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Representative levels of blood lead, mercury, and urinary cadmium in youth: Korean Environmental Health Survey in Children and Adolescents (KorEHS-C), 2012–2014

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ABSTRACT

Background: This study examined levels of blood lead and mercury, and urinary cadmium, and associated sociodemographic factors in 3–18 year-old Korean children and adolescents.

Materials and methods: We used the nationally representative Korean Environmental Health Survey in Children and Adolescents data for 2012–2014 and identified 2388 children and adolescents aged 3–18 years. The median and 95th percentile exposure biomarker levels with 95% confidence intervals (CIs) were calculated. Multivariate regression analyses were performed on log transformed exposure biomarker levels adjusted for age, sex, area, household income, and father's education level. The median exposure

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Blood lead
Blood mercury
Urinary cadmium

biomarker levels were compared with data from Germany, the US, and Canada, as well as the levels of Korean children measured at different times.

Results: The median levels of blood lead and mercury, as well as urinary cadmium were 1.23 μg/dL, 1.80 μg/L, and 0.40 μg/L (95% CIs, 1.21–1.25, 1.77–1.83, and 0.39–0.41, respectively). The blood lead levels were significantly higher in boys and younger children ($p < 0.0001$) and children with less educated fathers ($p = 0.004$) after adjusting for covariates. Urinary cadmium level increased with age ($p < 0.0001$). The median levels of blood mercury and urinary cadmium were much higher in Korean children and adolescents than those in their peers in Germany, the US, and Canada. Blood lead levels tended to decrease with increasing age and divergence between the sexes, particularly in the early teen years. Median levels of blood lead and urinary cadmium decreased since 2010.

Conclusion: Sociodemographic factors, including age, sex, and father's education level were associated with environmental exposure to heavy metals in Korean children and adolescents. These biomonitoring data are valuable for ongoing surveillance of environmental exposure in this vulnerable population.

1. Introduction

Environmental exposure to heavy metals is a known cause of a range of developmental disabilities in children (Stein et al., 2002). A low concentration of lead in the blood is a risk factor for attention deficit hyperactivity disorder among Korean children (Ha et al., 2009). Blood lead concentration is inversely correlated with arithmetic and reading scores in US children and adolescents at concentrations <5.0 μg/dL (Lanphear et al., 2000). Mercury is a neuro, nephro, and immunotoxic element that places the developing fetus and young children at particular risk (Bose-O'Reilly et al., 2010). A US study showed that children with higher urinary cadmium concentrations have an increased risk for learning disability and special education needs (Ciesielski et al., 2012).

Children are particularly susceptible to environmental exposure to heavy metals due to their physical and biological characteristics compared with adults (Morello-Frosch et al., 2011). Children have higher ratios of skin surface area to body weight and their susceptibility to environmental toxicants is associated with differences in rates of absorption, distribution, metabolism, and excretion of toxicants (Faustman et al., 2000). Children also have increased exposure to environmental toxicants because they play outside, frequently place their hands in their mouth, and have increased skin contact with surfaces via crawling. Moreover, their exposure to environmental hazards occurs by inhalation, dermal contact, and ingestion (Hubal et al., 2000; Levin et al., 2008).

Children spend most of their time at home; therefore, sources of environmental exposure in the living space are particularly important (Hornberg and Pauli, 2007). Furthermore, the socioeconomic status of a child affects their environmental exposure to toxicants and their susceptibility characteristics given a certain level of exposure to a harmful environment (Kohlhuber et al., 2006).

We conducted a nationally representative biomonitoring project in children and adolescents in Korea to examine the status of environmental exposure to lead, mercury, and cadmium based on sociodemographic factors. This study primarily aimed to report the representative levels of blood lead and mercury and urinary cadmium in Korean children and adolescents aged 3–18 years and secondarily to show the distributions associated with sociodemographic factors including age, sex, household income, area of residence, and father's education level using the 2012–2014 Korean Environmental Health Survey in Children and Adolescents (KorEHS-C).

2. Materials and methods

2.1. Study subjects

We used the 2012–2014 KorEHS-C data to investigate blood lead and mercury levels, as well as urinary cadmium in Korean children and adolescents. The KorEHS-C is the first nationwide representative survey on the environmental health of children and adolescents in Korea, and a detailed description of the study design, protocol, and the field work has been provided previously (Ha et al., 2014). The KorEHS-C used an institution-based sampling strategy to represent all children and adolescents in Korea, i.e., based on school, kindergarten, and child-care facilities in which 97.5% of children and adolescents aged 6–18 years and 87.5% pre-school children aged 3–5 years among whole population identified in the 2010 National census attended. The sampling units were stratified by area, school grade, and age, and 120 schools and 63 kindergartens and child-care facilities were selected randomly.

We identified 2388 children and adolescents aged 3–18 years for this study. Blood lead and mercury levels were determined for the 2346 participants and urinary cadmium levels were taken for 2379. Instead of blood cadmium, urinary cadmium levels were determined because they represent chronic exposure, whereas blood cadmium concentration is an indicator of current exposure.

This study was approved by the Institutional Review Board of Dankook University Hospital and a written consent was obtained from the students' parents or guardians before enrollment.

2.2. Lead, mercury, and cadmium measurements

Venous blood (10–15 mL) was collected from all participants. Whole blood for the lead level measurements was frozen, stored at −20 °C, and then thawed and prepared for assay using an atomic absorption spectrometer-graphite furnace (Analyst 900-Zeeman collection, Perkin Elmer, Singapore). The blood samples for mercury determination were stored at −70 °C until analysis and were analyzed by flow injection cold-vapor atomic absorption spectrometry (DMA-80; Milestone, Bergamo, Italy). Details of the methods were described previously (Ha et al., 2014). Urinary cadmium level was measured in the first morning spot urine in children and adolescents in schools and in 12-h urine of pre-school children by inductively coupled plasma mass spectrometry (ICP-DRC-MS II; PerkinElmer). The detection limit was 0.20 μg/L.

Commercial reference materials were obtained from Bio-Rad for internal quality assurance and control (Lyphocheks Whole Blood Metals Control; Bio-Rad, Hercules, CA, USA). The laboratory passed the German External Quality Assessment Scheme operated by Friedrich-Alexander University, and the Quality Assurance Program operated by the Korea Occupational Safety and Health Agency as part of external quality assurance and control.

2.3. Sociodemographic factors

Sociodemographic data were collected using a questionnaire administered to parents or guardians of all age groups, teach-

Table 1
Sociodemographic characteristics of study population of Korean Environmental Health Survey in Children and Adolescents, 2012–2014.

Characteristics	N	(%)
Age (years)		
3–5	427	17.9
6–11	958	40.1
12–18	1003	42.0
Gender		
Male	1228	52.2
Female	1160	47.8
School grade		
Preschool	576	24.1
Elementary (Lower grades)	449	13.7
Elementary (Upper grades)	462	18.1
Middle	444	22.6
High	457	21.6
Area		
Seoul Metropolitan	365	17.2
Urban	1364	68.0
Rural	659	14.8
Household income (%)[a]		
Low	314	13.1
Middle low	847	35.5
Middle high	797	33.4
High	381	16.0
Unknown	49	2.1
Father's education (years)		
≤12	891	37.3
≥13	1458	61.1
Unknown	39	1.6

[a] Household income (10^3 KRW/month) classified as Low (< 2000), Middle low (2000–< 4000), Middle high (4000–< 6000), and high (≥ 6000).

ers for preschoolers, and the students themselves for the middle and high schoolers. The participants were divided into 3–5, 6–11, and 12–18-year age groups in analysis. They were also divided into preschool, lower elementary, upper elementary, middle, and high school groups. Area of residence was categorized into Seoul metropolitan, urban, or rural. Household income (10^3 KRW/month) was classified as low (<2000), middle-low (2000–3999), middle-high (4000–5999), and high (≥6000). Father's education level was divided into ≤12 years of education and ≥13 years of education.

2.4. Statistical analysis

The distribution of exposure biomarkers is presented as median and 95th percentile (P95) levels of blood lead, blood mercury, and urinary cadmium with 95% confidence intervals (CIs) according to the study subject characteristics. The survey analysis accounted for the complex sampling methods was applied only to the each category of age groups because of a different sampling unit and frame between the 3–5-year-old group (based on kindergartens and child-care facilities) and the and others age groups (based on schools). We detected differences between or among groups using the *t*-test or analysis of variance. Multivariate linear regression models were used to explore the associations between log transformed levels of exposure biomarkers and the demographic factors. Data analyses were conducted using SPSS ver. 22 (IBM Corp., Armonk, NY, USA) and R ver. 3.0.3 (R Core Team, 2012).

3. Results

Table 1 shows the sociodemographic characteristics of the 2388 children and adolescents included in the study. About 42% of the subjects were in the 12–18-year age group and 52% were male. About 24% were in the preschool group, and 68% resided in an urban area; 35.5% of all participants were from middle-low income households and 33.4% were from middle-high income households; 61.1% of families had a father with ≥13 years of education.

Table 2 presents the median and P95 levels for blood lead and mercury, as well as urinary cadmium. The median levels of blood lead and mercury, as well as urinary cadmium were 1.23 μg/dL, 1.80 μg/L, and 0.40 μg/L (95% CIs, 1.21–1.25, 1.77–1.83, and 0.39–0.41, respectively). The median levels of all three biomarkers differed significantly among the age groups and school grades; lead levels were higher in younger children, whereas mercury and cadmium levels were higher in older children. Blood lead levels differed between boys and girls. Urinary cadmium level differed by father's education level. The distributions of the blood lead and mercury levels (Tables S1and S2) as well as urinary cadmium (Table S3) are presented by age group and sex.

Table 3 summarizes the results of multivariate regression analyses. Blood lead levels were significantly higher in boys and younger children ($p < 0.0001$) and children with less educated father ($p = 0.004$) after adjustment for each other. None of the sociodemographic variables was associated with blood mercury level. Urinary cadmium level increased with age ($p < 0.0001$). The age-distributions for blood lead and mercury, as well as urinary cadmium levels are illustrated by sex in Fig. 1.

4. Discussion

We obtained representative levels of blood lead (1.23 μg/dL), mercury (1.80 μg/L), and cadmium (0.40 μg/L) in a national sample of Korean children and adolescents aged 3–18-years in 2012–2014. Younger males had higher blood lead levels, whereas older children had higher blood mercury and urinary cadmium levels. In addition, higher blood lead levels were detected in children with a less educated father.

Lead and cadmium levels in Korean children tended to decrease in the past 8 years whereas mercury levels did not change (Fig. 2) although the levels of three heavy metals in Korean children seem to be still higher than those in other industrialized countries (Table 4).

Blood lead levels were more affected by socioeconomic factors, compared with those of mercury and urinary cadmium. Of all three heavy metals examined, lead exposure appears to have been the most extensively studied in relation to socioeconomic status of children. Previous studies have investigated the associations between lead levels and socioeconomic status. Blood lead levels in Korean children are significantly higher in children with lower socioeconomic status and lower household income (Ha et al., 2009; Lim et al., 2015b), which is consistent with findings for children in the US and Europe (Bolte et al., 2010; Pirkle et al., 1998). Concerns have been raised that chronic exposure to low levels of lead is a public health issue, particularly among socioeconomically disadvantaged groups, even in developed countries (Tong et al., 2000). Living in older houses and in low income households remain major risk factors for higher lead levels in US children (Gould, 2009; Jones et al., 2009).

In our analysis, blood lead levels were significantly higher in children with less educated fathers. The inverse correlation between children's blood lead levels and their parent's educational levels is consistent with findings from previous studies (Ha et al., 2014, 2009).

Previous studies suggest that the characteristics of a residential area may be associated with environmental exposure to toxicants by children, as lead poisoning in US children occurs more frequently in old housing and in families with low rates of home ownership (Sargent et al., 1995) and German children living in areas with greater environmental burdens (Hornberg and Pauli, 2007).

We showed that blood lead levels in children decreased with increasing age, whereas urinary cadmium levels increased. The higher blood lead levels are likely to be due to the frequent hand-

Table 2
Levels of blood lead, mercury and urinary cadmium by subjects' characteristics in Korean Environmental Health Survey in Children and Adolescents, 2012–2014.

	Lead (μg/dL) (N = 2346)				Mercury (μg/L) (N = 2346)				Cadmium (μg/L) (N = 2379)			
Variables	Median	(95% CI)	P95	(95% CI)	Median	(95% CI)	P95	(95% CI)	Median	(95% CI)	P95	(95% CI)
Age (years)												
All ages, 3–19	1.23	(1.21, 1.25)	2.14	(2.10, 2.21)	1.80	(1.77, 1.83)	3.68	(3.51, 3.88)	0.40	(0.39, 0.41)	1.07	(1.01, 1.14)
3–5	1.34	(1.27, 1.41)	2.28	(2.08, 2.50)	1.65	(1.56, 1.74)	3.24	(2.86, 3.66)	0.39	(0.35, 0.44)	1.37	(1.23, 1.53)
6–11	1.26	(1.24, 1.31)	2.12	(2.03, 2.27)	1.86	(1.81, 1.92)	3.94	(3.64, 4.20)	0.37	(0.35, 0.38)	0.84	(0.79, 0.94)
12–18	1.14	(1.11, 1.17)	2.09	(1.93, 2.18)	1.86	(1.79, 1.92)	3.62	(3.43, 3.88)	0.44	(0.42, 0.46)	1.00	(0.92, 1.11)
p-value		<0.0001				<0.0001				<0.0001		
Gender												
Male	1.31	(1.28, 1.34)	2.23	(2.17, 2.34)	1.77	(1.71, 1.83)	3.73	(3.47, 3.98)	0.41	(0.39, 0.43)	1.07	(0.99, 1.18)
Female	1.15	(1.12, 1.17)	2.05	(1.98, 2.11)	1.82	(1.78, 1.88)	3.61	(3.39, 3.86)	0.61	(0.57, 0.64)	1.58	(1.39, 1.83)
p-value		<0.0001				0.32				0.02		
School grade												
Preschool	1.33	(1.29, 1.37)	2.29	(2.14, 2.54)	1.65	(1.57, 1.71)	3.27	(3.05, 3.74)	0.42	(0.39, 0.47)	1.40	(1.29, 1.52)
Elementary (Lower grades)	1.31	(1.26, 1.36)	2.12	(2.04, 2.35)	1.81	(1.71, 1.89)	3.88	(3.43, 4.20)	0.34	(0.32, 0.37)	0.85	(0.79, 0.98)
Elementary (Upper grades)	1.22	(1.17, 1.26)	2.10	(1.98, 2.34)	1.90	(1.82, 1.99)	3.90	(3.62, 4.21)	0.37	(0.35, 0.40)	0.86	(0.81, 1.01)
Middle	1.21	(1.15, 1.26)	2.19	(2.09, 2.38)	1.92	(1.83, 2.04)	3.72	(3.42, 4.16)	0.45	(0.42, 0.47)	0.92	(0.87, 1.04)
High	1.06	(1.02, 1.12)	1.83	(1.73, 2.08)	1.82	(1.69, 1.89)	3.59	(3.28, 3.94)	0.45	(0.42, 0.49)	1.01	(0.92, 1.24)
p-value		<0.0001				<0.0001				0.001		
Area												
Seoul metropolitan	1.19	(1.13, 1.24)	2.26	(2.13, 2.79)	1.67	(1.60, 1.78)	3.72	(3.18, 4.15)	0.39	(0.36, 0.43)	1.04	(0.99, 1.22)
Urban	1.24	(1.22, 1.28)	2.13	(2.07, 2.21)	1.82	(1.79, 1.89)	3.71	(3.49, 3.96)	0.39	(0.38, 0.41)	1.08	(0.99, 1.17)
Rural	1.24	(1.19, 1.28)	2.12	(2.01, 2.34)	1.83	(1.74, 1.89)	3.61	(3.33, 4.07)	0.42	(0.41, 0.46)	1.06	(0.96, 1.18)
p-value		0.66				0.10				0.60		
Household income†												
Low	1.23	(1.14, 1.31)	2.18	(2.06, 2.38)	1.84	(1.71, 1.98)	3.78	(3.39, 4.22)	0.41	(0.38, 0.47)	0.94	(0.91, 1.26)
Middle low	1.18	(1.15, 1.24)	2.06	(1.98, 2.26)	1.83	(1.76, 1.91)	3.48	(3.26, 3.96)	0.40	(0.38, 0.43)	0.91	(0.84, 1.01)
Middle high	1.19	(1.15, 1.24)	2.04	(1.93, 2.19)	1.90	(1.84, 1.99)	3.96	(3.64, 4.82)	0.39	(0.37, 0.42)	0.98	(0.85, 1.06)
High	1.22	(1.17, 1.28)	2.15	(1.92, 3.10)	1.88	(1.79, 2.03)	3.78	(3.51, 4.17)	0.41	(0.38, 0.47)	0.91	(0.81, 0.99)
Unknown	1.33	(1.29, 1.37)	2.29	(2.14, 2.54)	1.65	(1.58, 1.69)	3.27	(3.05, 3.74)	0.41	(0.38, 0.45)	1.37	(1.28, 1.51)
p-value		0.99				0.37				0.61		
Father's education (years)												
≤12	1.21	(1.17, 1.25)	2.16	(2.04, 2.26)	1.85	(1.79, 1.94)	3.83	(3.48, 3.98)	0.42	(0.40, 0.45)	0.96	(0.89, 1.09)
≥13	1.19	(1.16, 1.23)	2.06	(1.97, 2.14)	1.87	(1.82, 1.92)	3.78	(3.59, 4.16)	0.38	(0.37, 0.41)	0.91	(0.85, 0.98)
Unknown	1.33	(1.29, 1.36)	2.29	(2.14, 2.63)	1.65	(1.57, 1.69)	3.26	(3.03, 3.74)	0.42	(0.39, 0.46)	1.39	(1.29, 1.55)
p-value		0.23				0.25				0.01		
Mother's education (years)												
≤12	1.22	(1.19, 1.25)	2.14	(2.01, 2.19)	1.87	(1.82, 1.93)	3.82	(3.43, 3.97)	0.41	(0.39, 0.43)	0.94	(0.89, 1.03)
≥13	1.17	(1.15, 1.22)	2.06	(1.95, 2.16)	1.86	(1.81, 1.93)	3.78	(3.61, 4.19)	0.39	(0.38, 0.41)	0.91	(0.84, 0.99)
Unknown	1.33	(1.29, 1.36)	2.29	(2.17, 2.63)	1.65	(1.58, 1.71)	3.28	(3.09, 3.74)	0.41	(0.39, 0.45)	1.39	(1.29, 1.52)
p-value		0.84				0.22				0.12		

LOD; Limit of Detection, 0.149 for lead, 0.121 for mercury, 0.031 for cadmium in children aged 3–5; 0.189 for lead, 0.200 for mercury, 0.071 for cadmium in children and adolescents aged 6–18. The values less <LOD replaced by LOD/$\sqrt{2}$. Detection rate were 100% for lead, 100% for mercury, 99.6% for cadmium in children aged 3–5; 100% for lead, mercury and cadmium in children and adolescents aged 6–18.

Household income (10^3 KRW/month) classified as Low (< 2000), Middle low (2000–< 4000), Middle high (4000–< 6000), and high (≥ 6000).

The values calculated using the survey data analysis only for age groups 3–5, 6–11, and 12–18.

Table 3
Multivariate regression analysis for blood lead, mercury and urinary cadmium (log transformed) in children and adolescents aged 3–18, Korean Environmental Health Survey in Children and Adolescents, 2012–2014.

	Lead (μg/dL) (N = 2346)		Mercury (μg/L) (N = 2346)		Cadmium (ug/L) (N = 2379)	
Variables	β	*p*-value	β	*p*-value	β	*p*-value
Age (years)	−0.03	<0.0001	−0.002	0.71	0.01	<0.0001
Female (versus Male)	−0.19	<0.0001	−0.03	0.27	0.0001	1.00
Area (versus Rural)						
Seoul Metropolitan	−0.06	0.25	−1.42	0.16	0.07	0.35
Urban	−0.04	0.25	0.61	0.54	−0.09	0.09
Household income (versus Low)						
Middle low	−0.03	0.38	−0.04	0.96	0.03	0.57
Middle high	−0.02	0.60	0.01	0.86	0.004	0.94
High	−0.004	0.93	0.02	0.36	−0.02	0.77
Father's education (versus ≤12 years)						
≥13 years	−0.06	0.004	0.01	0.57	−0.05	0.16

Household income (10^3 KRW/month) classified as Low (< 2000), Middle low (2000–< 4000), Middle high (4000–< 6000), and high (≥ 6000).

to-mouth activities of children, which increases lead exposure via soil and dust. Younger children are at much higher risk for higher lead levels in the US (Jones et al., 2009) and Germany (Seifert et al., 2000). Cadmium has a long half-life of several tens of years. It accumulates in the kidney cortex and concentrations increase with age (Vahter et al., 2007). The impact of age on urinary cadmium levels observed in our study appeared to continue into adulthood according to a previous study conducted among Korean adults (Son et al., 2009).

We showed that blood lead levels were higher in boys than in girls, which is consistent with findings of previous studies conducted among children in Korea (Lim et al., 2015b), Sweden

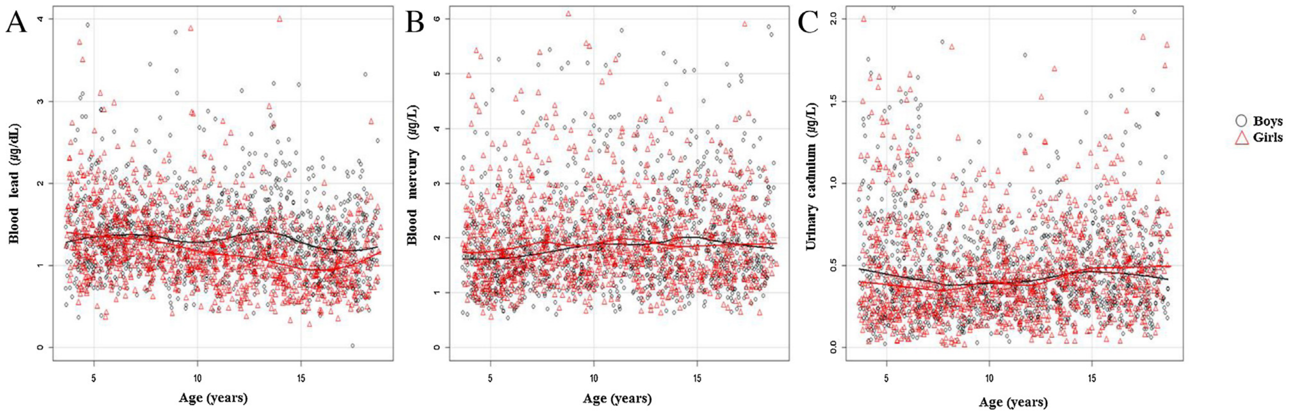

Fig. 1. Age-distribution of blood lead, mercury and urinary cadmium levels by gender in the Korean Environmental Health Survey in Children and Adolescents, 2012–2014. (A) Blood lead (ug/dL), (B) blood mercury (ug/L), (C) urinary cadmium (ug/L); black circles for boys and red triangles for girls. Lines were smoothing for each gender. Parameters (p value) estimated for age in the multivariate regression model adjusted for gender, area, and father's education were −0.03 (<0.0001) for lead (A), −0.002 (0.71) for mercury (B), and 0.01 (<0.0001) for cadmium (C). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

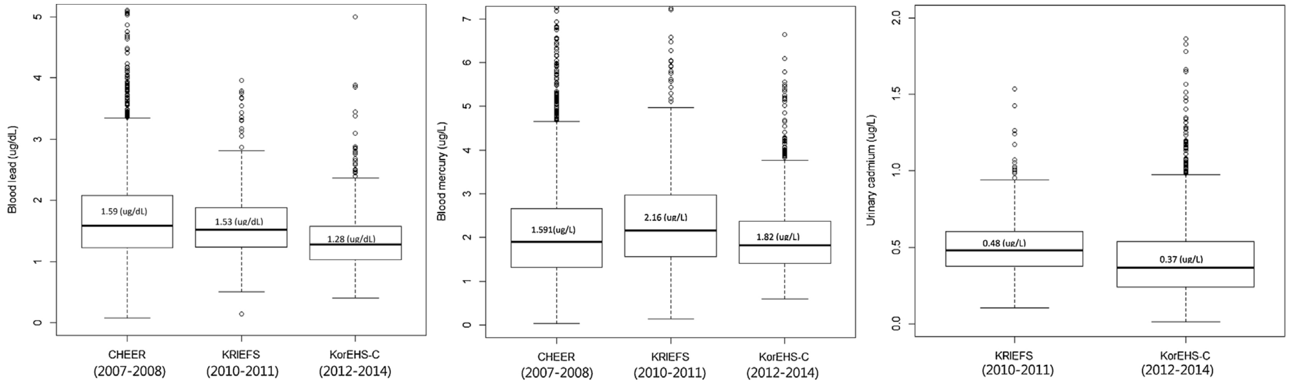

Fig. 2. Comparison of blood lead and mercury, and urinary cadmuim levels between 2007–2008, 2010–2011, and 2012–2014 in Korean children aged 6–11. CHEER: Children's Health and Environmental Research, 3376 children aged 6–11 at the second wave of the study for 2007 and 2008 were included. KRIEFS: Korean Research Project on the Integrated Exposure Assessment to Hazardous Materials for Food Safety, 505 children aged 6–11 for 2010–2011 were included. KorEHS-C: Korean Environmental Health Survey in Children and Adolescents, 958 children aged 6–11 for 2012–2014 were included. Boxes indicate 25th, 50th (solid line), and 75th percentiles, and whiskers indicate minimum and maximum excluding outliers (circles; a few, not shown in the figure but included in all the calculations). Numbers inside boxes indicate the median level of biomarkers.

Table 4

The levels of blood lead, mercury, and urinary cadmium in children and adolescents in Germany, US, Canada and Korea.

	Years	GerES-IV	NHANES IV	CHMS cycle 3	KorEHS-C
Survey years		2003–2006	2009–2010	2012–2013	2012–2014
Subjects' age (years)		3–14	1–19	3–19	3–18
Number of subjects		1551–1734	378–1183	1958–2453	2388
Level of heavy metals (P50)*					
Blood lead (μg/dL)	3–5	1.96	(1–5 years) 1.15	0.72	1.34
	6–11	(6–8 years) 1.79 (9–11 years) 1.56	0.81	0.67	1.26
	12–19	(12–14 years) 1.46	0.66	0.60	(12–18 years) 1.14
Blood mercury (μg/L)	3–5	0.2	(1–5 years) <LOD	<LOD	1.65
	6–11	(6–8 years) 0.2 (9–11 years) 0.2	0.36	<LOD	1.86
	12–19	(12–14 years) 0.3	0.45	<LOD	(12–18 years) 1.86
Urinary cadmium (μg/L)	3–5	0.06	–	0.25†	0.39
	6–11	(6–8 years) 0.07 (9–11 years) 0.08	0.06	0.27†	0.37
	12–19	(12–14 years) 0.09	0.08	0.30†	(12–18 years) 0.44

GerES: German Environmental Survey, NHANES: National Health and Nutritional Examination Survey, CHMS: Canadian Health Measures Survey, KorEHS-C: Korean Environmental Health Survey in Children and Adolescents. *Fifth percentile (median) of the distribution, † CHMS cycle 2 (2009–2010) data. LOD (limit of detection, μg/L): 0.21, 0.2, 0.05 in GerES-IV, 0.25, 0.33, 0.042 in NHANES IV, 0.2, 0.4, 0.07 in CHMS cycle 3, and 0.149 (0.189), 0.121 (0.200), 0.031 (0.071) in 3–5 years (6–18 years) of KorEHS-C, for blood lead, blood mercury and urinary cadmium, respectively.

(Stromberg et al., 2008), and Germany (Seifert et al., 2000). There are known differences in toxicokinetics and exposure patterns between male and female (Mergler, 2012). In general, higher blood lead levels in male are mainly ascribed to higher exposure and higher hematocrit levels, as lead is bound to erythrocytes in the blood (Vahter et al., 2007). Male infants also have more frequent hand-to-mouth contact, whereas females have longer contact durations (Beamer et al., 2008). The sex differences in blood lead levels appeared to change with age. Our analysis showed a growing disparity in blood lead levels between males and females in the early teen years. A US study also showed higher blood lead levels in boys than girls among children aged 1–2 and 12–19 years (Pirkle et al., 1998).

We found no evidence for a sex difference in blood mercury or urinary cadmium levels. Ha et al. (2014) also showed that blood cadmium and mercury levels do not differ between boys and girls after adjusting for covariates. No sex difference was observed in a blood cadmium analysis of Korean adults (Kim and Lee, 2011).

The comparisons of environmental exposure between countries reveal that blood lead and mercury, as well as urinary cadmium levels are generally higher in Korean children than their peers in Germany, the US, and Canada. The findings of higher mercury and cadmium exposure in Korea compared with that in Germany and the US are consistent with those of a prior study (Ha et al., 2014). Rice, seaweed, and fish are major sources of mercury, lead, and cadmium among Koreans (Lim et al., 2015a; Moon et al., 1995).

The only exception to the generally higher environmental exposure among Korean children was higher blood lead levels in German children. House dust is an important source of heavy metal exposure in children in moderate climate zones, such as Germany, where children spend > 80% of their time indoors (Meyer et al., 1999). However, higher blood lead levels in German children should be interpreted with caution as there was a time gap between the GerES-IV (2003–2006) and the KorEHS-C (2012–2014) surveys, particularly considering the remarkable decrease in blood lead levels in German children aged 6–14 years from 1990 to 1992 to 2003–2006 (Kolossa-Gehring et al., 2007). Blood lead levels also declined in US children in 1988–1991 (Jones et al., 2009) and in Swedish children during 1978–2001 (Stromberg et al., 2003). We also found that blood lead and mercury, as well as urinary cadmium levels in Korean children aged 6–11 years generally declined from 2007 to 2014, which may be a result of ongoing efforts to reduce the body burden of environmental toxicants.

We showed that some sociodemographic factors affected heavy metal levels in children. However, our results should be interpreted cautiously conserving the following limitations. First, the gap between the surveys should be considered when comparing the German and Korean data. Second, collinearity may have been a problem among the sociodemographic variables in the multivariate regression analysis. For example, a father's education level was used to represent his occupational exposure but can also influence household income. This may be why household income was not a significant predictor of any of the environment biomarkers in our analysis.

5. Conclusion

In conclusion, sociodemographic factors, including age, sex, and father's education level were associated with the heavy metal levels in Korean children and adolescents. Among all three heavy metals examined, lead was associated with most of the sociodemographic variables. Our findings suggest that programs to control lead levels should target the high-risk groups. Higher heavy metal levels in children compared with those in children in other developed countries highlight the need for policies designed to reduce and control environmental exposure to toxicants in Korean youth. This biomonitoring study was based on nationally representative survey data and thus provides valuable information for ongoing surveillance of environmental exposure to toxicants in vulnerable populations.

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Conflict of interest

All authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijheh.2016.04.004.

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