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Dietary determinants of cadmium exposure in the Strong Heart Family Study

Pablo Olmedo [a, b, *], Maria Grau-Perez [a, b], Amanda Fretts [c], Maria Tellez-Plaza [a, d], Fernando Gil [e], Fawn Yeh [f], Jason G. Umans [g], Kevin A. Francesconi [h], Walter Goessler [h], Nora Franceschini [i], Elisa T. Lee [f], Lyle G. Best [j], Shelley A. Cole [k], Barbara V. Howard [l], Ana Navas-Acien [a, b, m, n]

[a] Department of Environmental Health Sciences, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA
[b] Department of Environmental Health Sciences, Mailman School of Public Health, Columbia University, New York, NY, USA
[c] Department of Epidemiology, University of Washington School of Public Health, Seattle, WA, USA
[d] Fundación de Investigación Hospital Clínico de Valencia INCLIVA, Valencia, Spain
[e] Department of Legal Medicine and Toxicology, School of Medicine, University of Granada, Spain
[f] Center for American Indian Health Research, College of Public Health, University of Oklahoma Health Sciences Center, Oklahoma City, OK, USA
[g] Department of Medicine, Georgetown University Medical Center, Washington, DC, USA
[h] Institute of Chemistry -Analytical Chemistry, University of Graz, Austria
[i] Department of Epidemiology, University of North Carolina Gillings School of Global Public Health, Chapel Hill, NC, USA
[j] Missouri Breaks Industries Research, Inc, Timber Lake, SD, USA
[k] Department of Genetics, Texas Biomedical Research Institute, San Antonio, TX, USA
[l] MedStar Health Research Institute, Hyattsville, MD, USA
[m] Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA
[n] Welch Center for Prevention, Epidemiology and Clinical Research, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA

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A B S T R A C T

Urinary cadmium (Cd) concentrations in the Strong Heart Family Study (SHFS) participants are higher than in the general US population. This difference is unlikely to be related to tobacco smoking. We evaluated the association of consumption of processed meats and other dietary products with urinary Cd concentrations in the SHFS, a family-based study conducted in American Indian communities. We included 1725 participants with urine Cd concentrations (standardized to urine creatinine) and food frequency questionnaire data grouped in 24 categories, including processed meat. Median (IQR) urinary Cd concentrations were 0.42 (0.20–0.85) μg/g creatinine. The age, sex, smoking, education, center, body mass index, and total kcal adjusted geometric mean ratio (GMR) (95%CI) of urinary cadmium concentrations per IQR increase in each dietary category was 1.16 (1.04–1.29) for processed meat, 1.10 (1.00–1.21) for fries and chips, 0.87 (0.80–0.95) for dairy products, and 0.89 (0.82–0.97) for fruit juices. The results remained similar after further adjustment for the dietary categories associated with urinary Cd in the previous model except for fries and chips, which was no longer statistically significant. These findings revealed the potential importance of processed meat products as a dietary source of cadmium.

1. Introduction

Cadmium is a toxic metal with multiple health effects including kidney disease, bone fragility, cardiovascular disease and several cancers even at low exposure levels (Tellez-Plaza et al., 2013a, 2013b; García-Esquinas et al., 2014). Cadmium half-life in the body is extremely long (20–35 years) due to its cumulative capacity and binding to different proteins, especially in the kidneys and liver (Jomova and Valko, 2011). Tobacco is a major source of cadmium exposure in humans (Gil et al., 2011), as tobacco leaves bio-concentrate cadmium, which is then absorbed through the lungs during smoking. In non-smokers, the diet is the main source of

* Corresponding author. Department of Environmental Health Sciences, Columbia University Mailman School of Public Health, 722 West 168th St, New York, NY 10032, USA.
E-mail address: po2238@cumc.columbia.edu (P. Olmedo).

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cadmium (ATSDR, 2012) including root and leafy vegetables (e.g. potatoes, lettuce or spinach) (EFSA, 2009; Llobet et al., 2003), shellfish (e.g. clams or mussels) (Olmedo et al., 2013) and organ meats (e.g. liver or kidneys) (Jokanović et al., 2013).

The characterization and prevention of cadmium exposures are warranted, especially in disproportionately exposed populations. In the Strong Heart Study (SHS), a population-based prospective cohort study conducted in American Indian communities in Arizona, Oklahoma and North and South Dakota, baseline urinary cadmium concentrations were markedly higher in the study participants compared to the general US population, even among never smokers (Tellez-Plaza et al., 2013b; Pang et al., 2016). These findings suggest there are unaccounted sources of cadmium exposure in the SHS population. Fretts et al. (2012) have reported a high consumption of processed meats in the SHS communities (68% participants consumed at least 3 servings of processed meats per week). Processed meat products, commonly consumed by low-income families due to its low price, could constitute a relevant source of cadmium exposure as they contain heavily processed animal tissues, some of them potentially including organ meats. Several types of processed meats have historically been distributed free of charge by U.S. Department of Agriculture food assistance program in some Indian reservations and this distribution influences their diet (Smith et al., 1996; Taylor et al., 2006; Vaughan et al., 1997).

Baseline urinary cadmium concentrations, a biomarker of long-term exposure, were positively associated with incident cardiovascular disease in the SHS, even among non-smokers (Tellez-Plaza et al., 2013b). The goal of this study was to assess the association of different foods, with a specific interest on processed meat products, with urinary cadmium concentrations in the Strong Heart Family Study (SHFS), a family-based extension of the SHS that included a detailed food frequency questionnaire and urinary cadmium measures during the 2001–2003 visit. Our main hypothesis was that higher frequency and amount of processed meat consumption is associated with higher cadmium concentrations in urine. Given relatively high urinary cadmium concentrations in the SHS communities and its associated health effects, identifying relevant sources of exposure is critical for the development of prevention interventions.

2. Materials and methods

2.1. Study population

The SHFS is a multigenerational cohort recruited from the SHS (North et al., 2002). Families were eligible if they had a core sibship consisting of 3 original SHS participants and at least 5 additional living family members. During the 2001–2003 baseline visit, 2474 SHFS participants (15 years of age and older) were recruited who were free of diabetes at baseline and had urine metal concentrations measured as part of an ancillary study to evaluate gene-environment interactions for incident diabetes. We only included participants with dietary data available ($n = 2188$). We excluded 1 participant with missing urinary creatinine, 3 participants with abnormal concentrations of creatinine-corrected urine cadmium (concentrations 24, 30 and 200 times higher than the 90th percentile), and participants with missing values of educational level ($n = 8$), body mass index ($n = 7$), and smoking status ($n = 1$). We further excluded 443 participants from a community that has withdrawn their permission to conduct research in 2016, leaving a total of 1725 participants in this analysis (see participant flow chart in Supplemental Fig. 1).

The study protocol was approved by the institutional review boards of the Indian Health Service, the participating institutions and the participating tribes. All participants provided written informed consent.

2.2. Food frequency questionnaire

An interviewer-administered Block 119-item Food Frequency Questionnaire (FFQ) was used to measure usual food intake as previously described (Fretts et al., 2012). Serving sizes, described as standard units (e.g., 1 banana, 2 eggs, etc.) or standard vol/wt portions, were assessed using photographs of various portions as visual aids. Each participant was asked how often, on average, a particular food was consumed during the past year. The quantity was assessed using frequency measures of consumption (seasonally, never, a few times per year, once per month, 2–3 times/mo, once per week, twice per week, 2–3 times/wk, 5–6 times/wk, daily) and adjusted for portion size (small, medium, or large). In addition to standard Block FFQ food items, the FFQ included foods commonly consumed among American Indians such as menudo, pozole, guysava, red or green chili, Indian taco, fry bread, corn tortilla, flour tortilla, and “spam” (a term that refers to canned meats, usually a combination of heavily processed beef or pork meats, salt, sodium nitrate, potato starch and water).

Average daily energy and macronutrient intakes were calculated for each study participant by using the Block database (Block Dietary Systems). To obtain measures of average daily energy and nutrient intake, the frequency response for each food on the FFQ and American Indians supplementary foods questionnaire was multiplied by the nutrient content of the documented portion size of the food, then summed for all foods (Block et al., 1998).

The food items in the FFQ were grouped in 24 different categories according to their potential cadmium content based on data on cadmium concentrations in US foods from the Total Diet Study Market Baskets 2006 through 2011 conducted by the US Food and Drug Administration (FDA., 2014). As an example, leafy vegetables, fries and chips, nuts and seeds, organ meat and processed meat had their own categories. For instance, the classification of fries and chips together and separated from boiled or baked potatoes is due to different levels of cadmium concentrations in these modalities of potato preparation. The specific food stuffs included in each category is displayed in Supplemental Table 1. For processed meats, for instance, our goal was to include meats made of mixed parts of the animal and for that reason we did not include bacon or hamburgers. Total intake for each food category was expressed as grams (g) consumed per day (Supplemental Fig. 2).

2.3. Urine cadmium

Spot urine samples from baseline were collected in polypropylene tubes, frozen within 1–2 h of collection, shipped buried in dry ice and stored in freezers at −70 °C in the Penn Medical Laboratory, MedStar Research Institute, Washington, DC. Strict controls on the sampling, transport and storage of urine were conducted to ensure study quality (Strong Heart Study, 1991). The analyses of cadmium and other metals were performed by Inductively Coupled Plasma Mass Spectrometry ICP-MS (Agilent 7700x ICP-MS, Agilent Technologies, Waldbronn, Germany) and urine samples have already been used to measure creatinine and albumin (Tellez-Plaza et al., 2013b; Scheer et al., 2012). The inter-assay and the intra-assay coefficients of variation for urinary cadmium concentrations were 8.7% and 4.5%, respectively. Standard reference materials (National Institute of Standards and Technology, NIST 1640a and 1643e) were used to test the accuracy of the analyses. The limit of detection for urine cadmium was 0.015 μg/L (and the corresponding limit of quantification is 0.050 μg/L), but our limit of detection is estimated conservatively so we kept all values provided