International Journal of Hygiene and Environmental Health 219 (2016) 412–418

Contents lists available at ScienceDirect

International Journal of Hygiene and Environmental Health

journal homepage: www.elsevier.com/locate/ijheh

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

Eunae Burm[a,b,1], Inmyung Song[c,1], Mina Ha[d,*], Yu-Mi Kim[e], Kee Jae Lee[f], Hwan-Cheol Kim[g], Sinye Lim[h], Soo-Young Kim[i], Chul-Gab Lee[j], Su Young Kim[k], Hae-Kwan Cheong[l], Joon Sakong[m], Hee-Tae Kang[n], Mia Son[o], Gyung-Jae Oh[p], Yeni Kim[q], Ji-Yeon Yang[r], Soo-Jong Hong[s], Ju-Hee Seo[t], Jeongseon Kim[u], Seyong Oh[v], Jeesuk Yu[w], Seong-Sil Chang[i], Ho-Jang Kwon[d], Youn-Hee Choi[x], Wookhee Choi[y], Suejin Kim[y], Seung Do Yu[y]

[a] Department of Public Health, Graduate School of Dankook University, Cheonan, Republic of Korea
[b] Department of Nursing, Munkyung College, Mungyeong, Republic of Korea
[c] Division of Risk Assessment and International Cooperation, Korea Centers for Disease Control and Prevention, Cheongju, Republic of Korea
[d] Department of Preventive Medicine, Dankook University College of Medicine, Cheonan, Republic of Korea
[e] Department of Preventive Medicine, School of Medicine, Dong-A University, Busan, Republic of Korea
[f] Department of Information Statistics, College of Natural Science, Korean National Open University, Seoul, Republic of Korea
[g] Department of Occupational and Environmental Medicine, School of Medicine, Inha University, Incheon, Republic of Korea
[h] Department of Occupational and Environmental Medicine, School of Medicine, Kyung Hee University, Seoul, Republic of Korea
[i] Department of Occupational and Environmental Medicine, School of Medicine, Eulji University, Daejeon, Republic of Korea
[j] Department of Occupational and Environmental Medicine, School of Medicine, Chosun University, Gwangju, Republic of Korea
[k] Department of Preventive Medicine, School of Medicine, Jeju University, Jeju, Republic of Korea
[l] Department of Social and Preventive Medicine, School of Medicine, Sungkyunkwan University, Suwon, Republic of Korea
[m] Department of Preventive Medicine and Public Health, College of Medicine, Yeungnam University, Daegu, Republic of Korea
[n] Department of Occupational and Environmental Medicine, Wonju Severance Christian Hospital, Wonju College of Medicine, Yonsei University, Wonju, Republic of Korea
[o] Department of Preventive Medicine, School of Medicine, Kangwon National University, Chuncheon, Republic of Korea
[p] Department of Preventive Medicine, School of Medicine, Wonkang University, Iksan, Republic of Korea
[q] Department of Child and Adolescent Psychiatry, National Center for Mental Health, Seoul, Republic of Korea
[r] Institute for Environmental Research, Yonsei University College of Medicine, Seoul, Republic of Korea
[s] Department of Pediatrics, Childhood Asthma Atopy Center, Environmental Health Center, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Republic of Korea
[t] Department of Pediatrics, Dankook University College of Medicine, Cheonan, Republic of Korea
[u] Molecular Epidemiology Branch, National Cancer Center, Goyang, Republic of Korea
[v] Department of Food and Nutrition, College of Human Ecology, Kyung Hee University, Seoul, Republic of Korea
[w] Department of Pediatrics, Dankook University College of Medicine, Cheonan, Republic of Korea
[x] Department of Preventive Dentistry, School of Dentistry, Kyungpook National University, Daegu, Republic of Korea
[y] Environmental Health Research Department, National Institute of Environmental Research, Incheon, Republic of Korea

ARTICLE INFO

Article history:
Received 29 December 2015
Received in revised form 25 March 2016
Accepted 12 April 2016

Keywords:
National sample
Children and adolescents

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

* Corresponding author at: Department of Preventive Medicine, Dankook University College of Medicine, 119 Dandae-ro, Dongnam-gu, Cheonan-si, Chungnam-do 31116, Republic of Korea.
E-mail address: minaha@dku.edu (M. Ha).
[1] Equal contribution as first authors.

http://dx.doi.org/10.1016/j.ijheh.2016.04.004

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-