Journal of Preventive Medicine and Public Health
September 2010, Vol. 43, No. 5, 377-386

doi: 10.3961/jpmph.2010.43.5.377

Blood Mercury Concentration and Related Factors in an Urban Coastal Area in Korea

Eun-Mi Jo[1], Byoung-Gwon Kim[1,2], Yu-Mi Kim[1], Seung-Do Yu[3], Chang-Hun You[1], Joon-Youn Kim[1], Young-Seoub Hong[1,2]

[1]Department of Preventive Medicine, College of Medicine, Dong-A University; [2]Regional Cardiocerebrovascular Center, Dong-A University Medical Center; [3]Health Risk Research Department, Environmental Epidemiology Division, National Institute of Environmental Research

Objectives: This study was carried out for the purpose of evaluating the blood mercury concentration of the residents of Busan, Korea, as well as the relationship between the mercury concentration and the pattern of fish consumption along with other epidemiological factors.
Methods: Two hundred ninety-three subjects (147 men and 146 women), who were aged 40 years or more, were recruited into this study between June and October 2009. The mean age of the subjects was 54.3 years (with a range of 40-70 years). Mercury concentrations in blood samples were measured using a gold-amalgam collection method.
Results: The geometric mean concentration of mercury in the total subjects was 8.63 μg/L [range: 1.48~45.71 μg/L]. The blood mercury concentration of the men (9.55 μg/L) was significantly higher than that of the women (7.76 μg/L). The blood mercury concentration of those who eat fish more than 4 times per week was higher than others, and was statistically significant (male $p=0.0019$, female $p=0.0002$). According to the multiple analysis, the blood mercury concentration was significantly affected by the consumed fish but other epidemiological factors were not related.
Conclusions: It was found that the subjects who have consumed a large amount of fish may have high blood mercury concentration. It appears that fish consumption can influence blood mercury concentration. Therefore, guidelines for fish consumption that will decrease blood mercury concentration might be necessary in Korea.

Key words: Blood mercury, Fish consumption, Guidelines
J Prev Med Public Health 2010;43(5):377-386

INTRODUCTION

Mercury is the only metal that exists in liquid form at room temperature. In the natural system, it takes various forms such as metallic mercury, inorganic mercury, and organic mercury. The toxicity of mercury varies by form, inflow path, amount of exposure, and susceptibility of individuals [1]. Metallic mercury is rarely absorbed when consumed orally but may be absorbed if evaporated. Inorganic mercury is not easily absorbed via the digestive tract or skin but may be converted into organic mercury by microorganisms and be absorbed into the human body. Organic mercury is a fat-soluble substance that tends to be concentrated as it moves through the food chain of an ecosystem, serving as a source of contamination for agricultural, livestock and fish products. Over 90% of mercury is absorbed through the digestive tract and is mainly discharged into bile rather than into urine. With its half-life being 40-80, it is slowly excreted and is easily accumulated in the human body [2].

The general population without any experience of occupational exposure to mercury may develop acute/chronic mercury poisoning when they dwell in areas contaminated with mercury. A case in point is the Minamata disease in Japan [3].

Mercury poisoning leads to symptoms such as anorexia, nausea, and diarrhea. Chronic exposure to mercury results in emotional instabilities that entail intention tremor, speech disorder, cognitive dysfunction, and nervous exhaustion, affecting the central nervous system, kidneys, and the immune system and reportedly causing hereditary deformity and cancer [4,5].

Eating fish and shellfish has thus far been reported to be the main cause of mercury poisoning. In a study on fishermen in Australia, Canada, China, West Germany, Hong Kong, Italy, Japan, Monaco, Papua New Guinea, South Africa, the United Kingdom, and the United States, fishermen were found to have a significantly larger amount of organic mercury in their bodies than the general population due to their high average fish consumption [6]; the study also demonstrated eating fish increases the concentration of organic mercury in the blood and hair. Apostoli et al. [7] indicated that along with dental amalgam, fish consumption is the main

Corresponding author : Young Seoub Hong MD, PhD, 3-1 Dongdaesin-dong, Seo-gu, Busan, Korea, Tel : +82-51-240-2888, Fax : +82-51-253-5729, E-mail : yshong@dau.ac.kr
Received : 9 April 2010, Accepted : 29 June 2010

cause of occupational/environmental factors that influence mercury concentration.

Various studies have been made in many nations on mercury exposure levels and the criteria of exposure are increasingly lowered [8]. There have also been studies on the occupational mercury exposure of workers in some workplaces [9,10], a survey on the blood heavy metal concentration of Korean citizens [11], and the Ministry of Environment's (MOE) survey on hazardous substances in the body [12,13]. The MOE survey shows the blood mercury concentration of some residents in coastal areas exceeds the limit recommended by the World Health Organization (WHO). The cause for the high mercury exposure index is estimated to be fish consumption, given geographical characteristics, but the exact source of exposure has yet to be identified. For this reason, this study aims to examine the blood mercury concentration of residents in a large city in a coastal region and assess factors influencing the level of concentration. The focus of this study is to identify the residents' preference for fish and shellfish consumption known as the main cause of high blood mercury concentration and the correlation with weekly consumption frequency.

SUBJECTS AND METHODS

I. Study Subjects

This study was conducted on citizens aged 40 or above who visited the medical examination center of a major coastal city from June 2009 through October 2009. Survey subjects were classified by sex and age as variables known to affect blood mercury concentration. 333 subjects were selected through stratified random sampling ensuring the same ratio of intervals for men and women in their 40s, 50s, and 60s and analysis was made on 293 from among these who completed blood collection and survey. Before the survey, we provided sufficient explanations on this study to those surveyed and sought their voluntary consent; we also obtained approval from the Institutional Review Board of Dong-A University Medical Center.

II. Questionnaire Survey

A survey was conducted through 1:1 interviews between subjects and surveyors who completed training on the questionnaire in advance. With the aim of investigating mercury exposure, we developed a questionnaire covering demographic variables (e.g. sex and age), lifestyle factors (e.g. alcohol consumption and smoking), and mercury exposure-related factors (e.g. type of drinking water currently in use, fish consumption behavior, and cavity/amalgam treatment history for the past one year). Fish consumption behaviors were identified using items such as fish/shellfish preference and fish consumption frequency. The survey subjects also performed blood/kidney function tests to exclude from analysis those who had developed any mercury-related disease or are were of having any kidney disease.

III. Measurement of Blood Mercury Concentration

The venous blood of survey subjects who had not eaten for more than eight hours was collected with a 3 mL vacuum blood collection tube (Beckton Dickinson Vacutainer, Franklin lakes, NJ, USA) treated with EDTA to prevent blood coagulation. The blood was then transported with dry ice to be kept frozen at -70℃ until the analysis. The analysis on gross mercury content in the blood was carried out using frozen samples obtained two months prior. An analyzer (SP-3DS, NIC Co, Ltd., Tokyo, Japan) was used to apply the gold amalgamation method. The method decomposes the test samples via heating at high temperature to gasify mercury and collect/concentrate the material to a mercury collector made of a multi-porous substance coated with gold (Hg-Amalgam). This method is chosen for the present study because it directly quantifies Hg without performing wet decomposition of test samples and causes no mercury loss in the process of pre-treatment on the test samples, ensuring outstanding sensitivity and reproduction.

The blood samples were slowly thawed at room temperature immediately before the analysis, and a roll-mixer was used to mix them for 0.5-1 hours. All samples were pre-mixed and inserted in quantities of 100 mL to the sample boat, where additives (BHT, MHT) were applied.

10 mg of L-cysteine and 2 mL of nitric acid were used to produce a 0.001% L-cysteine solution. The 1000 ppm solution (Wako Pure Chemical Industry, Osaka, Japan) was then diluted with the L-cysteine solution to generate a 10 ppm solution. The solution was diluted again to 2 μg/L, 4 μg/L, 6 μg/L, and 8 μg/L, respectively, to produce standard samples, and a calibration curve was drawn.

Our laboratory obtained an "adequate" grade from the Korea Occupational Safety & Health Agency (KOSHA) for the quality management of mercury analysis on biological samples.

Table 1. General characteristics of subjects

Variable	Total (N=293) (Mean ± SD)	Male (N=147) (Mean ± SD)	Female (N=146) (Mean ± SD)	p*
Age (y)	54.29±8.73	54.61±8.83	53.97±8.65	0.54
	n (%)	n (%)	n (%)	
Frequency of alcohol consumption (wk)				
Never	136 (46.4)	41 (27.9)	95 (65.1)	<0.001
1	67 (22.9)	36 (24.5)	31 (21.2)	
≥ 2	90 (30.7)	70 (47.6)	20 (13.7)	
Smoking				
Non-smoker	163 (55.6)	29 (19.7)	134 (91.8)	<0.001
Ex-smoker	69 (23.6)	63 (42.9)	6 (4.1)	
Smoker	61 (20.8)	55 (37.4)	6 (4.1)	
Fish preference				
Yes	248 (84.6)	130 (88.4)	118 (80.8)	0.07
No	45 (15.4)	17 (11.6)	28 (19.2)	
Frequency of fish consumption (wk)				
Never	13 (4.4)	8 (5.4)	5 (3.4)	0.19
1	89 (30.4)	46 (31.3)	43 (29.5)	
2 - 3	140 (47.8)	74 (50.3)	66 (45.2)	
4 - 6	22 (7.5)	6 (4.1)	16 (11.0)	
7	29 (9.9)	13 (8.8)	16 (11.0)	
Past history of amalgam treatment				
Yes	18 (6.1)	8 (5.4)	10 (6.9)	0.62
No	275 (93.9)	139 (94.6)	136 (93.2)	

SD: standard deviation.
*p: p-value was calculated by a Chi-square test for categorical variables and by an independent t-test for continues variables.

IV. Statistical Analysis

The measured blood mercury concentration showed a skewed distribution, in line with a log-normal distribution, and hence the geometric mean was used after logarithmic conversion. To identify the general characteristics of survey subjects, a cross tabulation analysis was made on the basis of age groups by sex and other factors. An independent sample t-test and a one-way analysis of variance (ANOVA) were performed by using sex, age, alcohol consumption, smoking, fish/shellfish preference and frequency, and amalgam treatment as factors to determine blood mercury concentration. With blood mercury concentration as a dependent variable, a multiple regression analysis was conducted to identify levels of correlation and impact between individual variables considered. The level of significance for each screening was 5% ($p < 0.05$); all statistics were produced using the program SAS version 9.1 (SAS Inc., Cary, NC, USA).

RESULTS

I. General Characteristics of Subjects

The general characteristics of 293 subjects are suggested in Table 1. Their average age is 54.3±8.7, with little difference by gender (male 54.6±8.8, female 54.0±8.7; p=0.5409). Weekly alcohol consumption frequency differed between sexes in a statistically significant manner ($p<0.0001$), as the largest number of male respondents said they drank more than twice a week (70 persons; 47.6%) while a majority of women drank less than once a week (95 persons; 65.1%). Male and female subjects also showed statistically significant differences when it came to smoking ($p<0.0001$), with 63 men (42.9%) smoking and 134 women (91.8%) not smoking. As for fish/shellfish consumption preference, 130 male respondents (88.4%) and 118 female (80.8%) replied they liked to eat fish and shellfish, with no difference between sexes. As for weekly fish consumption frequency, those having fish/shellfish 2-3 times a week took up the largest proportion of both men (74 persons; 50.3%) and women (66 persons; 45.2%), demonstrating no difference by sex. 139 men (94.6%) and 136 women (93.2%) stated they had no experience of amalgam treatment for the past one year, and no difference was found between sexes.

II. Blood Mercury Concentration by Sex and Age

The geometric mean of blood mercury concentration for all survey subjects was 8.63 μg/L [range: 1.48-45.71

Table 2. Blood mercury concentration according to related factors

Unit : μg/L

Variable	Male			Female		
	GM (95%CI)	p*	Group†	GM (95%CI)	p*	Group†
Age (y)						
40 - 49	8.51 (7.08 - 10.23)	0.02	A	7.41(6.46 - 8.51)	0.68	
50 - 59	11.48 (10.00 - 13.18)		B	8.13 (6.76 - 10.00)		
≥ 60	9.12 (7.94 - 10.72)		AB	7.59 (6.46 - 8.71)		
Frequency of alcohol consumption (wk)						
Never	8.91 (7.59 - 10.72)	0.06		7.24 (6.61 - 8.13)	0.14	
1	8.51 (6.92 - 10.23)			8.13 (6.46 - 10.23)		
≥ 2	10.72 (9.55 - 12.02)			9.55 (7.08 - 12.88)		
Smoking						
Non-smoker	9.55 (7.41 - 12.02)	0.98		7.59 (6.92 - 8.32)	0.06	
Ex-smoker	9.55 (8.32 - 11.22)			8.71 (3.63 - 21.38)		
Smoker	9.77 (8.51 - 11.22)			12.88 (9.33 - 17.38)		
Fish preference						
Yes	10.00 (9.33 - 10.96)	0.03		8.13 (7.41 - 9.12)	0.007	
No	6.61 (4.57 - 9.55)			6.03 (4.79 - 7.41)		
Frequency of fish consumption (wk)						
Never	5.50 (3.39 - 8.91)	0.002	A	3.55 (1.62 - 7.94)	<0.001	A
1	9.33 (7.76 - 10.96)		AB	6.76 (5.75 - 7.94)		AB
2 - 3	9.55 (8.51 - 10.72)		AB	7.76 (6.76 - 8.91)		B
4 - 6	11.48 (6.92 - 19.50)		B	9.55 (7.59 - 12.02)		BC
7	14.45 (10.23 - 20.42)		B	11.22 (8.51 - 14.45)		C
Past history of amalgam treatment						
Yes	10.72 (7.24 - 15.85)	0.57		10.47 (6.76 - 16.60)	0.07	
No	9.55 (8.71 - 10.47)			7.59 (6.92 - 8.32)		
Total	9.55 (8.71 - 10.47)	-		7.76 (7.08 - 8.51)	-	

GM: geometric mean, CI: confidence interval.

*p: p-value was calculated by a one-way ANOVA for age, frequency of alcohol consumption, smoking, frequency of fish consumption and by independent t-test for fish preference, past history of amalgam treatment, †Group : post-hoc results after ANOVA by Tukey-Karmer grouping.

μg/L]. The blood mercury concentration of male subjects was 9.55 μg/L on average [range: 1.66-41.69 μg/L] and female 7.76 μg/L [range: 1.48-45.71 μg/L]. The average blood mercury concentration of men was shown to be higher than that of women, demonstrating statistically significant differences ($p<0.0001$).

The average blood mercury concentration levels of men varied by age in a statistically significant way ($p<0.05$): 8.51 μg/L [range: 1.66-25.70 μg/L] for men in their 40s; 11.48 μg/L [range: 3.98-41.69 μg/L] for those in their 50s; and 9.12 μg/L [range: 2.82-28.84 μg/L] for those in their 60s and older. Meanwhile, blood mercury concentration levels of women did not differ at a statistically significantly level by age: 7.41 μg/L [range: 1.95-18.62 μg/L] for women in their 40s; 8.13 μg/L [range: 1.48-45.71 μg/L] for those in their 50s; and 7.59 μg/L [range: 1.91-18.62 μg/L] for those in their 60s and older. Both men and women in their 50s, however, showed the highest average blood mercury concentration (Table 2).

III. Blood Mercury Concentration by Alcohol Consumption, Smoking, Fish Consumption, and Amalgam Treatment

There were no statistically significant differences in the average blood mercury concentration of men by weekly alcohol consumption frequency ($p=0.0614$): 8.91 μg/ L[range: 1.82-25.70 μg/L] for non-drinkers, 8.51 μg/L [range: 1.66-25.12 μg/L] for men drinking once a week, 8.51 μg/L [range: 1.66-25.12 μg/L] for those drinking twice a week, and 10.72 μg/L [range: 2.82-41.69 μg/L] for those drinking more than twice a week. The figures for women were: 7.24 μg/L [range: 1.48-18.62 μg/L] for non-drinkers, 8.13 μg/L [range: 1.95-45.71 μg/L] for women drinking less than once a week, and 9.55 μg/L [range: 3.47-43.65 μg/L] for those drinking more than twice a week. Blood mercury concentration seemingly increased in proportion to alcohol consumption frequency, but statistical significance was not demonstrated.

The average levels of blood mercury concentration by smoking were: 9.55μg/L [range: 1.82-28.84 μg/L] for male non-smokers, 9.55 μg/L [range: 2.82-41.69 μg/L]

Table 3. Multiple regression analysis about related factors with the blood mercury concentration

Variable	Male			Female		
	β	10β	p	β	10β	p
Constant	0.67	4.65	<0.001	0.66	4.60	<0.001
Age (y)						
40 - 49	0.00	1.00		0.00	1.00	
50 - 59	0.11	1.28	0.02	0.01	1.02	0.84
≥ 60	0.00	1.01	0.93	-0.01	0.97	0.79
Frequency of alcohol consumption (wk)						
1	-0.01	0.98	0.87	0.05	1.13	0.29
≤ 2	0.07	1.18	0.11	0.10	1.25	0.11
Never	0.00	1.00		0.00	1.00	
Smoke						
Smoker	-0.03	0.93	0.57	0.12	1.31	0.26
Ex-smoker	-0.05	0.90	0.37	0.03	1.08	0.73
Non-smoker	0.00	1.00		0.00	1.00	
Fish preference						
Yes	0.12	1.30	0.09	0.06	1.16	0.27
No	0.00	1.00		0.00	1.00	
Frequency of fish consumption (wk)						
1	0.13	1.35	0.15	0.21	1.63	0.06
2 - 3	0.13	1.36	0.15	0.25	1.78	0.04
4 - 6	0.23	1.71	0.06	0.34	2.18	0.009
7	0.31	2.03	0.005	0.41	2.57	0.002
Never	0.00	1.00		0.00	1.00	
Past history of amalgam treatment						
Yes	0.02	1.04	0.83	0.06	1.16	0.41
No	0.00	1.00		0.00	1.00	
R^2		0.202			0.200	

β: coefficient, R^2: R square.

for male former smokers, and 9.77 μg/L [range: 1.66 - 29.51 μg/L] for male smokers; and 7.59 μg/L [range: 1.48 - 43.65 μg/L] for female non-smokers, 8.71 μg/L [range: 4.79 - 45.71 μg/L] for female former smokers, and 12.88 μg/L [range: 9.12 - 18.20 μg/L] for female smokers. Blood mercury concentration tended to be greater for smokers, but this trend was not statistically significant.

The average levels of blood mercury concentration by fish/shellfish preference were: 10.00 μg/L [range: 2.82 - 41.69 μg/L] for the male fish preference group and 6.61 μg/L [range: 1.66 - 25.70 μg/L] for the male non-fish preference group; and 8.13 μg/L [range: 1.48 - 45.71 μg/L] for the female fish preference group and 6.03 μg/L [range: 1.91 - 14.79 μg/L] for the female non-fish preference group. Both men and women showed statistically significant differences between the fish preference group and non-fish preference group (male: p =0.0323, female: p=0.0067).

The blood mercury concentration levels of men increased gradually by fish/shellfish consumption frequency (p=0.0019): 5.50 μg/L [range: 1.66 - 10.47 μg/L] for those eating fish or shellfish 0 times a week; 9.33 μg/L [range: 1.82 - 41.69 μg/L] for once a week; 9.55 μg/L [range: 2.82-25.70 μg/L] for 2-3 times a week; 11.48 μg/L [range: 6.17 - 20.89 μg/L] for 4-6 times a week; and 14.45 μg/L [range: 3.39 - 29.51 μg/L] everyday. The concentration levels also increased gradually for women, showing statistically significant differences (p=0.0002): 3.55 μg/L [range: 1.91 - 7.94 μg/L] for those eating 0 times a week; 6.76 μg/L [range: 2.14 - 18.62 μg/L] for once a week; 7.76 μg/L [range: 1.48-43.65 μg/L] for 2-3 times a week; 9.55 μg/L [range: 4.47 - 16.22 μg/L] for 4-6 times a week; and 11.22 μg/L [range: 6.46-45.71 μg/L] everyday.

We analyzed the average levels of blood mercury concentration for the past year by amalgam treatment, and the results for both men and women demonstrated no statistical significance (male: p=0.5657, female: p=0.0731).

IV. Factors Influencing Blood Mercury Concentration

We conducted a multiple regression analysis, using factors found to have significant impact on mercury concentration in individual univariate analyses as independent variables, and the results are presented in Table 3.

After correcting the variables considered in the model,

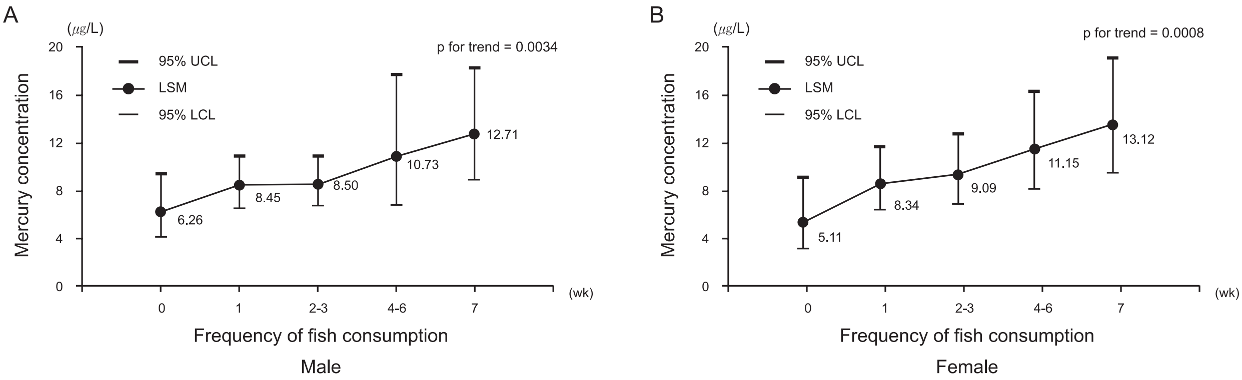

Figure 1. Blood mercury concentration according to frequency of fish consumption by sex group.
UCL: upper confidence limit, LSM: least square mean, LCL: lower confidence limit.

the average blood mercury concentration of male subjects was 1.28 times higher in those in their 50s than those in their 40s (p=0.0212). The level of blood mercury concentration was 2.03 times higher for men having fish and shellfish everyday than for those consuming fish/shellfish 0 times a week and was statistically significant (p=0.053). In the case of women, the average levels of blood mercury concentration for those consuming fish and shellfish 2-3 times a week (p=0.0410), 4-6 times a week (p=0.0090), and everyday (p=0.0019) after correcting the considered variables were 1.78 times, 2.18 times, and 2.57 times higher than those consuming fish and shellfish 0 times a week, respectively.

V. Dose - response Relationship between Fish/shellfish Consumption Frequency and Blood Mercury Concentration

Figures 1-A and 1-B represent the least squares of blood mercury concentration by weekly fish/shellfish consumption frequency after correcting variables such as age, alcohol consumption, smoking, fish/shellfish consumption preference, and amalgam treatment for the past year. The average levels of blood mercury concentration gradually showed a significant increase for male subjects (p for trend=0.0034): 6.26 μg/L for men having fish/shellfish 0 times a week; 8.45 μg/L for once a week; 8.50 μg/L for 2-3 times a week; 10.73 μg/L for 4-6 times a week; and 12.71 μg/L for everyday. Female subjects also demonstrated significant and gradually increasing differences in blood mercury concentration (p for trend=0.0008): 5.11 μg/L for women having fish/shellfish 0 times a week; 8.34 μg/L for once a week; 9.09 μg/L for 2-3 times a week; 11.15 μg/L for 4-6 times a week; and 13.12 μg/L for everyday.

DISCUSSION

This study has measured the average blood mercury concentration of 293 residents in a coastal city. The overall average was 8.63 μg/L (male: 9.55 μg/L, female: 7.76 μg/L). Another domestic study the 2005 National Blood Heavy Metal Concentration Survey conducted by the MOE on 2,000 Korean men and women aged 20 or above showed the average level of blood mercury concentration stood at 4.34 μg/L [11], while the figure was 3.80 μg/L in the 2nd National Survey on Hazardous Substances in the Human Body held in 2007 on 2,342 Korean men and women aged 18 or above [12]. In the 2008 National Survey on Hazardous Substances in the Human Body, held on 5129 men and women aged 20 or above, the average level of blood mercury concentration stood at 3.00 μg/L [13]. The figure was 3.19 μg/L in another similar study conducted in 2006 on 230 men and women dwelling in the southern, northern, and western parts of Seoul for over three years [14]. These results are lower than the findings of the present study. In the 2007 National Survey on Hazardous Substances in the Human Body, however, 62% of areas with the highest blood mercury concentration were coastal regions; the coastal areas were also found to have the highest level of blood mercury concentration in the 2008 survey. As this study has been targeted the residents of coastal areas, the results may be higher than that observed across the nation or in some inland areas. It also suggests a close correlation between blood mercury concentration and coastal areas.

There have also been active efforts in many countries to evaluate blood mercury concentrations: A Japanese survey held in 2007 on pregnant women reported the average level of blood mercury concentration to be 9.81 μg/L [range: 6.96-16.6μg/L] [15]; the figures were 8.5±

2.83 μg/L in an Egyptian study conducted in 2002 on the general public [16] and 9.1±0.4 μg/L in a Taiwanese study in 2007 [17]. Meanwhile, a U.S. study in 2003 showed the average levels of blood mercury concentration were 1.02 μg/L (95% CI=0.85-1.20 μg/L) for women aged between 16 and 49 and 0.34 μg/L (95% CI=0.30-0.39 μg/L) for infants aged 1-5 [18]. Another study in 2005 on reproductive women in the United States indicated that average blood mercury concentration stood at 1.8 μg/L [range: 0.1-21.4 μg/L] [19]; in a 2006 study on Polish citizens [20] and a 1991 study on the Norwegian general public [21], the numbers were 1.6 μg/L and 5.8 μg/L, respectively. A 2003 study on Danish ordinary citizens [22] and a 1988 study on Canadians [23] indicate relatively low levels of blood mercury concentration (1.38±1.00 μg/L and 1.10±0.85 μg/L). The average level of blood mercury concentration in the present study, 8.63 μg/L, is higher than the findings on ordinary citizens in the United States, Poland, Norway, Denmark, and Canada, lower than the results of Japanese pregnant women, and similar to those of Egyptian and Taiwanese people. These results represent regional differences in mercury exposure factors; the gross blood mercury concentration of residents in a coastal city in Korea is similar to that of coastal nations.

The average blood mercury concentration of all survey subjects in this study is 8.63 μg/L, which is higher than the HBM I standard of 5 μg/L suggested by WHO and the German Commission on Human Biological Monitoring (CHBM) as the threshold for causing no damage to the health of the general population and 5.8 μg/L as the standard set by the U.S. Environmental Protection Agency (EPA) as the level of blood mercury concentration that leads to no damage to the health of the general population throughout their lifetime. 252 subjects (86.0%) exceeded the mercury exposure threshold for the general population suggested by WHO and CHBM (5 μg/L); 232 (79.2%) went beyond the standard set by EPA (5.8 μg/L); and 46 (15.7%) exceeded the CHBM biological exposure limit that was calculated from toxicological and epidemiological studies and may affect sensitive individuals (15 μg/L). Against this backdrop, we believe the blood mercury concentration of residents in Korea's coastal areas is at a warning level and that more in-depth assessment of exposure factors and measures for comprehensive management are needed.

We have analyzed the average blood mercury concentration of survey subjects by demographical factors. Men (9.55 μg/L) showed higher blood mercury concentration than women (7.76 μg/L); the blood mercury concentration levels of both men and women in their 50s (male: 11.48 μg/L, female: 8.13 μg/L) were higher than those in their 40s (male: 8.51 μg/L, female: 7.41 μg/L) and those in their 60s and older (male: 9.12 μg/L, female: 7.59 μg/L). These results differed from the findings of previous studies that suggested average blood mercury concentration grew higher by age [24].

With respect to smoking, smokers showed higher blood mercury concentration (male: 9.77 μg/L, female: 12.88 μg/L) than non-smokers (male: 9.55 μg/L, female: 7.59 μg/L) and former smokers (male: 9.55 μg/L, female: 8.71 μg/L) regardless of sex. The results are consistent with those of previous studies [14,16,25,26] but were not statistically significant (male: $p=0.9827$, female: $p=0.0640$).

Mercury (Hg) can be naturally discharged into and exist in nature, but often times is released in massive volume as a result of industrial and agricultural activities, leading to environmental problems [1]. It flows into water bodies through various channels and is accumulated in organisms and affects the food chain. It has been reported that 80-90% of mercury in the human body comes from fish consumption [27]; 75-95% of mercury in the fish is organic mercury [28], and around 75% of mercury in the human blood is attributable to the inflow of organic mercury from fish consumption in the past 30 days [28-31]. In other words, consumption of fish and shellfish is the main source of human exposure to mercury.

This study has demonstrated that the blood mercury concentration of both male and female subjects gradually increased in a statistically significant manner as fish consumption frequency rose (male: $p=0.0019$, female: $p=0.0002$). We have also analyzed blood mercury concentration by weekly fish/shellfish consumption frequency by correcting factors such as age, alcohol consumption, smoking, fish/shellfish consumption preference, and amalgam treatment in the past year. Both men and women showed a gradual and statistically significant increase in average blood mercury concentration (male: p for trend=0.0034, female: p for trend=0.0008). These results are consistent with previous studies that pointed out the general population consuming more fish have higher mercury concentrations [6,19,32-34]; this positive correlation suggests that fish consumption has a considerable influence on the blood mercury concentration of residents in the coastal areas of Korea.

Fish/shellfish consumption frequency increased over age but blood mercury concentration was the highest among those in their 50s, potentially because fish consumption frequency did not reflect the sheer amount of fish consumption. Therefore, weekly fish/shellfish consumption frequency and exact consumption amounts should be examined to study their correlation with blood mercury concentration. There are also possibilities that biological differences of women and older population in mercury metabolism may have impacted the results. After correcting other variables, no trend characterized by a linear increase was found in blood mercury concentration by age, but an increase of blood mercury concentration of survey subjects in their 50s and in their 60s or older was clear compared to those in their 40s.

The present study results show the blood mercury concentration of residents in the coastal areas of Korea is higher than the internationally recommended level and that fish consumption may be the main source of mercury exposure.

In Korea, however, little information is currently available on the population potentially exposed to mercury and the impact of mercury on the human body. Active research has been recently undertaken to evaluate the human body's reactions to mercury dose, but further research will be needed to provide a clear answer given the complicated activities of the human body. The safe level of blood mercury concentration has recently changed with the introduction of new research findings, requiring further research and reassessment of relevant safety recommendations. International organizations are using a threshold (0.5 μg/g) for fish mercury levels in order to protect against dangerous exposure to mercury [9], but this limit is not adequate as a safety scheme for fish that human beings frequently consume. For this reason, active research is needed on the impact of mercury exposure and other environmental factors on the human body to assess such human body impacts not just in workplaces but also for the general population not subjected to direct mercury exposure and to establish guidelines to ensure the safety of fish and shellfish that human beings eat. As mercury exposure levels vary considerably by nation and region, potential sources of exposure should be managed and observed on a continued basis. In Japan, a survey on Japanese women aged between 34 and 65 conducted in 1994 prior to the introduction of the national guidelines on fish consumption reported the average level of blood mercury concentration to be 18.2 μg/L [35], while a more recent study held in 2003, after the guidelines were adopted, on pregnant women in Japan showed a much lower average blood mercury concentration of 9.81 μg/L [15]. This suggests the importance of fish consumption guidelines for the management of mercury exposure.

This study has the following limitations: First, the study targets the residents of a certain area who visited a medical examination center and thus they do not represent the general population of all cities across the nation. Second, fish consumption amount was estimated as fish consumption frequency based on a self-developed questionnaire without using the food frequency questionnaire (FFQ). Lastly, the mercury content by fish/shellfish types was not taken into account. Therefore, a FFQ should be carried out in the future to examine the exact amount of fish consumption and its correlation with blood mercury concentration. In addition, the amount of mercury contained in each fish/shellfish type should be investigated to study consumption amount, consumption frequency, and correlation with mercury concentration by fish/shellfish type. Future studies should also examine the correlation between fish consumption frequency and mercury concentration by accurately measuring the amount of organic mercury from among all mercury types contained in the blood.

This study has examined the current blood mercury concentration levels of residents of a coastal city along with other related factors. The study results indicate that the blood mercury concentration of both men and women is significantly correlated with their fish/shellfish preference and weekly consumption frequency, implying the lifestyle factors of individuals have the greatest impact on mercury exposure. In this regard, we believe this study provides meaningful findings on the mercury exposure of the general population as opposed to occupational exposure in the workplace. It is also believed to be a meaningful study that demonstrates the correlation between fish consumption and blood mercury level poisoning for the populations of some coastal urban areas. To reduce future mercury accumulation in the human body, a larger number of subjects should be surveyed, and their exposure to mercury should be assessed according to regional and environmental differences, individual dietary habits, and lifestyle.

ACKNOWLEDGMENTS

This study was supported by the Dong-A University fund.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare on this study.

REFERENCES

1. Navarro M, López H, Sánchez M, López MC. The effect of industrial pollution on mercury levels in water, soil and sludge in the coastal area of Montril, southeast Spain. *Arch Environ Contam Toxicol* 1993; 24(1): 11-15
2. WHO. *Environmental Health Criteria 1 : Mercury*. Geneva: World Health Organization; 1976, p. 94-131.
3. Harada M. Minamata disease: methylmercury poisoning in Japan caused by environmental pollution. *Crit Rev Toxicol* 1995; 25(1): 1-24.
4. Kim YS, Lee EJ, Bae SH, Ohtsuka R, Suzuki T. Mercury concentrations in pregnant women's hair in the Seoul area. *Korean J Environ Health* 1992; 18(1): 105-111. (Korean)
5. Magos L, Clarkson TW, Sparrow S, Hudson AR. Comparison of the protection given by selenite, selenomethionine and biological selenium against the renotoxicity of mercury. *Arch Toxicol* 1987; 60(6): 422-426.
6. Airey D. Total mercury concentration in human hair from 13 countries in relation to fish consumption and location. *Sci Total Environ* 1983; 31(2): 157-180.
7. Apostoli P, Cortesi I, Mangili A, Elia G, Drago I, Gagliardi T, et al. Assessment of reference values for mercury in urine: the results of an Italian polycentric study. *Sci Total Environ* 2002; 289(1-3): 13-24.
8. WHO/IPCS. Methylmercury *In Environmental Health Criteria 101*. Geneva: World Health Organization; 1990.
9. Park SB. *The Relationship between Amalgam Use and The Concentration of Urine Mercury of Workers in Dental Hospitals*[dissertation]. Daegu: Yeungnam University; 2009. (Korean)
10. Park JT, Kim KJ, Bang SH. A follow up study on the mercury concentration in air and in urine of workers after implementing controls of work environment in mercury vapor exposed industry. *J Korean Ind Hyg Assoc* 1994; 4(2): 198-207. (Korean)
11. Ministry of Environment. *Survey of Blood Heavy Metal Concentration in Koreans*. Seoul: Ministry of Environment; 2005. (Korean)
12. National Institute of Environmental Research. *Secondary Survey of in vivo Hazardous Materials Level in Koreans*. Incheon: National Institute of Environmental Research; 2007, p. 157-170. (Korean)
13. National Institute of Environmental Research. *Tertiary Survey of in vivo Hazardous Materials Level in Koreans*. Incheon: National Institute of Environmental Research; 2008, p. 240-246. (Korean)
14. Ho Mk, Lim YW, Lim JH, Yang JY, Shin DC. Association between blood mercury concentration and factor of health/life. *Korean J Environ Toxicol* 2006; 21(3): 229-238. (Korean)
15. Sakamoto M, Kaneoka T, Murata K, Nakai K, Satoh H, Akagi H. Correlations between mercury concentrations in umbilical cord tissue and other biomarkers of fetal exposure to methylmercury in the Japanese population. *Environ Res* 2007; 103(1): 106-111.
16. Mortada WI, Sobh MA, el-Defrawy MM, Farahat SE. Reference intervals of cadmium, lead, and mercury in blood, urine, hair, and nails among residents in Mansoura City, Nile delta, Egypt. *Environ Res* 2002; 90(2): 104-110.
17. Hsu CS, Liu PL, Chien LC, Chou SY, Han BC. Mercury concentration and fish consumption in Taiwanese pregnant women. *BJOG* 2007; 114(1): 81-85.
18. Schober SE, Sinks TH, Jones RL, Bolger PM, McDowell M, Osterloh J, et al. Blood mercury levels in US children and women of childbearing age, 1999-2000. *JAMA* 2003; 289(13): 1667-1674.
19. Vupputuri S, Longnecker MP, Daniels JL, Guo X, Sandler DP. Blood mercury level and pressure among US women: results from the National Health and Nutrition Examination Survey 1999-2000. *Environ Res* 2005; 97(2): 195-200.
20. Cole DC, Wainman B, Sanin LH, Weber JP, Muggah H, Ibrahim S. Environmental contaminant levels and fecundability among non-smoking couples. *Reprod Toxicol* 2006; 22(1): 13-19.
21. Brune D, Nordberg GF, Vesterberg O, Gerhardsson L, Wester PO. A review of normal concentrations of mercury in human blood. *Sci Total Environ* 1991; 100: 235-282.
22. Grandjean P, White RF, Weihe P, Jørgensen PJ. Neurotoxic risk caused by stable and variable exposure to methylmercury from seafood. *Ambul Pediatr* 2003; 3(1): 18-23.
23. Mahaffey KR, Mergler D. Blood levels of total and organic mercury in residents of the upper St. Lawrence River basin, Quebec: association with age, gender, and fish consumption. *Environ Res* 1988; 77(2): 104-114
24. Wennberg M, Lundh T, Bergdahl IA, Hallmans G, Jansson JH, Stegmayr B, et al. Time trends in burdens of cadmium, lead, and mercury in the population of northern Sweden. *Environ Res* 2006; 100(3): 330-338.
25. Siblerud RL, Kienholz E, Motl J. Evidence that mercury from silver dental fillings may be an etiological factor in smoking. *Toxicol Lett* 1993; 68(3): 307-310.
26. Kim NY. *Effects of Life-style on the Blood Mercury Levels in Korean* [dissertation]. Seoul: Chung-Ang University; 2009. (Korean)
27. Urieta I, Jalón M, Eguilero I. Food surveillance in the Basque Country(Spain). Ⅱ. Estimation of the dietary intake of organochlorine pesticides, heavy metals, arsenic, aflatoxin M1, iron and zinc through the Total Diet Study, 1990/91. *Food Addit Contam* 1996; 13(1): 29-52.
28. Mahafffery KR, Clicker RP, Bodurow CC. Blood organic

mercury and dietary mercury intake: National Health and Nutrition Examination Survey. 1999 and 2000. *Environ Health Perspect* 2004; 112(5): 562-570.
29. Falter R, Schöler HF. Determination of methyl-, ethyl-, phenyl and total mercury in Neckar River fish. *Chemosphere* 1994; 29(6): 1333-1338.
30. Morgan JN, Berry MR, Graves RL. Effects of commonly used cooking practises on total mercury concentration in fish and their impact on exposure assessments. *J Expo Anal Environ Epidemiol* 1997; 7(1): 119-133.
31. Storelli MM, Stuffler RG, Marcotrigiano GO. Total and methylmercury residues in tuna-fish from the Mediterranean sea. *Food Addit Contam* 2002; 19(8): 715-720.
32. Passos CJ, Mergler D, Lemire M, Fillion M, Guimarães JR. Fish consumption and bioindicators of inorganic mercury exposure. *Sci Total Environ* 2007; 373(1): 68-76.
33. Björnberg KA, Vahter M, Petersson-Grawé K, Glynn A, Cnattingius S, Darnerud PO, et al. Methyl mercury and inorganic mercury in swedish pregnant women and in cord blood: influence of fish consumption. *Environ Health Perspect* 2003; 111(4): 637-641.
34. Mahaffey KR, Clickner RP, Bodurow CC. Blood organic mercury and dietary mercury intake: National Health and Nutrition Examination Survey, 1999 and 2000. *Environ Health Perspect* 2004; 112(5): 562-570.
35. Yamamura Y, Yoshinaga Y, Arai F, Kishimoto T. Background levels of total mercury concentrations in blood and urine. *Sangyo Igaku* 1994; 36(2): 66-69.