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Menopause and Blood Mercury Levels: The Korea National Health and Nutrition Examination Survey (KNHANES) 2008–2011

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Abstract This study aimed to evaluate the association between menopause and blood mercury concentrations in South Korean women. Women aged ≥20 years who participated in the Korean National Health and Nutrition Examination Survey 2008–2011 were included in this study. Primary and secondary analyses included women aged ≥20 years (n= 1,642) and 45–55 years (i.e., perimenopausal; n=325), respectively. For all analyses, the mercury levels were log-transformed. The linear regression model for mercury levels was adjusted for age, body mass index, household income, menopausal status, hormone replacement therapy, use of oral contraceptives, smoking history, alcohol intake, physical activity, number of pregnancies, serum ferritin levels, and fish consumption. After adjusting for covariates, log-transformed blood mercury levels were significantly lower in women who were menopausal [β-coefficient −0.1488; 95 % confidence interval −0.2586, −0.0389; P=0.01) than in those who were premenopausal. A similar relationship was identified in perimenopausal women (β-coefficient −0.1753; 95 % confidence interval −0.3357, −0.015; P=0.03). The blood mercury concentration was lower in postmenopausal women than in premenopausal women. There was a significant positive correlation between blood mercury concentrations and both the frequency of alcohol intake and serum ferritin levels.

Keywords Alcohol · Ferritin · Menopause · Mercury

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Introduction

Various forms of mercury cause permanent damage to the brain and kidney, which can lead to fetal disorders (i.e., neurologic symptoms), anomaly, and death [1, 2]. The most notorious case of mercury poisoning was the Minamata disease in 1956 [3]. The main sources of mercury exposure in humans include fish and shellfish, dental amalgams, thermometers, and batteries [1, 4, 5]. Mercury accumulates in the kidney and brain for years, while the half-life of mercury in blood is only 1~3 months [1]. Therefore, blood mercury concentrations represent relatively current exposures to mercury.

The hormonal levels of a woman can vary throughout life, such as during premenarche, menarche, pregnancy, lactation, and menopause. The timing of natural menopause is influenced by extrinsic factors (i.e., smoking, oral contraceptives, and dietary intake) [6]. Although the causality is unclear, the timing of menopause is also related to the effects of several heavy metals (i.e., cadmium and lead) [7, 8]. It has been previously observed that mercury acts as estrogen; however, only a few studies have been conducted to assess the relationship between menopause and blood mercury concentration [9].

The aim of this study was to evaluate the association between menopause and blood mercury concentrations in a nationally representative sample in South Korea.

Materials and Methods

Study Population

Data from the Korean National Health and Nutrition Examination Survey (KNHANES), conducted between 2008 and 2011, were used for this study [10]. Originating in 1998,

KNHANES was an annual survey designed to evaluate the health and nutritional status of South Koreans for the Nation by the Korea Centers for Disease Control and Prevention. The survey consisted of health and nutrition interviews and physical examinations. The KNHANES 2008–2011 involved a complex, stratified, and a multistage probability cluster rolling survey sampling of the non-institutionalized South Korean population (n=37,753). Twenty families had been randomly selected from all 192 regions of South Korea each year and every family member had been included for the survey. The KNHANES 2008–2011 data of women ≥20 years (n=2,001) were used for this study to evaluate blood mercury levels. Women who underwent surgical menopause, had a history of hysterectomy or bilateral oophorectomy, or had missing information were excluded from the study. Finally, a total of 1642 participants aged ≥20 years were included in our analyses.

Data Collection

The physical examination included height, weight, and levels of blood mercury and serum ferritin. Data regarding age, household income, menopausal status, hormone replacement therapy, oral contraceptive use, smoking history, alcohol consumption, physical activity, and the number of pregnancies were collected during the health interview. Fish consumption was measured during the nutrition interview, which involved a 24-h dietary recall.

The body mass index (BMI; <18.5 kg/m^2, 18.5–24.9 kg/m^2, ≥25 kg/m^2), household income (quartiles of the participants in each year of the KNHANES), hormone replacement therapy (ever, never), oral contraceptive use (ever, never), smoking history (current, past, never), alcohol consumption (none, ≤1 drink/month, 2–4 drinks/month, ≥2 drinks/week), physical activity (hours of moderate exercise per week), and fish consumption (servings of fish per week; <1/week, 1/week, >1/week) were categorized according to a previous study [11]. Menopause was defined, by a health interview, as having no menstruation during the past 12 months. Premenopause was defined as having >1 menstruation during the past 12 months. The perimenopausal group included women who were aged 45–55 years, based on the average menopausal age (i.e., 50 years) according to KNHANES data.

Measurement of Mercury and Ferritin

Whole blood specimens were stored and shipped to the Neodin Medical Institute (Seoul, Republic of Korea). Blood mercury concentrations were measured using the Direct Mercury Analyzer (DMA-80; Milestone, Inc., Bergamo, Italy) with gold amalgamation. Serum ferritin concentrations were measured using the 1470 Wizard gamma-counter (PerkinElmer, Inc., Turku, Finland) with an immunoradiometric assay.

Statistical Analyses

Blood mercury levels were right-skewed (skewness 3.75) and log-transformed for analyses. Primary analyses were conducted for all women. Primary analyses consisted of three multivariable linear regression weighted models. The first linear regression model for log-transformed blood mercury levels was adjusted for age, BMI, household income, menopausal status, hormone replacement therapy, oral contraceptive use, smoking history, alcohol intake, physical activity, number of pregnancies, serum ferritin levels, and fish consumption. The second linear regression model for log-transformed blood mercury levels was adjusted for age, BMI, household income, menopausal status, alcohol intake, serum ferritin levels, and fish consumption. The third linear regression model for log-transformed blood mercury levels was adjusted for age, BMI, menopausal status, alcohol intake, and serum ferritin levels. Secondary analyses were conducted in a similar manner as primary analyses; however, the participants were restricted to women aged 45–55 years (i.e., perimenopausal group; n=325).

We performed all statistical analyses including the complex sampling design and weights in the KNHANES using the R survey package, Version 2.15.3 (The R foundation, Vienna, Austria). A P value <0.05 (two-tailed) was considered significant.

Ethics Statement

This research was approved by the MizMedi Hospital Institutional Review Board under the exempt category because the identities of all human subjects were protected by using anonymous identifications.

Results

The relationship between mean blood mercury concentrations and participants' characteristics for women ≥20 years (mean age 45.2 years, 95 % confidence interval (CI) 44.48, 45.92 years) and 45–55 years (mean age 49.52 years, 95 % CI 49.20, 49.83 years) are shown in Table 1. After log transformation, the blood mercury level was normally distributed. The geometric mean mercury concentrations were 3.77 μg/L (95 % CI 3.65, 3.89 μg/dL) in participants ≥20 years and 4.34 μg/L (95 % CI 4.07, 4.64 μg/dL) in participants aged 45–55 years. Although not statistically significant, the geometric mean blood mercury level in women ≥20 years was lower in menopausal women (3.73 μg/L; 95 % CI 3.54, 3.93) compared to women who were still menstruating (3.79 μg/L; 95 % CI 3.66, 3.93; Table 1). Similar findings were observed in women aged 45–55 years; the mean blood mercury level in

Table 1 The mean and 95 % confidence interval values of blood mercury concentrations (μg/L) of women ≥20 years, Korea, 2008–2011

Classification variables	20 years~				45~55 years			
	N	Blood mercury			*N*	Blood mercury		
		Geometric mean		*P*		Geometric mean		*P*
All	1642	3.77	(3.65–3.89)		325	4.34	(4.07–4.64)	
Age (years)				<0.01				0.03
20–29	329	3.41	(3.21–3.63)					
30–39	361	3.64	(3.47–3.83)					
40–49 (45–49)	320	4.31	(4.05–4.58)		154	4.64	(4.21–5.11)	
50–59 (50–54)	314	4.07	(3.86–4.30)		171	4.05	(3.75–4.37)	
≥60	318	3.53	(3.28–3.80)					
BMI				0.01				0.43
≤18.4	95	3.43	(3.08–3.82)		5	4.40	(2.04–9.52)	
18.5–24	1108	3.72	(3.60–3.84)		219	4.22	(3.92–4.53)	
≥25	439	4.01	(3.76–4.27)		101	4.64	(4.08–5.28)	
House income				<0.01				0.34
Q1	309	3.59	(3.34–3.86)		43	3.91	(3.26–4.70)	
Q2	428	3.62	(3.42–3.83)		79	4.11	(3.63–4.66)	
Q3	471	3.73	(3.55–3.93)		101	4.67	(4.13–5.29)	
Q4	434	4.09	(3.87–4.31)		102	4.37	(3.92–4.87)	
Menopause				0.61				0.02
No	1034	3.79	(3.66–3.93)		177	4.62	(4.25–5.04)	
Yes	608	3.73	(3.54–3.93)		148	3.98	(3.64–4.35)	
HRT				0.75				0.07
No	1518	3.77	(3.64–3.89)		282	4.43	(4.13–4.74)	
Yes	124	3.83	(3.47-4.23)		43	3.79	(3.23-4.44)	
OC				0.61				0.43
No	1316	3.76	(3.63–3.88)		261	4.29	(3.99–4.62)	
Yes	326	3.83	(3.57–4.12)		64	4.59	(3.95–5.32)	
Smoking status				0.08				0.25
None	1431	3.77	(3.65–3.90)		296	4.29	(4.01–4.60)	
Ever	106	3.51	(3.13–3.94)		10	4.71	(2.98–7.45)	
Current	105	4.08	(3.75–4.44)		19	4.99	(4.21–5.93)	
Alcohol status				<0.01				<0.01
None	566	3.54	(3.36–3.73)		121	3.97	(3.59–4.39)	
≤1/month	622	3.69	(3.54–3.85)		107	4.10	(3.71–4.53)	
2–4/months	309	4.06	(3.84–4.30)		66	4.92	(4.38–5.52)	
2≥weeks	145	4.48	(4.05–4.96)		31	5.57	(4.32–7.18)	
No. of pregnancy				<0.01				0.62
None	280	3.48	(3.27–3.70)		4	3.44	(1.82–6.49)	
1–2	429	3.69	(3.50–3.89)		90	4.14	(3.72–4.61)	
3–4	557	4.06	(3.85–4.27)		165	4.45	(4.03–4.92)	
≥5	376	3.70	(3.48–3.93)		66	4.46	(3.96–5.03)	

Values in parentheses are 95 % confidence intervals

BMI body mass index, *Hb* hemoglobin, *HRT* hormone replacement therapy, *OC* oral contraceptive, *SES* socioeconomic status

menopausal women was low (3.98 μg/L; 95 % CI 3.64, 4.35) compared to premenopausal women (4.62 μg/L; 95 % CI 4.25, 5.04; P=0.02; Table 1). After adjusting for covariates, the log-transformed blood mercury levels were significantly lower in menopausal women (β-coefficient −0.1488; 95 % CI −0.2586, −0.0389; P=0.01) than in premenopausal women

Table 2 Weighted linear mixed models of natural log-transformed blood mercury concentrations after adjusting for covariates among women in the Korea national health and nutrition examination survey, Korea, 2008–2011

Independent variables		20 years~				45~55 years			
		Beta coefficient (95 % CI)		*P*	R^2	Beta coefficient (95 % CI)		*P*	R^2
Model 1[a]					0.068				0.139
Menopause									
	No	0				0			
	Yes	−0.1488	(−0.2586~−0.0389)	0.01		−0.1753	(−0.3357~−0.015)	0.03	
Alcohol									
	None	−0.2357	(−0.3507~−0.1207)	<0.01		−0.2689	(−0.5182~−0.0196)	0.04	
	≤1/month	−0.1818	(−0.2911~−0.0725)	<0.01		−0.2603	(−0.5137~−0.0069)	0.04	
	2–4/months	−0.0729	(−0.1857~0.0399)	0.21		−0.0950	(−0.35~0.16)	0.42	
	≥2/weeks	0				0			
Serum ferritin		0.0008	(0.0001~0.0016)	0.02		0.0022	(0.0009~0.0035)	<0.01	
Model 2[b]					0.067				0.117
Menopause									
	No	0				0			
	Yes	−0.1458	(−0.2492~−0.0423)	0.01		−0.1598	(−0.3139~−0.0058)	0.04	
Alcohol									
	None	−0.2484	(−0.3587~−0.1381)	<0.01		−0.2729	(−0.5233~−0.0225)	0.03	
	≤1/month	−0.1912	(−0.2957~−0.0868)	<0.01		−0.2720	(−0.5246~−0.0194)	0.04	
	2–4/months	−0.0800	(−0.1907~0.0308)	0.16		−0.0963	(−0.358~0.1655)	0.27	
	≥2/weeks	0				0			
Serum ferritin		0.0008	(0.0001~0.0015)	0.02		0.0022	(0.0009~0.0036)	<0.01	
Model 3					0.044				0.100
Intercept		1.3422	(1.1703~1.5141)	<0.01		2.1123	(0.9991~3.2255)	<0.01	
Age		0.0053	(0.0018~0.0089)	<0.01		−0.0079	(−0.0308~0.0151)	0.5	
BMI									
	≤18.4	−0.1461	(−0.1433~−0.0068)	0.03		0.0213	(−0.707~0.7495)	0.95	
	18.5–24	−0.0751	(−0.2738~−0.0185)	0.03		−0.0878	(−0.2161~0.0405)	0.18	
	≥25	0				0			
Menopause									
	No	0				0			
	Yes	−0.1597	(−0.2631~−0.0563)	<0.01		−0.1656	(−0.3183~−0.013)	0.03	
Alcohol									
	None	−0.2563	(−0.3658~−0.1468)	<0.01		−0.2941	(−0.5465~−0.0418)	0.02	
	≤1/month	−0.1925	(−0.2962~−0.0887)	<0.01		−0.2884	(−0.5423~−0.0346)	0.03	
	2–4/months	−0.0840	(−0.1942~0.0263)	0.14		−0.1287	(−0.3897~0.1323)	0.33	
	≥2/weeks	0				0			
Serum ferritin		0.0008	(0.0001~0.0015)	0.03		0.0022	(0.0009~0.0035)	<0.01	

Values in parentheses are 95 % confidence intervals

CI confidence interval, *BMI* body mass index

[a] Covariates—age, body mass index, household income, hormone replacement treatment, use of oral contraceptive, smoking history, physical activity, number of pregnancies, and fish consumption

[b] Covariates—age, body mass index, household income, and fish consumption

(Table 2). A similar relationship was identified in women aged 45–55 years (β-coefficient −0.1753; 95 % CI −0.3357, −0.015; P=0.03).

The log-transformed blood mercury concentrations were significantly different according to the age group (i.e., women aged ≥20 years and 45–55 years) per 5 years (Table 1). After

adjusting for BMI, menopause, alcohol, and serum ferritin levels in model 3, the log-transformed blood mercury concentrations in women ≥20 years were significantly different according to the age group per 5 years (β-coefficient 0.0053; 95 % CI 0.0018, 0.0089; $P<0.01$), but not in women aged 45–55 years (Table 2).

An association of lower log-transformed blood mercury concentrations with lower BMI was shown in women ≥20 years after adjustment, but not in women who were 45–55 years (Table 2).

The frequency of alcohol intake had a positive correlation with log-transformed blood mercury levels in both groups (i.e., women aged ≥20 years and 45–55 years). Most notably, the mercury level in non-alcohol drinkers was markedly lower than frequent alcohol drinkers who were ≥20 years (β-coefficient −0.2357; 95 % CI −0.3507, −0.1207; $P<0.01$) and 45–55 years (β-coefficient −0.2689; 95 % CI −0.5182, −0.0196; $P=0.04$; Table 2).

After adjusting for all covariates in model 1, serum ferritin levels were significantly related with log-transformed blood mercury levels; for every 1 ng/mL increase in the serum ferritin concentration, the blood mercury level increased 0.008 μg/L (95 % CI 0.0001, 0.0016) in the ≥20 years group and 0.0022 μg/L (95 % CI 0.0009, 0.0035) in the 45–55 years group (Table 2).

In the ≥20 years group, the log-transformed blood mercury concentrations were lower in women who consumed fish <1 per week compared to those who consumed fish >1 per week (β-coefficient −0.1161; 95 % CI −0.1855, −0.0466; $P<0.01$). However, this finding was not observed in women aged 45–55 years (Table 2).

Discussion

Menopause and Blood Mercury

In this study, the association between menopause and blood mercury concentrations was evaluated in a nationally representative sample of South Korean adults. To our knowledge, this was the first study to evaluate the relationship between menopause and blood mercury levels. We found that menopausal women had lower blood mercury concentrations compared to premenopausal women. The exact reasons for this finding are currently unknown; however, a possible explanation is outlined below. Blood mercury concentrations are typically reflected by an exposure to organic mercury [4]. The majority of organic mercury originates from methylmercury, which is mostly derived from the consumption of fish and other seafood [4]. Therefore, blood mercury concentrations would reflect blood methylmercury concentrations [12]. About 95 % of methylmercury from fish or seafood is absorbed through the gastrointestinal tract [12, 13]. Methylmercury, which exists in vivo as a water-soluble complex linked to the sulfur atom of thiol ligands, can traverse the blood–brain barrier and be easily transported to other cells through the bloodstream [14].

Glutathione (GSH) has a key role in the secretion of mercury from the body. Erythrocyte GSH excretes methylmercury from cells according to its combination with methylmercury [14–17]. Therefore, approximately 90 % of the absorbed methylmercury is excreted through biliary secretion. GSH also plays an essential role in biliary excretion [12, 14, 18]. When biliary secretion of methylmercury is diminished during low levels of GSH, the excretion of methylmercury in the body or cells is also decreased [12, 14, 16, 15, 17, 18]. It has been found that menopausal women have lower erythrocyte GSH levels than premenopausal women [19, 20]. Therefore, we postulate that the excretion of methylmercury in the body is decreased in menopausal women.

In our study, the blood mercury concentrations were lower in women who were postmenopausal compared to those who were premenopausal, despite decreased excretion of methylmercury in the menopausal state. This raised the possibility of methylmercury accumulation in the cell. More studies are necessary to measure methylmercury concentrations of various cells during the premenopausal and postmenopausal period. In light the results of the present study, it would be necessary to consider the menopausal status of women when determining the normal range of mercury levels.

Alcohol and Blood Mercury

Several studies have been conducted to evaluate the relationship between alcohol and blood mercury levels. In a previous study, ingested alcohol inhibited the absorption of inhaled mercury vapor [21]. Similarly, alcohol was found to reduce mercury retention in humans exposed to mercury vapor in another study [22]. However, the main focus of these studies was mercury vapor levels, not blood mercury concentrations, which were evaluated in our study. Blood mercury concentrations reflect blood methylmercury concentrations, not mercury vapor. Therefore, it is not reasonable to compare our study findings with previous studies.

Martin et al. showed that alcohol reduced urinary mercury concentrations [23]. This effect could be explained by the diuretic effect of alcohol, which dilutes urinary mercury concentrate with water. However, reduced urinary mercury concentrations were maintained even when few alcohol units were consumed per week, causing a very weak diuretic effect. Therefore, the diuretic effect of alcohol is negligible. It can be explained that alcohol decreases urinary excretion of mercury and increases mercury concentrations in the body. This explanation has been supported by Lye et al. who showed that blood mercury concentration increases as alcohol consumption increases, which was consistent with the findings from

this study [24]. In our study, it was shown that women with higher log-transformed blood mercury concentrations had a higher frequency of alcohol intake after adjusting for other cofactors.

Ferritin and Blood Mercury

Ferritin is an intracellular protein, which is central to iron storage [25]. Zabiński et al. showed that mercury vapor increases serum ferritin levels [26]. However, Fonseca et al. observed that hair methylmercury concentrations were not associated with serum ferritin levels. Again, these studies did not involve an evaluation of blood mercury levels. To the best of our knowledge, no studies have been conducted to evaluate the relationship between blood mercury and serum ferritin levels, except for a study that was conducted using KNHANES data [27].

We observed a positive correlation between blood mercury and serum ferritin concentrations in this study. The exact mechanism for this positive correlation is currently known; however, possible explanations are described below. One of the reasons could be that the serum ferritin level is simply a confounding factor between blood mercury levels and menopause. Serum ferritin levels in women who are menopausal have been observed to be higher compared to those who are premenopausal because of the reduced menstrual blood loss during menopause [28]. However, blood mercury concentrations during menopause were lower than the premenopausal period, while serum ferritin levels during menopause was higher compared to premenopause [28]. The positive correlation between blood mercury and serum ferritin concentrations observed in this study was different from previous results, which may indicate that serum ferritin levels may not be a simple confounding factor. Another explanation could be that serum ferritin is a marker of inflammation against mercury. Mercury can cause various autoimmune and allergic diseases, which induce inflammation [29]. Serum ferritin is a known marker of acute and chronic inflammation in various conditions, such as infection, cancer, and autoimmune disorders [25]. Therefore, mercury might not only induce inflammation, but also increase serum ferritin concentrations. However, further studies will be needed to confirm this hypothesis.

Limitations

This study has some limitations. Firstly, we were not able to validate a causal relationship between menopause and mercury due to the cross-sectional nature of this study. It still remains unclear whether mercury levels are a determinant or an effect of menopause. Secondly, we did not evaluate the occupations of the participants in this study; certain occupations (i.e., dentists, industrial workers, and miners) should be considered when evaluating exposures to mercury. Thirdly, only blood mercury concentrations were evaluated in this study, not hair mercury concentrations. Although hair mercury concentrations provide information regarding long-term mercury exposures, blood mercury concentrations provide the most accurate information regarding recent mercury exposures [13, 30]. Therefore, the analysis of long-term mercury exposure was limited in this study.

Conclusion

In conclusion, blood mercury concentrations were lower in postmenopausal women compared to premenopausal women. A positive correlation was observed between blood mercury concentrations and both the frequency of alcohol intake and serum ferritin levels.

Conflict of Interest None declared.

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