Biomarker Levels of Toxic Metals among Asian Populations in the United States: NHANES 2011–2012

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Introduction

Cadmium, lead, mercury, and arsenic are among the most toxic environmental contaminants. The International Agency for Research on Cancer (IARC) classifies arsenic and cadmium as human carcinogens (Group 1), and lead and mercury (methylmercury) as possibly carcinogenic to humans (Group 2B) (IARC 2013). Although levels of exposure to these metals/metalloids (hereafter, collectively referred to simply as “metals”) have been generally decreasing in the United States, various adverse health effects, such as cardiovascular and developmental effects, damage to the nervous system, and kidney failure, have been associated with exposure to these metals at the current, relatively low, environmental exposure levels (Ferraro et al. 2010; Lebel et al. 1996; McLaine et al. 2013; Moon et al. 2013). The health effects of low-level exposures are also important because some of the effects have been regarded to have no safe exposure threshold (Anderson 1983; Jakubowski 2011). Therefore, exposure to these toxic metals still poses a significant public health risk, and it is vital to reduce overall exposure and subsequently health risks, especially for those highly exposed subpopulation groups.

Asian populations have considerably higher blood and urinary levels of these metals than other racial/ethnic groups (i.e., whites, blacks, and Hispanics) in the United States (CDC 2014; McKelvey et al. 2007). For example, based on a recent analysis of biomarker data by the Centers for Disease Control and Prevention (CDC) in 2014, the geometric mean blood mercury levels among Asians (1.86 μg/L) is four times greater than that of Mexican Americans (0.48 μg/L) (CDC 2014). Asian populations in the United States include multiple ethnic subgroups that are culturally, religiously, historically, and geographically diverse. Hence, the differences in these characteristics across subgroups may affect biomarker levels of these metals. However, this was not examined in the original CDC analysis.

The National Health and Nutrition Examination Survey (NHANES) is a national population-based survey program conducted by the National Center for Health Statistics (NCHS) that assesses the health and nutritional status of the civilian noninstitutionalized general U.S. population. The NCHS collects data continuously and releases data every 2 years in a 2-year data cycle. An important addition to the most recent data cycle (i.e., NHANES 2011–2012) was that Asian populations were oversampled, and data for Asians were reported in a separate race category as opposed to being included in the “other” race category (NCHS 2013). Because studies evaluating the health and nutrition status among Asians on a national level are relatively scarce, the addition of the Asian category should allow researchers to investigate the health and nutrition status of this race group. Further, evaluation of exposure characteristics across Asian subgroups could help identify highly exposed subpopulations and also their potential exposure sources.

The objective of the present study was to expand the CDC’s analysis of biomarker data and further evaluate the higher metal biomarker levels among Asians by comparing the biomarker levels of four metals (cadmium, lead, mercury, and arsenic) in Asians with those of other racial and ethnic groups in the United States. We examined variations in biomarker levels of metals in the major Asian subgroups (Chinese and Asian Indian) in the United States and the association of biomarker levels with various demographic, socioeconomic, physical, dietary, behavioral, and geographical characteristics within the subgroups.

Methods

Data Source

NHANES data available through the CDC were used as the data source. NHANES recruits approximately 5,000 participants annually, using a complex, multistage, probability sampling design. The multistage sampling procedure includes sampling from
four stages of geographical units (county, city block, household, and individual), where subsequent sampling occurs within the unit selected in the prior stage. Multiple samples can be drawn from the same unit (e.g., multiple individuals from one household).

Self-reported demographic, socioeconomic, dietary, and health-related information is collected through interview and questionnaire, whereas medical examination and collection of biological specimens (blood/urine) for laboratory tests are administered by health professional and qualified staff at the mobile examination center. The NHANES data collection procedures are described in detail elsewhere (Johnson et al. 2014).

The majority of the NHANES data are publicly available and were obtained directly from the CDC web site (CDC 2015). Access to certain data sets is restricted to protect study participant confidentiality. The restricted data used in this study (i.e., Asian ancestry and geographical information of the participants) were accessed and analyzed at the CDC Research Data Center (RDC), following a strict NCHS protocol (NCHS 2012a). Data collection for NHANES was approved by the NCHS Research Ethics Review Board (ERB). Analysis of de-identified data from the survey is exempt from federal regulations for the protection of human research participants. Analysis of restricted data through the NCHS RDC was also approved by the NCHS ERB.

Study Population

For this study, the study population was the general U.S. population (≥ 6 years of age), including both males and females and all racial and ethnic groups, except those categorized as “other” (i.e., Pacific Islanders, Native Americans/Alaskan Natives, and multiracial individuals). The “other race” group was excluded because of its small sample size and the heterogeneous nature of the group. Additionally, the non-Hispanic Asian group [Far East Asia, Southeast Asia, or South Asia/Indian subcontinent (NCHS 2013)] was subdivided into Chinese (Chinese and Taiwanese), Asian Indian (Asian Indian, Bengalese, Bharat, Dravidian, East Indian, and Goanese), and Other Asians based on the answer to DMQ 336 in the NHANES’s survey questionnaire. When a participant selected multiple Asian ancestries (e.g., Chinese and Filipino), they were categorized into the “Other Asian” subgroup. Chinese and Asian Indians were selected because they are the two largest Asian subgroups. Each subgroup accounts for approximately 20% of the Asian population (Hoeffel et al. 2012). There was no oversampling of the specific subgroups within the Asian population performed in NHANES 2011–2012.

Biomarker Data

We evaluated five biomarkers: blood cadmium (B-Cd), blood lead (B-Pb), blood mercury (B-Hg), urinary total arsenic (U-tAs) and urinary dimethylarsinic acid (U-DMA). Study participants age ≥ 1 year were eligible for collection of blood samples, whereas urinary samples were obtained from a randomly selected one-third subset of the participants (≥ 6 years old). Arsenic acid, arsenous acid, monomethylarsonic acid (MMA), and DMA are metabolites of inorganic arsenic. Although methylated species such as MMA and DMA can be metabolites of less harmful organic arsenic, these five inorganic arsenic metabolites are often summed to represent inorganic arsenic exposure. Because inorganic arsenic metabolites other than DMA typically have low frequency of detection (< 40%), we only evaluated biomarker levels of U-DMA in our study. Similar to the CDC study of metal biomarkers (CDC 2014), urinary metal concentrations were adjusted using the concentration of creatinine in urine to account for the effect of urinary dilution:

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\text{Creatinine-corrected urinary concentration (µg/g)} = \frac{[1000 \cdot \text{mg/dL} \cdot g]}{[\text{creatinine in urine (µg/L)} + [\text{creatinine in urine (mg/dL)]]}
\]

For samples with biomarker levels below the limit of detection (LOD), NHANES uses “fill values” (LOD divided by the square root of 2). In accordance with the Fourth National Report on Human Exposure to Environmental Chemicals (CDC 2014), we used these fill values in our analyses. The LOD for biomarker parameters used to establish the fill values were as follows: B-Cd, 0.16 µg/L; B-Pb, 0.25 µg/dL; B-Hg, 0.16 µg/L; U-tAs, 1.25 µg/L; U-DMA, 1.80 µg/L. The detection frequency of B-Cd ranged from 63% among Mexican Americans to 87% among Asians; for U-DMA, the detection frequency ranged from 73% among whites to 91% among Asians. The biomarker levels of three other metal variables presented a relatively high frequency of detection in all groups: B-Pb (≥ 98%), B-Hg (≥ 91%), U-tAs (≥ 91%). The biomarker data were log-transformed to reduce skewness. Detailed information about laboratory procedures including sample collection, storing, and handling of specimens, quality control, and instrument and equipment used for the chemical analyses can be found elsewhere (NCHS 2011a, 2011b, 2012b).

Covariates

The covariates included in the analyses were sex, age, education, household income, birthplace, poverty–income ratio (PIR) according to the Department of Health and Human Services poverty guidelines (dichotomized based on the median value of 1.63) (DHHS 2013), body mass index (BMI) (underweight, < 18.5 kg/m²; normal weight, 18.5–< 25 kg/m²; overweight, 25–< 30 kg/m²; obese, ≥ 30 kg/m²), smoking (based on the tertile of serum cotinine level), fish consumption, urbanization classification based on 2013 NCHS urban–rural classification scheme for counties (Ingram and Franco 2014), and U.S. Census region. BMI was included based on the association between lower BMI and high B-Hg levels observed in previous studies (Buchanan et al. 2015; Rothenberg et al. 2015). For participants < 20 years of age, education level of the household reference person (frequently, the adult owner/renter of the residence) was used. BMI category was determined based on the CDC’s sex-specific 2000 BMI for-age growth charts for the age group < 20 years (underweight, < 5th percentile; normal weight, 5th–< 85th percentile; overweight, 85th–< 95th percentile; obese, ≥ 95th percentile). Table 1 provides details on the breakdown and response categories of each of these covariates.

Statistical Analysis

All statistical analyses were performed using SAS-callable SUDAAN version 11.0.1 (RTI International, Research Triangle Park, NC, USA) installed as an add-on to SAS software version 9.3 or higher (SAS Institute Inc., Cary, NC, USA). We accounted for the NHANEs’s complex sample design and applied appropriate strata, cluster, and weights, as described in the NHANES documentation (CDC 2015), in all the statistical analyses.

We stratified the data by five NHANES race/ethnic groups: non-Hispanic white, non-Hispanic black, Mexican American, other Hispanic and Asian subgroups (Chinese, Asian Indian, and Other Asian), and computed weighted statistics for biomarker levels by each covariate. The statistics included the geometric mean and its 95% confidence interval (CI), as well as the 50th and 95th percentiles based on the Taylor series linearization method (RTI International 2012). Summary statistics were presented for five biomarker variables [B-Cd, B-Pb, B-Hg, U-tAs (creatinine-corrected), and U-DMA (creatinine-corrected)]. In accordance with the Fourth National Report on Human Exposure to Environmental Chemicals, the geometric mean concentration was not calculated when the level for a biomarker was below the LOD in > 40% of the samples (CDC 2014). For the protection of study participants’ confidentiality, analyses using geographical covariates (urbanization and census region) were not conducted for Asian subgroups.

We compared geometric means of biomarker levels for each covariate category across five NHANES race/ethnic groups and then compared geometric means of biomarker levels across three Asian subgroups, using
analysis of variance (ANOVA). Further, differences in geometric means within each covariate were assessed using ANOVA, stratified by NHANES race/ethnic group and Asian subgroup. For all analyses, \( p < 0.05 \) was considered statistically significant.

**Results**

**Sample Characteristics**

Table 1 presents the study participants’ characteristics by racial/ethnic group. The final number of samples included in the analysis was 6,951 out of 9,756; approximately one-third (2,427) were used for urinary biomarker analyses.

Since differences in biomarker levels may reflect group characteristics such as socioeconomic status and dietary patterns, we first examined the comparability of the various racial/ethnic groups and subgroups by the covariates. The distribution of age groups varied across the racial/ethnic groups. The Asian group had a distribution similar to those of blacks and other Hispanics and tended to be younger than whites and older than Mexican Americans. The Asian group had the highest percentage of college graduates or above. Socioeconomic status (denoting household income and PIR) of the Asian group mirrored that of the white group, with these two groups having higher percentages of the highest income category (> $75,000) and above median PIR than the other three groups. Asians had the lowest percentage of U.S.-born participants (24.8%), compared with > 90% of the white and black populations having been born in the United States. The distributions of recent fish consumers

| Covariates | Non-Hispanic white [2,374 (66.4)] | Non-Hispanic black [1,957 (12.2)] | Mexican American [920 (9.4)] | Other Hispanic [755 (6.9)] | Non-Hispanic Asian [945 (5.0)] | Asian subgroups (%) |
|------------|----------------------------------|-----------------------------------|-------------------------------|---------------------------|---------------------------------|--------------------|
| Sex        | Male 1,205 (48.8) 949 (45.5) 479 (51.6) 361 (47.7) 471 (47.4) (49.5) (50.1) (45.6) | Female 1,169 (51.2) 1,008 (54.5) 441 (48.4) 394 (52.3) 474 (52.6) (50.5) (49.9) (54.4) | | | | |
| Age        | 6–11 years 242 (6.1) 320 (9.9) 222 (13.6) 114 (8.8) 89 (5.8) (6.9) (5.5) (5.6) | 12–19 years 251 (10.0) 346 (15.1) 199 (18.0) 125 (13.0) 155 (10.9) (9.2) (8.5) (12.3) | | | | |
| Education  | < High school (HS) 394 (11.5) 393 (18.6) 506 (51.6) 286 (35.3) 147 (14.1) (8.3) (11.9) (16.8) | HS graduate/GED 488 (19.5) 520 (26.1) 186 (21.1) 167 (23.7) 127 (12.6) (9.3) (9.4) (15.0) | | | | |
| Household Income | < $20,000 557 (13.4) 584 (32.5) 240 (27.3) 207 (29.1) 112 (12.4) (12.4) (9.6) (13.6) | $20,000–< $50,000 805 (31.7) 693 (37.2) 444 (48.6) 274 (38.8) 261 (30.8) (29.0) (24.6) (34.0) | | | | |
| Poverty to income ratio | < Median (1.63) 970 (25.8) 942 (51.9) 547 (61.5) 372 (53.6) 241 (28.4) (22.1) (17.2) (31.5) | > Median (1.63) 1,299 (74.2) 843 (48.1) 291 (38.5) 312 (46.4) 584 (73.6) (77.9) (82.9) (68.5) | | | | |
| Birthplace | USA 2,275 (96.1) 1,790 (91.4) 538 (53.7) 293 (36.9) 277 (24.8) (27.3) (15.9) (27.4) | Outside USA 99 (3.9) 167 (8.6) 380 (46.3) 480 (63.1) 668 (75.2) (72.7) (84.1) (72.7) | | | | |
| BMI        | Underweight 52 (2.0) 42 (2.2) 14 (1.4) 13 (1.8) 42 (4.1) (5.2) (3.9) (3.9) | Normal 859 (35.2) 660 (30.4) 321 (30.9) 254 (31.4) 569 (60.2) (71.5) (51.7) (59.7) | | | | |
| Smoking (cotinine level) | < 0.05 was considered statistically significant. | 1st tertile 846 (41.3) 364 (19.6) 371 (40.0) 314 (41.3) 339 (36.6) (37.1) (27.2) (40.1) | | | | |
| Recent fish consumption | Yes 1,490 (68.6) 1,277 (71.4) 472 (58.6) 430 (64.9) 605 (77.4) (85.7) (56.4) (83.0) | No 774 (31.4) 543 (28.6) 374 (41.4) 247 (35.1) 189 (22.5) (14.3) (43.7) (17.0) | | | | |

Abbreviations: AA, Associate in Art degree; GED, General Educational Development.

aSample counts and weighted percentage among five NHANES race and ethnic groups and weighted percentage among three Asian subgroups.

bRaw sample counts are not provided for the restricted data.

cCotinine levels: 1st tertile (< 0.019 ng/mL), 2nd tertile (0.019–< 0.144 ng/mL), 3rd tertile (≥ 0.144 ng/mL).

dFish eaten during past 30 days.

eBecause of potential disclosure risk, geographical analysis on Asian subgroups is not included.
(those who had eaten fish in the 30 days before the study) were generally comparable across the five groups. Large geographical variations existed across the groups. Asians as well as Hispanics and Mexican Americans tended to live in urban areas, with the largest populations of Asian and Mexican-American participants being found in the West.

The weighted percentages of the Asian subgroup samples (Chinese and Asian Indians) were roughly proportional to those observed in the 2010 U.S. Census data (Hoefel et al. 2012). In general, age groups were distributed similarly. Education and economic status among Chinese and Asian Indians was higher than those of Other Asians. Asian Indians had an approximately 10% lower percentage of U.S.-born individuals than other two subgroups. The proportion of individuals with a normal BMI was highest among Chinese. There was a noticeably higher rate of recent fish consumers in the Chinese and Other Asian subgroups (> 80%) than that of Asian Indians (56.4%).

**Analysis of Biomarker Data**

Weighted summary statistics of biomarker data (geometric mean and 50th and 95th percentile) are provided in Tables S1–S5 for the five groups and in Tables S6–S10 for the three Asian subgroups. The patterns of the U-DMA levels across age groups were similar to those of the U-tAs (Table 3). U-DMA levels were often higher among the youngest age group (6–11 years) than those among other age groups. Across the age groups (> 12 years), there was a general trend of increasing U-DMA levels with age. Recent fish consumers had higher U-DMA levels than non-consumers in all three Asian subgroups.

**Overall Comparison across Racial/Ethnic Groups and Asian Subgroups**

For all biomarkers, the geometric mean value in Asians was significantly ($p < 0.05$) higher than that in each of the other racial/ethnic groups (Table 2). This observation was consistent in nearly all of the comparisons performed within subsets of data based on the various demographic, socioeconomic, physical, dietary, behavioral, and geographical characteristics. Biomarker levels among Asians were significantly lower than those of other groups in only two cases: the comparisons of B-Cd and B-Pb levels in U.S.-born individuals (see Tables S1 and S2). For all other comparisons, biomarker levels among Asians are either the highest (mostly significantly) or not significantly different from those of other race/ethnic groups with higher biomarker levels.

Across the Asian subgroups, biomarker levels were generally similar between the Chinese and Other Asian subgroups (Table 3). The Asian-Indian subgroup had lower biomarker levels than those of the other two Asian subgroups, with the exception of B-Pb. Although the differences in B-Pb levels were not significant, Asian Indians had the highest overall geometric mean B-Pb across the three Asian subgroups. In comparisons made within Asian subgroups, B-Pb levels were significantly higher among Asian Indians for adolescents (12–19 years old) (0.90 μg/dL), older adults (≥ 60 years old) (2.19 μg/dL), those with household income ≥ $75,000 (1.33 μg/dL), and above-mean PIR (1.37 μg/dL) categories than those in the other two Asian subgroups.

**Predictors of Biomarker Levels in Asian Subgroups**

**Cadmium.** Sex was significantly associated with B-Cd levels in two of the three Asian subgroups. Females had higher B-Cd levels than males across all subgroups (Table 3). A general trend of increasing B-Cd with age was observed. There was an apparent inverse trend with socioeconomic status (education, income, and PIR) and B-Cd levels. B-Cd levels were significantly higher in individuals born outside of the United States, compared with those born in the United States in all of the Asian subgroups. A clear trend of B-Cd levels increasing with cotinine levels was observed in all subgroups.

**Lead.** B-Pb levels were significantly associated with sex. B-Pb levels were significantly higher among males than females in all three Asian subgroups (Table 3). B-Pb level generally increased with age. There was a general trend of decreasing B-Pb levels with higher educational status. Individuals born outside of the United States had higher B-Pb levels than those born in the United States across all of the Asian subgroups. A clear trend of B-Pb levels increasing with cotinine levels was observed in all subgroups.

**Mercury.** A general trend of increasing B-Hg levels with age was observed, with the exception of the Asian-Indian subgroup (Table 3). Significant differences in B-Hg across BMI categories were observed among Chinese and Other Asian subgroups, although no consistent pattern of B-Hg was seen between these two subgroups. Recent fish consumers had higher B-Hg levels than non-consumers in all three Asian subgroups.

**Arsenic, total.** The general patterns of the U-tAs levels across age groups were similar in all Asian subgroups (Table 3). U-tAs levels decreased from the youngest group (6–11 years) to the second youngest age group (12–19 years) and then generally increased with age after childhood (≥ 12 years). U-tAs levels were significantly higher among recent fish consumers than non-consumers in all three Asian subgroups.

**Discussion**

Our study confirmed there are racial/ethnic differences in the biomarker levels of toxic metals—cadmium, lead, mercury, and arsenic—in the United States. Overall, biomarker levels among Asians were higher than in other racial/ethnic groups regardless of sociodemographic, physical, behavioral, dietary, and geographic characteristics (see Tables S1–S5). Asians had significantly lower biomarker levels than other groups in only two comparisons: a) The B-Cd among U.S.-born blacks was significantly higher than that among U.S.-born Asians, and b) U.S.-born whites and blacks had significantly higher B-Pb levels than U.S.-born Asians. Across the Asian subgroups, the lowest biomarker levels were generally observed among Asian Indians, except for B-Pb levels. Although no significant difference was observed in the overall comparison of B-Pb levels across Asian subgroups (≥ 6 years old), significantly higher B-Pb levels among Asian Indians were found in adolescents (12–19 years old), older adults (≥ 60 years old), people in the highest income category (≥ $75,000), and people above the median PIR. The elevated B-Pb levels in Asian

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**Table 2. Comparison of weighted geometric mean biomarker levels across NHANES racial and ethnic group.**

| Group                  | Cadmium (blood) (μg/L) | Lead (blood) (μg/dL) | Mercury (blood) (μg/L) | Arsenic, total (urinary) (μg/g-creatinine) | DMA (urinary) (μg/g-creatinine) |
|------------------------|------------------------|---------------------|------------------------|-------------------------------------------|-------------------------------|
| Group                  | n  | GM (95% CI) | p-Value          | GM (95% CI) | p-Value          | GM (95% CI) | p-Value          | GM (95% CI) | p-Value          | GM (95% CI) | p-Value          |
| Non-Hispanic Asian     | 945 | 0.41 (0.37, 0.45) | 0.001          | 1.16 (1.07, 1.25) | 0.001          | 1.93 (1.85, 2.27) | 0.001          | 23.23 (19.1, 26.1) | 0.001          | 356 | 8.99 (8.58, 11.41) | 0.001          |
| Non-Hispanic white     | 2,374 | 0.29 (0.27, 0.31) | < 0.001         | 1.00 (0.92, 1.08) | 0.004          | 0.71 (0.61, 0.84) | < 0.001         | 818 | 7.13 (6.05, 8.39) | 0.004          | 824 | 3.68 (3.44, 3.93) | < 0.001         |
| Non-Hispanic black     | 1,957 | 0.31 (0.29, 0.33) | < 0.001         | 0.98 (0.93, 1.03) | 0.002          | 0.71 (0.57, 0.89) | < 0.001         | 669 | 7.24 (5.53, 9.48) | < 0.001         | 672 | 3.16 (2.67, 3.73) | < 0.001         |
| Mexican American       | 920 | 0.23 (0.21, 0.24) | < 0.001         | 0.83 (0.76, 0.91) | 0.001          | 0.51 (0.45, 0.58) | < 0.001         | 317 | 8.00 (6.87, 9.32) | < 0.001         | 317 | 4.12 (3.84, 4.43) | < 0.001         |
| Other Hispanic         | 755 | 0.25 (0.23, 0.28) | < 0.001         | 0.88 (0.79, 0.98) | < 0.001         | 0.91 (0.81, 1.02) | < 0.001         | 256 | 8.25 (8.17, 10.49) | < 0.001         | 257 | 5.02 (4.50, 5.61) | < 0.001         |

**Notes:**

DMA, dimethylarsinic acid.

$^a$Sample size was the same for all three blood biomarkers (cadmium, lead, and mercury).

$^b$Asian Indians were used as the reference group.
Indians may be associated with their spice and cosmetic use, since elevated levels of lead have been found in turmeric (Gleason et al. 2014), a main ingredient of curry, and in eye makeup, such as surma or kohl, that are often used in Indian communities (Goawali 2013).

In general, biomarker levels among Indians in the United States were lower than the levels reported in studies conducted in Asian countries. Ding et al. (2014) evaluated the B-Cd and B-Pb levels of the general population in China, based on randomly selected study participants aged 6–60 years (n = 18,120) from 24 districts in eight provinces in China between 2009 and 2010. Geometric mean B-Cd and B-Pb levels from this study were 0.49 μg/L and 3.49 μg/dL, respectively, compared with the geometric mean B-Cd (0.45 μg/L) and B-Pb (1.22 μg/L) levels observed among the Chinese subgroup in the present study (Table 4). Geometric mean biomarker levels (2011) reported in the Korean NHANES (Seo et al. 2015), a Korean national health survey similar to the CDC’s NHANES, were slightly higher, but comparable with the levels observed among the Other Asian subgroup, which is assumed to consist mainly of Filipino, Vietnamese, Korean, and Japanese people according to the 2010 Census (Hoejfelt et al. 2012). The geometric mean biomarker levels among those Koreans ≥19 years were 0.86 μg/L (B-Cd), 1.99 μg/dL (B-Pb), and 3.08 μg/L (B-Hg) (Table 4). In our study, the ranges of the geometric mean of B-Cd, B-Pb, and B-Hg levels in the corresponding age group (≥20 years old) of Other Asians were 0.42–0.74 μg/L (B-Cd), 0.92–1.53 μg/dL (B-Pb), and 2.18–3.80 μg/L (B-Hg). Urinary arsenic levels in Koreans were noticeably higher than the levels observed in the present study. Geometric mean U-tasl levels reported in the Korean NHANES (2008–2009) ranged from 90.6 μg/g-creatinine (20–39 years old) to 157.6 μg/g-creatinine (≥60 years old) (Rhee et al. 2013), whereas U-tasl levels observed in our study were 24.21 μg/g-creatinine (20–39 years old) to 52.85 μg/g-creatinine (60 years old) among the Other Asian subgroup (Table 4).

Except for lead, the exposure pathway of the metals we evaluated is known to be

| Covariate                  | Cadmium (blood) (μg/L) | Lead (blood) (μg/L) | Mercury (blood) (μg/L) | Arsenic, total (urinary) (μg/g-creatinine) | DMA (urinary) (μg/g-creatinine) |
|----------------------------|-----------------------|--------------------|-----------------------|-------------------------------------------|---------------------------------|
| Age                        |                       |                    |                       |                                           |                                 |
| 6–11 years                 | 0.37 ± 0.09 < 0.001   | 0.03 ± 0.01 < 0.001| 0.03 ± 0.003 < 0.001  | 0.01 ± 0.002 < 0.001                      | 0.01 ± 0.002 < 0.001            |
| Education                  |                       |                    |                       |                                           |                                 |
| < High school (HS)         | 0.55 ± 0.08 0.60 ± 0.078 | 1.39 ± 1.90 ± 0.48 | 1.08 ± 0.24 ± 0.28 | 1.34 ± 0.10 ± 0.03 | 1.08 ± 0.08 ± 0.01 |
| Household income           | < $20,000             | 0.30 ± 0.61 0.06 ± 0.18 | 0.82 ± 1.20 ± 0.153 | 0.12 ± 0.24 ± 0.03 | 0.20 ± 0.62 ± 0.11 |
| Poverty to income ratio    | < Median (1.5x)       | 0.34 ± 0.49 0.14 ± 0.48 | 1.59 ± 1.38 ± 0.19 | 0.02 ± 0.12 ± 0.01 | 0.05 ± 0.15 ± 0.13 |
| Birthplace                 | USA                   | 0.27 ± 0.17 0.25 ± 0.02 | 0.82 ± 0.71 ± 0.93 | 0.63 ± 0.25 ± 0.15 | 0.08 ± 0.50 ± 0.03 |
| BMI                        | < Underweight         | 0.57 ± 0.21 0.07 ± 0.03 | 1.35 ± 0.65 ± 0.20 | 0.24 ± 0.40 ± 0.17 | 0.21 ± 0.62 ± 0.01 |
| Smoking (cigarette level)  | 1st tertile           | 0.35 ± 0.24 0.36 ± 0.01 | 1.02 ± 0.87 ± 0.94 | 0.54 ± 0.23 ± 0.49 | 0.15 ± 0.21 ± 0.05 |
| Recent fish consumption    | Yes                   | 0.43 ± 0.28 0.44 ± 0.01 | 1.20 ± 1.22 ± 1.11 | 0.42 ± 0.27 ± 0.11 | 0.01 ± 0.02 ± 0.00 |
| No                        | 0.35 ± 0.23 0.28 ± 0.01 | 1.01 ± 1.31 ± 0.83 | < 0.001 ± 0.01 ± 1.17 | 0.30 ± 0.07 ± 0.01 | 0.01 ± 0.02 ± 0.00 |

Table 3. Comparison of weighted geometric mean biomarker levels across Asian subgroup.

Abbreviations: AA, Associates in Art (AA) degree; AI, Asian Indian; C, Chinese; GED, General Educational Development.
Significance of difference in geometric mean across Asian subgroups.
Significance of difference in geometric mean across categories within covariate.
Due to small sample size, the results for two income ranges ($20,000–$50,000 and $50,000–$75,000) were aggregated.
Results are not presented due to small sample size.
Metal biomarker levels of Asian population

Asians had significantly lower B-Cd and B-Pb levels than those of other racial/ethnic groups. Further characterization of metal exposure depending on birthplace and its relationship with biomarker levels will be warranted in future studies. These patterns of biomarker levels based on sex, age, and birthplace among Asians agreed with the results reported in previous studies based on the general U.S. population (Caldwell et al. 2009; Mortensen et al. 2014; Peters et al. 2014). In contrast, there appear to be different patterns of B-Hg and U-tAs among Asians for the covariates representing socioeconomic status. A general trend of increasing B-Hg and U-tAs with increasing educational and socioeconomic status was observed among the racial/ethnic groups other than Asians, with this trend being more pronounced in the white group.

Further, our study found that several other characteristics are important predictors of biomarker levels. Sex and age differences in biomarker levels were generally consistent across Asian subgroups. Females had higher B-Cd and lower B-Pb levels than males. Biomarker levels generally increased with age. A higher level of U-tAs and U-DMA were observed in the youngest age group (6–11 years). This may be attributable to greater arsenic exposure and/or age-dependent toxicokinetic characteristics (e.g., efficient absorption or poor excretion of arsenic) of this age group. Additionally, we found birthplace to be an important predictor of biomarker levels: consistently higher biomarker levels (albeit not always significant) were observed among Asians born outside of the United States compared with Asians born in the United States. Although higher, the biomarker levels among non-U.S.-born Asians are less than the levels reported in their countries of origins described in the previous paragraph. Further, as discussed earlier, within the comparisons among U.S.-born individuals, Asians had significantly lower B-Cd and B-Pb levels compared to those of other racial/ethnic groups.

Table 4. Comparison of geometric mean biomarker levels of Asian subgroups in the U.S. to those reported in Asian countries.

| Metal                  | NHANES 2011–2012          | Studies in Asian countries |
|------------------------|---------------------------|----------------------------|
|                        | Subgroup | Concentration | Age group | Country | Concentration | Age group | Reference  |
| Cadmium (μg/L)         | Chinese   | 0.45          | ≥ 8 years | China    | 0.49          | 6–60 years | Ding et al. 2014 |
|                        | Other Asian | 0.42–0.74 | ≥ 20 years | Korea    | 0.86          | ≥ 19 years | Seo et al. 2015  |
| Lead (μg/dL)           | Chinese   | 1.22          | ≥ 6 years | China    | 3.49          | 6–60 years | Ding et al. 2014 |
|                        | Other Asian | 0.92–1.53 | ≥ 20 years | Korea    | 1.99          | ≥ 19 years | Seo et al. 2015  |
| Mercury (μg/L)         | Other Asian | 2.18–3.80 | ≥ 20 years | Korea    | 3.08          | ≥ 19 years | Seo et al. 2015  |
| Arsenic, total (μg/g-creatinine) | Other Asian | 24.2–52.8 | ≥ 20 years | Korea    | 90.6–157.6    | ≥ 20 years | Rhee et al. 2013  |

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of genetic variants that influence absorption, distribution, metabolism, elimination/excretion processes and such differences could also be related to differences in biomarker levels of metals across groups.

Another uncertainty associated with the current study is how representative our sample was of the Asian population. Asians typically have a lower participation rate in national surveys than other racial/ethnic groups, and the NHANES response rate among Asian in 2011 was approximately 10–20% lower than that of other groups (Broitman 2012). Because of potential response bias, the NCHS performed an analysis of nonresponders by comparing the demographic and socioeconomic characteristics of responders and nonresponders (NCHS 2013). Based on this analysis, the NCHS concluded that, although a potential for nonresponse bias may exist, weight adjustment lessens the bias. Our analysis used appropriate sample weights; however, it still remains uncertain to what extent this potential bias may have remained and distorted the results. Furthermore, we used biomarker levels of Asians from one NHANES data cycle. The Asian group was divided into three subgroups, and the results are based on a relatively small number of samples. Therefore, some of our results may be statistically unreliable and should be viewed with caution. Because oversampling of the Asian population continues in the next NHANES data cycle (2013–2014), the findings of this study should be verified with the larger data set in future studies.

This study also had several strengths. We evaluated differences in biomarker levels of five metals across different racial/ethnic groups in the United States, with a specific interest in the Asian population, due to previously reported elevated concentrations of metal biomarkers in this group. The NHANES 2011–2012 is the first data cycle to include a specific Asian race category, and to the best of our knowledge, this is one of the first studies to investigate biomarker levels in this historically less-studied racial group using nationally representative data. We evaluated biomarker levels of three subgroups of the Asian population: Chinese, Asian Indian, and Other Asian. Although NHANES is not designed to evaluate small sample groups and the results are not nationally representative, our study was able to assess general biomarker patterns among subgroups of Asians, which have rarely been evaluated, especially on a national scale.

According to the 2010 U.S. Census (U.S. Census Bureau 2013), Asians were the fastest-growing race/ethnic group in the United States with an increase of 43.2% between 2000 and 2010. As this study demonstrated, there are considerable variations in sociodemographic, behavioral, and exposure characteristics between Asians and other racial/ethnic groups and also between Asian subgroups. As the Asian population in the United States continues to grow, more studies are warranted to improve our understanding of the health and nutritional status of this minority group.

### Conclusion

Asian populations were found to have the highest levels of B-Cd, B-Pb, B-Hg, U-tAs, and U-DMA across the five racial/ethnic groups assessed in the NHANES. Generally, this observation did not change when data were further examined by various demographic, socioeconomic, physical, dietary, behavioral, and geographical characteristics. Within the Asian group, considerable variations in biomarker levels are present across the Chinese, Asian Indian, and Other Asian subgroups. Biomarker levels of toxic metals, except B-Pb, are generally lowest among Asian Indians. Sex, age, education, birthplace, smoking, and fish consumption were found to be significant predictors of biomarker levels for certain metals.

### References

Anderson EL. 1983. Quantitative approaches in use to assess cancer risk. Risk Anal 3(4):277–295.

ATSDR (Agency for Toxic Substances and Disease Registry). 1999. Toxicological Profile for Mercury. http://www.atsdr.cdc.gov/toxprofiles/tp46.pdf [accessed 23 October 2014].

ATSDR. 2007a. Toxicological Profile for Arsenic. http://www.atsdr.cdc.gov/toxprofiles/tp2.pdf [accessed 23 October 2014].

ATSDR. 2007b. Toxicological Profile for Lead. http://www.atsdr.cdc.gov/toxprofiles/tp3.pdf [accessed 23 October 2014].

ATSDR. 2008. Case Studies in Environmental Medicine (CSEM). Cadmium Toxicity. WB 1096. http://www.atsdr.cdc.gov/csem/cadmium/docs/cadmium.pdf [accessed 20 November 2015].

ATSDR. 2010. Case Studies in Environmental Medicine (CSEM). Lead Toxicity. WB 1105. http://www.atsdr.cdc.gov/csem/lead/docs/lead.pdf [accessed 17 September 2015].

ATSDR. 2012. Toxicological Profile for Cadmium. http://www.atsdr.cdc.gov/toxprofiles/tp5.pdf [accessed 12 March 2015].

Broitman L. 2012. Ongoing Activities to Support the Asian Over-sample in NHANES. http://www.cdc.gov/nchs/ppt/nchs2012/ss_14_broitman.pdf [accessed 9 October 2014].

Buchanan S, Anglen J, Turyk M. 2015. Methyl mercury exposure in populations at risk: analysis of NHANES 2011–2012. Environ Res 140:56–64.

Caldwell KL, Jones RL, Verdon CP, Jarrett JM, Cauldfid SP, Osterhol JD. 2009. Levels of urinary total and speciated arsenic in the US population: National Health and Nutrition Examination Survey 2003–2004. J Expo Sci Environ Epidemiol 19(1):59–68.

CDC (Centers for Disease Control and Prevention). 2014. Fourth National Report on Human Exposure to Environmental Chemicals. Updated Table. http://www.cdc.gov/biomonitoring/pdf/FourthReport_UpdatedTables_Feb2015.pdf [accessed 27 July 2014].

CDC. 2015. National Health and Nutrition Examination Survey. http://www.cdc.gov/nchs/nhanes.htm [accessed 10 October 2016].

Davis MA, Mackenzie TA, Cottingham KL, Gilbert-Diamond D, Punshon T, Karagas MR. 2012. Rice consumption and urinary arsenic concentrations in U.S. children. Environ Health Perspect 120:1418–1424, doi: 10.1289/ehp.1205014.

DHHS (U.S. Department of Health and Human Services). 2013. Poverty Guidelines, Research, and Measurement. Washington, DC:DHHS. https://aspe.hhs.gov/2013-poverty-guidelines [accessed 23 September 2015].

Ding C, Pan Y, Zhang A, Wu B, Huang H, Zhu C, et al. 2014. Study of distribution and influencing factors of lead and cadmium in whole blood and urine among population in 8 provinces in China [in Chinese]. Zhonghua Yu Fang Yi Xue Za Zhi 48(2):91–96.

Egan SK, Bolger PM, Carrington CD. 2007. Update of US FDA’s Total Diet Study food list and diets. J Expo Sci Environ Epidemiol 17(1):573–582.

Ferraro PM, Costanza S, Naticchia A, Storniolo A, Gambaro G. 2010. Low level exposure to cadmium increases the risk of chronic kidney disease: analysis of the NHANES 1999–2006. BMC Public Health 10:304, doi: 10.1186/1471-2458-10-304.

Gleason K, Shine JP, Shobnam N, Rokoff LB, Shankede HS, Illi Hassan MOS, et al. 2014. Contaminated turmeric is a potential source of lead exposure for children in rural Bangladesh. J Environ Public Health 2014:730636, doi: 10.1155/2014/730636.

Goswami K. 2013. Eye cosmetic ‘surma’: hidden threats of lead poisoning. Indian J Clin Biochem 28(1):71–73.

He P, Lu Y, Liang Y, Chen B, Wu M, Li S, et al. 2013. Exposure assessment of dietary cadmium: findings from Shanghainese over 40 years, China. BMC Public Health 13(1):590, doi: 10.1186/1471-2458-13-590.

Hightower JM, Moore D. 2003. Mercury levels in high-end consumers of fish. Environ Health Perspect 111:604–608, doi: 10.1289/ehp.5637.

Hoefel EM, Rastogi S, Kim MO, Shahid H. 2012. The Asian Population: 2010. 2010 Census Briefs. C2010BR-11. https://www.census.gov/prod/cen2010/briefs/c2010br-11.pdf [accessed 21 October 2014].

IARC (International Agency for Research on Cancer). 2013. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Agents Classified by the IARC Monographs, Volumes 1–117. http://monographs.iarc.fr/ENG/Classification/ [accessed 20 December 2013].

Ingram DD, Franco SJ. 2014. 2013 NCHS urban–rural classification scheme for counties. Vital Health Stat 2 162:1–73.

Jakubowski M. 2011. Low-level environmental lead exposure and intellectual impairment in children—the current concepts of risk assessment. Int J Occup Med Environ Health 24(1):1–7.

Johnson CL, Dohrmann SM, Burt VL, Mohadjer LK. 2014. National Health and Nutrition Examination Survey: sample design, 2011–2014. Vital Health Stat 12 612:1–33.

Lebel J, Mergler D, Lucotte M, Amorim M, Dolbec J, Miranda D, et al. 1996. Evidence of early nervous system dysfunction in Amazonian populations exposed to low-levels of methylmercury. Neurotoxicology 17(1):157–167.

Mckelvey W, Gwyrm RC, Jeffery N, Kass D, Thorpe LE, Garg RK, et al. 2007. A biomonitoring study of lead, cadmium, and mercury in the blood of New York City adults. Environ Health Perspect 115:1435–1441, doi: 10.1289/ehp.100506.
Metal biomarker levels of Asian population

McLaine P, Navas-Acien A, Lee R, Simon P, Diener-West M, Agnew J. 2013. Elevated blood lead levels and reading readiness at the start of kindergarten. Pediatrics 131(6):1081–1089.

Moon KA, Guallar E, Umans JG, Devereux RB, Best LG, Francesconi KA, et al. 2013. Association between exposure to low to moderate arsenic levels and incident cardiovascular disease. A prospective cohort study. Ann Intern Med 159(10):649–659.

Mortensen ME, Caudill SP, Caldwell KL, Ward CD, Jones RL. 2014. Total and methyl mercury in whole blood measured for the first time in the U.S. population: NHANES 2011–2012. Environ Res 134:257–264.

NCHS (National Center for Health Statistics). 2011a. Laboratory Procedure Manual. Arsenobetaine, Arsenocholine, Trimethylarsine Oxide, Monomethylarsonic Acid, Dimethylarsinic Acid, Arsenous (III) Acid, Arsenic (V) Acid. Hyattsville, MD:NCHS.

NCHS. 2011b. Laboratory Procedure Manual. Creatinine. Hyattsville, MD:NCHS. http://www.cdc.gov/nchs/data/nhanes/nhanes_11_12/biopro_g_met_creatinine.pdf [accessed 15 October 2015].

NCHS. 2012a. Disclosure Manual. Preventing Disclosure: Rules for Researchers. Hyattsville, MD:NCHS. http://www.cdc.gov/rdc/data/b4/disclosuremanual.pdf [accessed 16 July 2015].

NCHS. 2012b. Laboratory Procedure Manual. Cadmium, Lead, Manganese, Mercury, and Selenium. Hyattsville, MD:NCHS. http://www.cdc.gov/nchs/data/nhanes/nhanes_11_12/pbcd_g_met_blood-metals.pdf [accessed 15 October 2015].

NCHS. 2013. National Health and Nutrition Examination Survey: Analytic Guidelines, 2011–2012. Hyattsville, MD:NCHS. http://www.cdc.gov/nchs/data/nhanes/nhanes_11_12/analytic_guidelines_11_12.pdf [accessed 15 October 2015].

Peters JL, Fabian MP, Levy JI. 2014. Combined impact of lead, cadmium, polychlorinated biphenyls and non-chemical risk factors on blood pressure in NHANES. Environ Res 132:93–99.

Rothenberg SE, Korrick SA, Fayad R. 2015. The influence of obesity on blood mercury levels for U.S. non-pregnant adults and children: NHANES 2007–2010. Environ Res 139:173–180.

RTI International. 2012. SUDAAN 11. Language Manual. 2012; 1 and 2 (Release 11). Research Triangle Park, NC:Research Triangle Institute.

Seo JW, Kim BG, Kim YM, Kim RB, Chung JY, Lee KM, et al. 2015. Trend of blood lead, mercury, and cadmium levels in Korean population: data analysis of the Korea National Health and Nutrition Examination Survey. Environ Monit Assess 187(3):146, doi: 10.1007/s10661-015-4348-2.

Tsuij JS, Yost LJ, Barraj LM, Scrafford CG, Mink P. 2007. Use of background inorganic arsenic exposures to provide perspective on risk assessment results. Regul Toxicol Pharmacol 48(1):59–68.

U.S. Census Bureau. 2013. Asians Fastest-Growing Race Or Ethnic Group in 2012, Census Bureau Reports. CB13-112. http://www.census.gov/newsroom/press-releases/2013/cb13-112.html [accessed 13 June 2013].