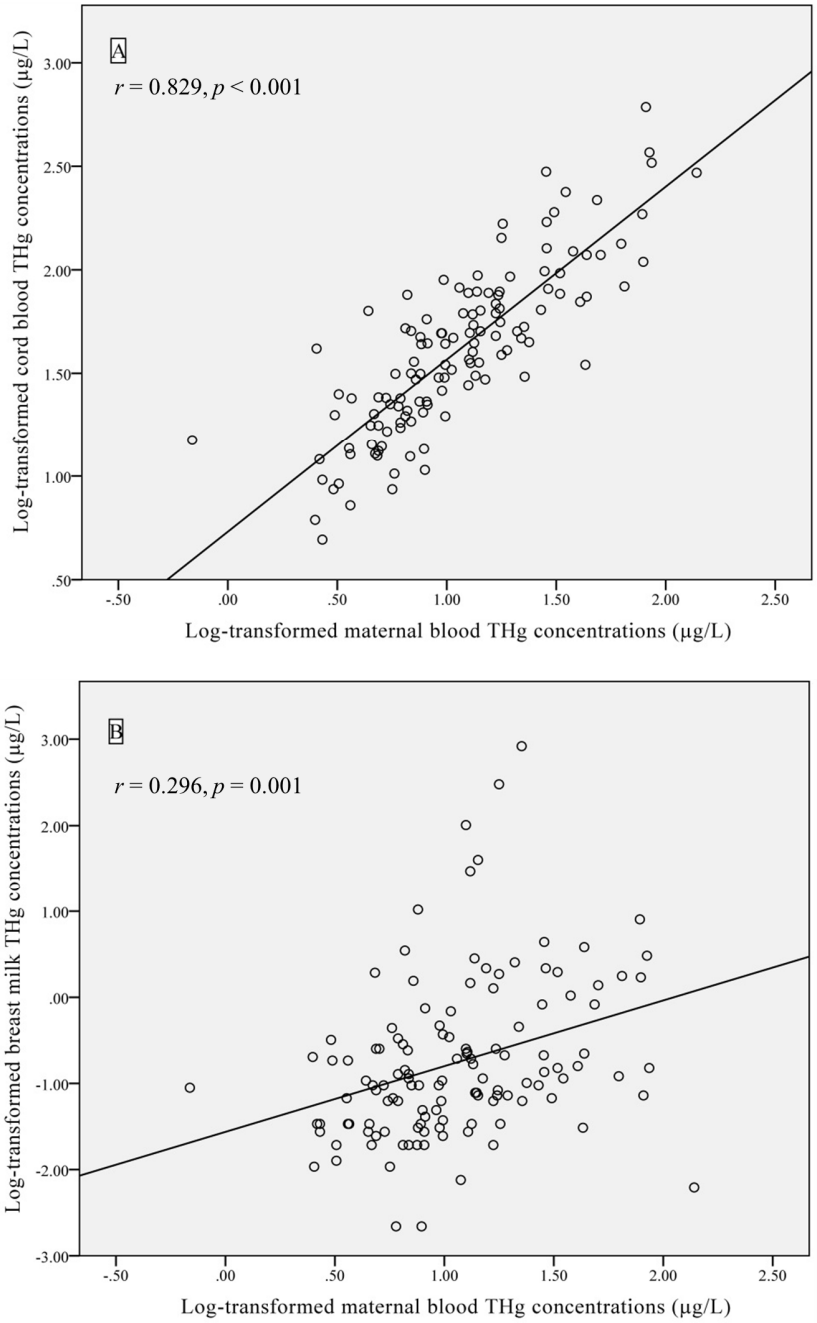

Figure 1. Associations between total mercury (THg) concentrations by sample site, analyzed by Pearson's correlation analysis: (A) maternal blood versus cord blood (n=127), (B) maternal blood versus breast milk (n=127). Log-transformed concentrations of THg in maternal blood, cord blood, and breast milk were used.

each sample and maternal age, weight, or parity. Likewise, no significant correlations were found with frequency of exercise, alcohol consumption, or pack-years of smoking. Among dietary factors, the consumption of fish, shellfish, chicken, eggs, mushrooms, fruits, and beans showed significant positive correlations with the log-transformed concentration of THg in maternal blood. The consumption of fish, crustaceans, chicken, miscellaneous meats, milk, and beans showed significant positive correlations with the concentration of THg in cord blood. The consumption of fish, seaweed, crustaceans, processed seafood, beef, chicken, miscellaneous meats, and beans showed significant positive correlations with the log-transformed concentration of THg in breast milk (Table 2).

In multiple linear regression analysis, fish consumption (β=0.345, p<0.0001) had a significant positive correlation with the log-transformed concentration of THg in maternal blood. Bean consumption (β=−0.055, p=0.048) had a significant negative correlation with the log-transformed concentration of THg in maternal blood. Fish consumption (β=0.482, p<0.0001) and maternal age (β=0.025, p=0.049) were positively correlated with the concentration of THg in cord blood. Bean consumption (β=−0.134, p=0.027) and parity (β=−0.172, p=0.015) showed a significant negative correlation with the concentration of THg in cord blood. Beef consumption (β=0.031, p=0.007) had a significant positive correlation with the log-transformed concentration of THg in breast milk. Bean consumption (β=−0.019, p=0.003) and maternal age

Table 2. Association of total mercury concentrations with dietary and demographic factors (n=127)

Factors	Maternal blood‡		Cord blood		Breast milk‡	
	r	*p* value§	*r*	*p* value§	*r*	*p* value§
Dietary factors†						
Seafood and seaweed						
Fish	0.442	<0.0001	0.332	<0.0001	-0.015	0.014
Seaweed	0.038	0.669	0.062	0.486	0.076	0.003
Crustaceans	0.122	0.170	0.176	0.047	-0.042	<0.0001
Shellfish	0.052	0.559	0.014	0.873	-0.053	0.589
Processed seafood	0.039	0.662	0.005	0.956	0.109	0.006
Meats						
Pork	0.069	0.439	0.036	0.692	0.227	0.748
Beef	0.105	0.240	0.026	0.768	0.217	0.023
Chicken	0.080	0.370	-0.001	0.987	0.110	<0.0001
Processed meats	-0.079	0.377	-0.058	0.519	-0.016	0.413
Miscellaneous meats	0.028	0.758	-0.001	0.987	0.043	0.000
Eggs	-0.086	0.339	-0.116	0.195	-0.154	0.991
Milk	-0.108	0.248	-0.018	0.844	-0.118	0.302
Vegetables						
Root vegetables	-0.103	0.250	-0.130	0.145	-0.086	0.513
Leaf vegetables	-0.064	0.478	-0.080	0.373	0.074	0.860
Mushrooms	-0.015	0.867	-0.059	0.508	-0.105	0.934
Fruits	-0.017	0.846	0.004	0.968	-0.154	0.345
Nuts	-0.179	0.377	-0.137	0.125	-0.209	0.522
Beans	-0.141	0.029	0.092	0.047	-0.117	0.016
Instant food types						
Beverages	-0.178	0.046	-0.131	0.141	-0.041	0.962
Instant food	-0.111	0.216	-0.109	0.221	-0.109	0.031
Snacks	0.109	0.224	0.026	0.770	-0.094	0.620
Age (years)	0.057	0.522	0.094	0.291	-0.134	0.134
Maternal weight (kg)	-0.015	0.868	0.103	0.250	0.001	0.994
Parity	-0.048	0.595	-0.121	0.177	-0.027	0.767
Exercise (frequency/week)	0.076	0.154	0.129	0.302	0.013	0.876
Alcohol (times/week)	0.059	0.512	-0.006	0.950	0.056	0.499
Smoking (pack-years)	0.080	0.374	-0.020	0.822	0.009	0.917

†Calculated by multiplying frequency and portion size. Dietary portion sizes were classified into three categories (small, medium, and large) using a food frequency questionnaire based on the Korean National Health and Nutritional Examination Survey.
‡Log-transformed breast milk mercury concentrations were used.
§Calculated by Pearson's correlation coefficient.

(β=−0.083, *p*=0.004) showed a significant negative correlation with the log-transformed concentration of THg in breast milk (Table 3).

DISCUSSION

As the amount of fish intake is higher in Asian populations than in Western populations, subjects living close to the sea were chosen in order to make it likely that a high fish intake would be observed.[20] Consequently, our subjects were intended to be appropriate in terms of age and region for discovering the potential risks of mercury exposure to fetuses and infants in the Republic of Korea.

Previous studies have found various mercury excretion levels in breast milk in different populations and ethnic groups. The THg concentrations in breast milk found in our study were lower than those found in studies conducted in Austria (arithmetic mean of 1.59±1.21 μg/L; n=116), Spain (geometric mean of 0.53 μg/L; n=98) and Turkey (arithmetic mean of 3.42±1.66 μg/L; n=44), and higher than in studies conducted in Iran (range of 0.12-0.86 μg/L; n=80).[21-24] Abadin et al have proposed that 3.5 μg/L is an adequate screening level of mercury concentration in breast milk, indicating that this is an appropriate guideline for breastfeeding infants.[13] The average breast milk mercury concentration in our study was below 3.5 μg/L, but five mothers (3.9%, range of 4.36-18.5 μg/L) exceeded the suggested screening level, and for these mothers, breastfeeding may be a potential risk factor for their infants. As the actual amount of mercury absorbed by an infant is affected by multiple factors, including the concentration of mercury in the breast milk, the body weight of the infant, and the daily amount of milk intake, additional consideration would be necessary to determine whether or not there is a latent risk to an infant from a given concentration of mercury in breast milk.

The average THg concentration in maternal blood in our study was similar to that reported in previous studies of pregnant Korean woman (arithmetic mean of 2.94 μg/L in 2006, 3.08 μg/L in 2011; n=63),[17,25] higher than that reported in Canada (arithmetic mean of 0.48 μg/L; n=159) and in the USA (arithmetic mean of 2.59±2.50 μg/L for fish consumers; n=114, 1.67±1.78 μg/L for non-fish consumers; n=54),[26,27] and lower than that reported in Greenland (arithmetic mean of 12.8 μg/L; n=180) and Taiwan (arithmetic mean of 9.1±0.40 μg/L; n=65).[28,29] Our results indicated that eight mothers (6.2%, range of 6.03-8.51 μg/L) had higher THg concentrations in their blood than the level of 5.8 μg/L considered by the Environmental Protection Agency of the United States to be safe.[30]

Table 3. Multiple linear regression analysis for variables related to total mercury concentrations (n=127)

Sampling site	Variables	β	SE	Standardized β	*p* value	Adjusted R^2	VIF
Maternal blood†							
	Constant	1.713	1.101		0.122	0.203	
	Fishes	0.345	0.059	0.466	0.000		1.01
	Beans	-0.055	0.033	-0.134	0.048		1.03
	Parity	-0.265	0.061	-1.39	0.167		1.16
	Maternal age	0.046	0.191	0.104	0.224		1.16
Cord blood							
	Constant	1.093	0.359		0.003	0.163	
	Fish	0.482	0.108	0.368	0.000		1.02
	Beans	-0.134	0.060	-0.185	0.027		1.03
	Parity	-0.172	0.345	-0.216	0.015		1.16
	Maternal age	0.025	0.068	0.169	0.049		1.16
Breast milk†							
	Constant	1.565	0.819		0.059	0.159	
	Fish	-0.006	0.007	-0.083	0.382		1.33
	Seaweed	0.018	0.011	0.160	0.092		1.32
	Crustaceans	-0.024	0.017	-0.130	0.167		1.31
	Processed seafood	0.008	0.011	0.071	0.467		1.42
	Beef	0.031	0.011	0.308	0.007		1.88
	Chicken	0.010	0.012	0.093	0.425		2.02
	Miscellaneous meats	0.013	0.023	0.050	0.582		1.25
	Beans	-0.019	0.006	-0.301	0.003		1.45
	Instant food	-0.015	0.01	-0.146	0.152		1.53
	Parity	-0.009	0.139	-0.006	0.947		1.25
	Maternal age	-0.083	0.028	-0.275	0.004		1.30

†Log-transformed breast milk mercury concentrations were used.
β: regression coefficient; SE: standard error; VIF: variation inflation factor.

The mean transmission of THg from mother to infant via breast milk was calculated to be 3.08 μg per week with a provisional tolerable weekly intake (PTWI) of 0.92 μg/kg of body weight per week, based on simple arithmetic using the following conditions: the mean mercury concentration in breast milk was 0.91 μg/L, the neonate breast milk intake within the first week after birth was 483 mL/day, and the average birth weight of full-term babies in Korea was 3.35 kg.[31,32] The Joint Food and Agriculture Organization and World Health Organization Expert Committee on Food Additives (JECFA) has established a PTWI of 5.0 μg/kg of body weight for THg and 1.6 μg/kg of body weight for methylmercury.[33] Our results did not exceed the PTWI of 5.0 μg/kg of body weight established by the JECFA. However, five mothers (3.9%) in our study had higher breast milk THg concentrations than the PTWI established by the JECFA. The highest level of THg concentration in breast milk in our study was 18.5 μg/L. In this case the THg absorbed by the infant was estimated, using the above assumptions, to be 62.6 μg per week (8.94 μg per day), which is 3.73 times higher than an infant's tolerable intake level for THg.

The two major routes of mercury transport from mother to fetuses and infants are cord blood, which moves across the placenta in the gestational period, and breastfeeding after birth. Previous studies assessing mercury concentration have shown different associations depending on the sample site (maternal blood versus cord blood, and maternal blood versus breast milk). Prior studies have shown that maternal blood mercury concentration has a significant positive correlation with cord blood mercury concentration.[12,34-36] In our study, maternal blood mercury concentration was also found to have a significant positive correlation with cord blood mercury concentration, and the conclusion that mercury accumulates in cord blood during pregnancy was similar to the findings of previous studies**.** Prior studies have shown that mercury concentrations in maternal blood have a significant positive correlation with mercury concentrations in breast milk.[15,36] However, our study found a weak correlation between the mercury concentrations in maternal blood and breast milk. One study has shown a significant association between THg concentration in breast milk and the concentration of inorganic mercury in maternal blood (r=0.61, p=0.006), but this association did not hold for methylmercury (r=0.26, p=0.28), and it was suggested that these results can be explained if inorganic mercury is readily transported from maternal blood to breast milk, whereas organic mercury is not.[36] The composition of mercury found in maternal blood was not characterized in our study, and it is likely that the weak correlation between the THg concentrations in maternal blood and breast milk resulted from the presence of a relatively high proportion of organic mercury in maternal blood.[36] Moreover, as there was a time difference in our study between the sampling of maternal blood and breast milk, our results could have been affected by possible changes in food intake during the prenatal and postnatal periods, as well as the different biological half-life of mercury in maternal blood and breast milk**.**

A positive correlation was found between fish consumption and THg concentrations in both maternal blood and cord blood. An investigation in the 2000s by the Korean Food and Drug Agency found that the mean concentration of mercury in fish was high as 195 μg/kg.[37] The correlation between the amount of fish intake and mercury concentration in maternal blood was assumed to be

caused by the high concentration of mercury in fish. However, fish consumption did not significantly affect mercury concentrations in breast milk in our study. This result likely stems from by the different rates at which methylmercury and inorganic mercury are transferred from maternal blood to breast milk. The different composition of maternal blood and breast milk, especially with regard to protein and lipid content, might affect the transfer and accumulation of different mercury species. Casein, which is found mostly in breast milk, combines with inorganic mercury,[38] whereas organic mercury is found mostly in red blood cells.[39]

Bean consumption was determined to have a statistically significant correlation with reduced THg concentrations in maternal blood and cord blood, but the correlation was weak. The mechanism involved in this excretion effect is not yet clear. A bean-heavy diet is reported to increase biliary lipid secretion by three times.[40] As mercury is excreted in the bile, a diet with higher amounts of beans may facilitate mercury excretion.[41] Beef consumption showed a significant association with mercury concentrations in breast milk. Livestock and plants have been reported as sources of mercury exposure, although less important than fish.[7] The accumulation pathway of mercury in livestock is related to feed and environmental exposure, which are almost the same as the risk factors for humans. As a result, land and water pollution may lead to mercury accumulation in livestock. A study conducted by the Korean Food and Drug Agency in the 2000s found mean mercury levels of 1.2 μg/kg in beef and 2.3 μg/kg in soybeans.[37] Considering this result, it is unlikely that THg in beef made a substantial contribution to the elevated THg concentrations in our subjects. Although our statistical model adjusted for demographic factors, alcohol and smoking habits, and a range of dietary habits, not all possible variables have been accounted for, and beef consumption may be a confounding factor in the relationship between dietary factors and THg concentration.

Parity was a significant negative factor affecting the concentration of THg in cord blood, which suggests that mercury in the maternal body may be excreted by sharing body fluids such as plasma during pregnancy and delivery, and through the occurrence of cord blood loss during delivery. A previous study conducted in Spain showed that parity was negatively associated with cord blood THg concentrations, whereas no correlation was found between parity and breast milk mercury concentration in a study conducted in Turkey.[22,42]

Multiple regression analysis showed that advanced age was related to a significant increase in cord blood THg concentration and a decrease in breast milk THg concentration. Age may have a significant positive correlation with cord blood mercury concentration because mercury has a long biological half-life and age-related accumulation from food and other environmental factors may occur. It is also possible that that increased maternal age might result in elevated breast milk mercury levels.[23] Little is known about the effect of maternal age on breast milk composition, although one study has suggested that advanced age may elevate colostrum fat content.[43] Based upon this result, advanced age may result in an increased concentration of the molecules that bind to mercury and, consequently, an elevated concentration of mercury in breast milk.

Our study had some limitations. First, the temporal interval between the maternal blood and breast milk samples may have affected our findings, because it is possible that changes in environment and lifestyle factors during the period leading up to delivery, along with the variable biological half-life of mercury depending on its form, may have affected the mercury concentrations of our samples. Second, concentrations of THg were analyzed in this study, but further analyses of the specific effect of methylmercury are needed because fetuses and infants are known to be more susceptible to methylmercury than inorganic mercury. Third, our study did not account for the presence of dental amalgams, which are a source of inorganic mercury exposure. Several studies have shown that once the setting process is completed, the amount of mercury released from dental amalgams has no significant correlation with adverse health effects.[44] However, since 15.3% of the total mercury given off from dental amalgams (mostly inorganic mercury) is absorbed through the gastrointestinal tract, dental amalgams may have contributed to inorganic mercury concentrations in our sample, which may have affected our results.[45] Fourth, we did not consider fish size in the food frequency questionnaire. Due to the biomagnification and bioaccumulation of methylmercury, large predatory fish have higher mercury levels.[46] Fifth, as breast milk in our subjects consisted of colostrum and transitional milk, our results may not correspond with previous findings. The composition of breast milk varies among its three distinct stages, which may have been a confounder. It has been reported that colostrum has a significantly higher protein concentration and a consistently higher mean mercury concentration compared to mature milk.[47]

Conclusion

Mercury concentrations in maternal blood and cord blood showed a significant positive association, while a significant positive correlation was found between mercury concentrations in breast milk and maternal blood. Mean breast milk THg concentrations in most samples were found to be below the guidelines set by the JECFA; however, as some samples partly exceeded the guidelines, further evaluation of these subjects should be considered. In our results, the factors that affected mercury concentration were different depending on which source was sampled. THg concentrations in maternal blood and cord blood were affected in the same way by fish and bean consumption, but this was not the case for THg concentrations in breast milk. Further systematic research is needed to characterize the mechanisms of mercury transport from each food group and the bioaccumulation of mercury in human tissue.

AUTHOR DISCLOSURES

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Original Article

Factors associated with total mercury concentrations in maternal blood, cord blood, and breast milk among pregnant women in Busan, Korea

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韩国釜山孕妇母亲血、脐带血、母乳中总汞浓度影响因素

本研究调查了母亲血、脐血和乳汁中总汞浓度（THg）及其与膳食因素的关系。在韩国釜山招募 127 名孕妇。分别于怀孕 36 周时采集母亲血，分娩时采集脐带血，出生 1 周后采集母乳。收集每位志愿者的饮食习惯和其他因素方面的信息。母亲血、脐血和乳汁中平均汞浓度分别为 3.12±1.36 μg/L，5.46±2.41 μg/L 和 0.91±2.08 μg/L。对数转换后的母亲血和脐血 THg 浓度（r=0.829, p<0.001），母亲血和乳汁 THg 浓度呈正相关（r=0.296, p=0.001）。多重线性回归模型显示对数转换后的母亲血 THg 浓度与鱼摄入量呈显著正相关（β=0.345, p<0.0001），与豆类摄入量呈显著负相关（β=−0.055, p=0.048）。鱼摄入量（β=0.482, p<0.0001）和母亲年龄（β=0.025, p=0.033）与脐血 THg 浓度呈显著正相关，而豆类（β=−0.134, p=0.027）和豆类似物摄入量（β=−0.172, p=0.015）与脐血 THg 浓度呈显著负相关。牛肉摄入（β=0.031, p=0.007）与对数转换后的母乳 THg 浓度呈显著正相关，而豆类摄入（β=−0.019, p=0.003）和母亲年龄（β=−0.083, p=0.004）与对数转换后的母乳 THg 浓度呈显著负相关。本研究发现膳食因素和人口学因素对 THg 浓度有影响，且在母亲血，脐血和母乳样本中影响程度不同。

关键词：母乳、膳食、脐血、母亲血、汞浓度