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Environmental exposures to lead, mercury, and cadmium among South Korean teenagers (KNHANES 2010–2013): Body burden and risk factors

Nam-Soo Kim[a,1], Jaeouk Ahn[b,1], Byung-Kook Lee[c], Jungsun Park[d], Yangho Kim[e,*]

[a] Institute of Occupational and Environmental Medicine, Soonchunhyang University, Asan, South Korea
[b] Department of Medical IT Engineering, Soonchunhyang University, Asan, South Korea
[c] Department of Preventive Medicine, Soonchunhyang University, Asan, South Korea
[d] Department of Occupational Health, Catholic University of Daegu, Gyeongsan, South Korea
[e] Department of Occupational and Environmental Medicine, Ulsan University Hospital, University of Ulsan College of Medicine, Ulsan, South Korea

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ABSTRACT

Introduction: Limited information is available on the association of age and sex with blood concentrations of heavy metals in teenagers. In addition, factors such as a shared family environment may have an association. We analyzed data from the Korean National Health and Nutrition Examination Survey (KNHANES, 2010–2013) to determine whether blood levels of heavy metals differ by risk factors such as age, sex, and shared family environment in a representative sample of teenagers.

Methods: This study used data obtained in the KNHANES 2010–2013, which had a rolling sampling design that involved a complex, stratified, multistage, probability-cluster survey of a representative sample of the non-institutionalized civilian population in South Korea. Our cross-sectional analysis was restricted to teenagers and their parents who completed the health examination survey, and for whom blood measurements of cadmium, lead, and mercury were available. The final analytical sample consisted of 1585 teenagers, and 376 fathers and 399 mothers who provided measurements of blood heavy metal concentrations.

Results: Male teenagers had greater blood levels of lead and mercury, but sex had no association with blood cadmium level. There were age-related increases in blood cadmium, but blood lead decreased with age, and age had little association with blood mercury. The concentrations of cadmium and mercury declined from 2010 to 2013. The blood concentrations of lead, cadmium, and mercury in teenagers were positively associated with the levels in their parents after adjustment for covariates.

Conclusion: Our results show that blood heavy metal concentrations differ by risk factors such as age, sex, and shared family environment in teenagers.

1. Introduction

Lead, cadmium, and mercury are widely dispersed in the general environment, and the general populations of many regions are increasingly exposed to these heavy metals. Workers may be exposed to these metals in their places of employment, but teenagers are mainly exposed *via* non-occupational sources.

Lead can damage the central nervous system, kidneys, cardiovascular system, reproductive organs, and hematological system. A recent paper reported that blood lead levels well below 10 µg/dL were associated with reduced IQ, deficits in executive function, and attention deficit hyperactivity disorder in children (Bellinger, 2011). The main environmental sources of lead are leaded gasoline, lead paint (including lead paint-contaminated dust and soil), water from lead pipes, and industrial emissions (Tong et al., 2000). Lead exposure also occurs through cigarette smoking or consumption of certain foods (De Temmerman and Hoenig, 2004; WHO, 1995). Thus, lead from environmental sources enters the body by inhalation or ingestion (Lockitch, 1993). Blood lead concentration accounts for a part of the total body burden, because it reflects uptake due to recent exposure and slow release from the endogenous skeletal pool (Hu et al., 2007).

Cumulative exposure to cadmium can increase the risk for overall mortality, as well as cardiovascular, neurological, renal, and developmental diseases (ATSDR, 2011). A recent paper showed that prenatal low-level exposure to cadmium had adverse effects on neurodevelopment (Wang et al., 2016; Jeong et al., 2015). Environmental cadmium

* Correspondence to: Department of Occupational and Environmental Medicine, Ulsan University Hospital, University of Ulsan College of Medicine, #290-3 Cheonha-Dong, Dong-Gu, Ulsan 682-060, South Korea.
E-mail address: yanghokm@nuri.net (Y. Kim).
[1] These authors contributed equally to this study.

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is ubiquitous in air, soil, and water due to industrial activities, use of phosphate fertilizers, combustion of motor fuels, and particles released by tire wear (ATSDR, 2011; Pan et al., 2010; Sanchez-Martin et al., 2000). Cadmium has a biological half-life of more than 10 years in the whole body. Cadmium levels in the body increase with age, as only a minute part of the body burden (0.01–0.02%) is excreted each day (ATSDR, 2011). In nonsmokers, diet is the major source of cadmium exposure; in smokers, tobacco is the most important source, because tobacco plants, like other plants, take up cadmium (Satarug, 2010). The cadmium concentration in blood is a useful indicator of exposure in recent months. After long-term cadmium exposure, an increasing proportion of blood cadmium will account for the total body burden (Nordberg et al., 2002; Järup and Åkesson, 2009).

Researchers have recognized the devastating impact of high prenatal exposure to methylmercury for decades. In addition, prenatal exposure to low levels of methylmercury adversely affects infant development, and is associated with behaviors such as attention deficit hyperactivity disorder (Bellinger, 2013; Budtz-Jørgensen et al., 2007; Strain et al., 2008; Sagiv et al., 2012). The general population, including teenagers, are mainly exposed through ingestion of contaminated fish (methylmercury) (Bjornberg et al., 2003) or dental amalgams (inorganic mercury) (Dorea and Barbosa, 2003). Blood mercury level reflects the body burden of organic mercury that has accumulated in the body, whereas urinary mercury reflects exposure to inorganic mercury (Grandjean et al., 1994; Tsuji et al., 2003).

Various risk factors, such as age, sex, and shared family environment, are associated with elevated blood heavy metal concentrations in the general population, although many workers have elevated blood concentrations due to occupational exposure. Advanced age is associated with higher concentrations of heavy metals because of bioaccumulation following long-term environmental exposure. Thus, previous reports showed that advanced age increases the risk for elevated blood metal concentrations in the general adult population (Lee and Kim, 2014). However, little is known about age-related changes in blood heavy metal concentrations in specific age groups, such as teenagers. In addition, increasing evidence suggests that environmental pollutants, including heavy metals, may have different patterns of accumulation in men and women. Previous epidemiological studies reported sex differences in the blood levels of heavy metals in the general adult population (Vahter et al., 2002, 2004, 2007; Ferraro et al., 2012), but little is known about sex differences in teenagers. Teenagers experience puberty and hormonal changes, and this may affect blood metal concentrations. For example, estrogen triggers rapid bone formation during pubertal development, and this induces more rapid deposition of calcium, and also lead, from blood into bone, and thereby decreases blood lead concentration. As a result, women have lower levels of blood lead than men.

There are many environmental sources of heavy metals. Smoking is a risk factor for elevated blood cadmium and lead in adults (Satarug et al., 2010; Lee et al., 2014), and secondhand smoke is also a potential source of exposure to cadmium and lead in teenagers. Alcohol consumption is lower in teenagers than adults, but alcoholic beverages, especially wines, may contain high lead concentrations partly due to the use of lead arsenate as a fungicide in vineyards and contamination from containers, including crystal decanters and glasses (Graziano and Blum, 1991). Diet may also affect the body burden of heavy metals. Consumption of rice and fish, which are the main sources of cadmium and mercury, respectively (Ikeda et al., 2000; Mozaffarian and Rimm, 2006), is decreasing in Korea, particularly among teenagers.

Physical activities (walking and exercise) may cause inter-individual variations in uptake of air contaminants, and thereby affect blood metal concentrations. In addition, low physical activity may lead to bone loss and mobilization of bone lead into the blood, particularly in adults (Kamel et al., 2002). Nutritional surveys indicate that children of low-income groups consume less than the recommended dietary allowances of iron, calcium, and zinc, and deficiencies of these minerals can increase the risk of lead or cadmium poisoning (Bradman et al., 2001; Wright et al., 2003; Yasuda et al., 2011; Ziegler et al., 1978). Poor housing, in which lead-based paint is present, can also increase the risk of lead exposure (Bradman et al., 2001). Thus, the type of housing, such as apartment, detached house, or tenement, may be a surrogate marker of socioeconomic status.

In general, urban environments are more polluted than rural areas, and industrialization increases exposures directly through emissions and indirectly through its products (Scott and Nguyen, 2011; WHO, 2000). However, there is a recent trend in Korea of building factories in rural areas rather than urban areas. Urban areas tend to have higher socioeconomic status than rural areas, and fish consumption may be more prevalent in rural areas than urban areas. Thus, there is no simple relationship between heavy metal exposure and region of residence. A shared living environment, including consumption of similar foods, may lead to similar risks for elevated heavy metal concentrations among family members (Hopper and Mathews, 1983; Björkman et al., 2000). Thus, the diet and environment of teenagers would be dependent on their parents; however, as they age and become more independent, their exposures could differ from their parents. Thus, it is important to examine risk factors associated with blood metal levels in teenagers, which could be different from those in adults.

We analyzed data from the Korean National Health and Nutrition Examination Survey (KNHANES, 2010–2013) to determine whether blood levels of heavy metals differ by risk factors such as age, sex, and shared environment in a representative sample of teenagers.

2. Methods

2.1. Design and data collection

This study used data obtained in the 3 years of the KNHANES V and first year of the KNHANES VI. The 4 years of data (2010–2013) was collected using a rolling sampling design that involved a complex, stratified, multistage, probability-cluster survey of a representative sample of the noninstitutionalized civilian population in South Korea. The survey was performed by the Korean Ministry of Health and Welfare, and had three components: the health interview survey, the health examination survey, and the nutrition survey. This survey was approved by the Institutional Review Board of the Korean Centers for Disease Control and Prevention (approval nos. 2010-02CON-21-C, 2011-02CON-06-C, 2012-01EXP-01-2C, 2013-07CON-03-4c).

The cross-sectional analysis was restricted to teenagers and their parents who completed the health examination survey and received measurements of blood cadmium, lead, and mercury. The final analytical sample consisted of 1585 teenagers (801 males and 784 females), and 376 fathers and 399 mothers who received measurements of blood cadmium, lead, and mercury. The blood metal levels of both parents were only available for 11 teenagers; all others had blood metal levels from only one parent. All teenagers were from different households.

Parental age, education, smoking history, and alcohol intake were collected during the health interview. Height and weight of the teenagers was determined with the subjects wearing light clothing and no shoes. Body mass index (BMI) was calculated as weight divided by height squared (kg/m^2). Age at the time of the health interview was categorized into 5 age groups. Smoking status was classified as smoking or nonsmoking. Nonsmoking teenagers were those who said they had never smoked, and the others were classified as smokers. Drinking status was classified as drinking or nondrinking. Nondrinking teenagers were those who said they never had a drink, and all others were classified as drinkers. History of alcohol and tobacco consumption was taken confidentially, so that parents did not know the answers. Information about the frequency of seafood consumption (fish, shellfish, and seaweed) was obtained from the nutrition survey within KNHANES 2010–2012, which was performed separately on different