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Association of Electronic Cigarette Use with Lead, Cadmium, Barium, and Antimony Body Burden: NHANES 2015–2016

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Structured Abstract

BACKGROUND—Exposure of toxic metals from e-cigarette use is a cause for public health concern because youth, young adults, and non-smokers are the target population rapidly adopting e-cigarette use. The purpose of this research is to determine the association of the body burden of heavy metals with e-cigarette use using NHANES (U.S.) 2015–2016 data.

METHODS—Blood lead (N=1899) and urinary cadmium, barium, and antimony (N=1302) data were extracted from NHANES, 2015–2016; geometric means were calculated and bivariate and multivariable linear regression analyses were conducted. Participants were categorized as having neither e-cigarette nor cigarette use; smoking history (including dual use with e-cigarettes); and only e-cigarette (current or former).

RESULTS—In multivariable analyses adjusted for sex, race/ethnicity, age, and poverty levels, current or former e-cigarette use failed to reach a statistical significance in the association with

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Author statement

CRediT roles:

RC Wiener: Conceptualization; Data curation; Formal analysis;
RC Wiener, R Bhandari: Investigation;
RC Wiener: Methodology;
RC Wiener: Software;
RC Wiener: Validation;
RC Wiener, R Bhandari: Visualization;
RC Wiener, R Bhandari: Roles/Writing - original draft;
RC Wiener, R Bhandari: Writing - review & editing.

Conflict of Interest

The authors (R. Constance Wiener and Ruchi Bhandari) would like to state the following:

1. The authors do not have financial or other relationships that might lead to a conflict of interest;
2. The manuscript has been read and approved by both the authors, the requirements for authorship have been met, and each author believes that the manuscript represents honest work; and
3. The manuscript has not been published nor is under consideration elsewhere.

metals. However, participants with a smoking history were more likely to have higher blood lead and urinary cadmium than participants who neither used e-cigarettes nor cigarettes.

CONCLUSION—Blood lead levels, and urinary cadmium, barium, and antimony levels were similar between participants who used e-cigarettes and participants who did not.

Keywords

e-cigarettes; metals; lead; cadmium; barium; antimony

Introduction

Nationally, 15% of the U.S. adults had ever used electronic cigarettes (e-cigarettes) in 2014 [1] and they are the most common form of tobacco product used among adolescents, with 3.6 million middle and high school students in the U.S. currently using e-cigarettes [2]. Researchers have identified more than 7,000 chemicals, including 69 carcinogens, present in tobacco smoke [3]. In earlier studies using data from the National Health and Nutrition Examination Survey (NHANES), researchers found that smokers had higher urinary lead, cadmium, antimony, and barium levels than nonsmokers [4–6].

E-cigarette fluids contain over 7,700 flavor chemicals [7], other organic chemicals [8,9], and heavy metals [10,11], some of which are known carcinogens [12]. Compared with conventional cigarette smoke, the e-cigarette aerosols have higher levels of sodium, iron, aluminum, and nickel [10]. In a recent systematic review of 12 studies, researchers found the following trace metals in e-cigarette aerosols: nickel; chromium; cadmium; tin; aluminum; and lead [13]. The levels of these metals in e-cigarette liquid and aerosols sometimes exceed the permissible exposure limit determined by Occupational Safety and Health Administration [14]. This issue is more challenging because of the increasing dual use of tobacco products [9]. Dual users have higher concentrations of nicotine and toxicants [15].

Chronic inhalation of these elements and metals have harmful effects on human health. Prolonged lead exposure affects the cardiovascular system, lungs [16], and brain [17]. Antimony, can also cause heart and lung problems [18]. Cadmium is classified as a known human carcinogen linked with lung cancer [16], and an independent risk factor for cardiovascular and metabolic diseases [19]. Barium has the potential to cause gastrointestinal disturbances and muscular weakness [20]. Although heavy metals are present in e-cigarette aerosols, the body burden of the heavy metals in relationship with e-cigarette use has had limited research [4, 5]. The purpose of this research is to determine the association of e-cigarette use with the body burden of lead, cadmium, antimony, and barium.

Methods

This study received West Virginia University Institutional Review Board Non-Human Study Research (NHSR, secondary data analysis) acknowledgement (protocol 1908692730).

The data used in this study were obtained from NHANES 2015–2016, publicly available from the NHANES website [21]. NHANES is a cross-sectional survey to assess the health and nutrition status of U.S. population. Data are collected through interviews, medical examination, and laboratory tests among a sample of about 10,000 participants who are selected through stratified random sampling. This study included participants aged 18–65 years who had blood and urine tested for heavy metals and e-cigarette data.

Heavy metal data were extracted from the NHANES “Blood Lead, Cadmium, Total Mercury, Selenium, and Manganese” file and from the “Metals-Urine” file. For the lead analysis, a sample of the collected blood sample was vortexed, anti-coagulant was added, and diluted [21]. The chemicals in the diluent helped release lead from the red blood cells, prevented clogging, and helped standardize the analysis. The liquid was then placed into a mass spectrometer through inductively coupled plasma ionization source, forced through a nebulizer, and passed through a spray chamber by a flowing argon stream. Plasma at 6000–8000K vaporized the liquid drops, atomized the molecules and ionized the atoms [21]. Then the ions and argon entered the mass spectrophotometer (Inductively Coupled Plasma Mass Spectrometer with Dynamic Reaction Cell Technology (ELAN® DRC II) (PerkinElmer Norwalk, CT, www.perkinelmer.com). The ions were detected and processed into digital information. Detailed descriptions are available at the NHANES website [21].

For the urinary analysis of cadmium, barium, and antimony, liquid samples were placed into the mass spectrometer through the inductively coupled plasma ionization source, aerosolized with a nebulizer and the drops entered the inductively coupled plasma, passed through a focusing region, dynamic reaction cell, quadrupole mass filer, and to the detector.

E-cigarette use and combustible smoking data were extracted from the “Smoking-Cigarette Use, SMQ_I” file in which participants were asked about: ever smoking 100 combustible cigarettes during his or her life-time; ever using e-cigarettes; past 30 day use of e-cigarettes; and, past 30 day use of combustible cigarettes.

The heavy metal variables for this study were created by log transformations of the metal concentrations. The e-cigarette/combustible cigarette use variable was categorized as: 1) neither (participants reported never using e-cigarettes and never having smoked 100 combustible cigarettes); 2) positive combustible cigarette smoking history (participants who were current or former smokers with/without e-cigarette use); and, 3) positive e-cigarette use (participants who reported ever using e-cigarettes with or without reporting a past 30-day use).

Other variables known to impact heavy metal accumulation included in the study were sex (male, female), age (18–25, 26–44, 45–65 years); race/ethnicity (non-Hispanic white, non-Hispanic black, Mexican American, other); and federal poverty level (<200%, ≥200%).

Data were analyzed for frequency, simple and multiple linear regression analyses accounting for the survey weights provided in the NHANES 2015–2016 metal files. Adjustments were made for the complex sample design. Estimates for geometric means and 95% confidence intervals (CI) were determined for the demographic variables in unadjusted analyses for all metals [23] and in creatinine adjusted analyses [24,25] for urinary samples. Two adjusted linear regression models were created with: 1) sex, age, race/ethnicity, and federal poverty level. Cadmium, barium, and antimony results were presented with/without creatinine adjustment. Data analyses were conducted using SAS 9.4 (SAS Institute, Inc., Cary, NC).

Results

There were 1,899 blood samples for the lead analysis with 51% female; 40.7% ages 26–44 years; 61.7% non-Hispanic white; 65.9% at or above the 200% federal poverty level; and, 53.4% who reported neither smoking nor using e-cigarettes. There were 1302 participants who provided urinary samples for metal detection: 51.4% females; 41.0% ages 26–44 years; 61.5% non-Hispanic white; 67.2% at or above the federal poverty level; and, 52.2% who reported neither smoking nor using e-cigarettes.

The overall geometric mean blood lead level in e-cigarette users (with or without dual use with e-cigarettes) was 37 μg/L lower than that in participants who did not use combustible cigarettes but had current or former e-cigarette use. Results are presented in Table 1. The overall geometric mean urinary cadmium level in e-cigarette users (with or without dual use with e-cigarettes) was 0.02 μg/L lower than that in participants who did not use combustible cigarettes but had current or former e-cigarette use. Results are presented in Table 2. The overall geometric mean urinary barium level in e-cigarette users (with or without dual use with e-cigarettes) was 0.20 μg/L lower than that in participants who did not use combustible cigarettes but had current or former e-cigarette use. Results are presented in Table 3. The overall geometric mean urinary antimony level in e-cigarette users (with or without dual use with e-cigarettes) was 0.01 μg/L lower than that in participants who did not use combustible cigarettes but had current or former e-cigarette use. Results are presented in Table 4.

In an adjusted linear regression model, smoking history remained significant as compared with participants who neither used e-cigarettes nor combustible cigarettes for lead (adjusted odds ratio: 1.32 [1.21 to 1.45]; $P<.0001$), and for cadmium (adjusted odds ratio: 1.81 [1.49 to 2.20]; $P<.0001$) but failed to reach significance for barium and antimony. Results are presented in Table 5. Although not a focus of this study, age, sex, race/ethnicity, and income were independently associated with smoking e-cigarettes.

The correlation of the presence of metals in the participants was weak but significant for lead and cadmium ($r=0.23$; $P<.001$); and it was very weak and negative, although significant, for barium and antimony ($r = -.04$; $P=0.0334$). When correlations were specific to only e-cigarette use, there failed to be a relationship of lead with cadmium ($P= 0.9201$); however cadmium and barium had a weak significant correlation ($r=0.3622$; $P=0.022$).

Discussion

In multivariable analyses adjusted for sex, race/ethnicity, age, and poverty levels, current or former e-cigarette use failed to reach a statistical significance in the association with metals. In sensitivity analyses with dichotomized e-cigarettes use, participants who used e-cigarettes ≥ 1 day within the previous 30 days were more likely to have higher lead and cadmium levels than participants who did not use e-cigarettes within the previous 30 days.

While researchers have reported the presence of elements and metals in e-cigarettes, few studies have estimated the health risk associated with this exposure. Jain and colleagues (2019) found lower cadmium among participants who used e-cigarettes to be similar to non-smokers [5]. In one study, cadmium was present in e-cigarette aerosol, but not in cigarette smoke [14]. Goniewicz and colleagues found cadmium exposure to be higher with e-cigarette use compared with never use [15]. In a third study, researchers estimated the health effect of metal exposure in e-cigarettes by comparing the highest levels reported in the literature with the permissible daily exposure limit defined by regulatory authorities [22]. Among the 14 e-cigarette samples tested, cadmium was lower compared to chronic permissible daily exposure or similar to background environmental air levels on average [22]. It was found to be 10% higher than permissible daily exposure only in one sample [22].

Williams and colleagues (2019) found that lead concentration in e-cigarette aerosols was higher than in cigarette smoke [14]. In addition, lead concentration was higher in the aerosols produced by high voltage and the concentrations were higher than the permissible exposure limit proposed by Occupational Safety and Health Administration. Similar to their findings on lead, Goniewicz and colleagues (2018) found lead exposure to be higher with e-cigarette use compared with never use [15]. Unlike the findings in Williams and colleagues' study [11], Jain and colleagues (2019) [4] found lower lead levels with e-cigarette use, similar to never smoking. In the health-effects study, although lead was found in all e-cigarette samples, exposure to lead was lower than permissible daily exposure, and there were large variations within the e-cigarette products [22]. Researchers did not find barium in 13 of the 14 e-cigarette samples tested, and in one sample barium was found to be significantly below the safety limit [22]. In another study using previous 5-day e-cigarette use, the researchers found no difference in blood and urinary cadmium, lead, and mercury comparing participants who used e-cigarettes, combustible cigarettes, or had dual use; however, the researchers excluded participants with no such use [4].

The effects of e-cigarette use upon body burden of metals are complex and are influenced by many factors such as the definitions of use, frequency of use, type of e-cigarette device, manufacturer, and e-cigarette liquid. One concern with the available research is that the operational definition of prevalence of e-cigarette use is not standardized. Some researchers define current e-cigarette use as "any use in the past 30 days," while others use the definition of "use on every day or some days" [23]. Prevalence is also reported by some researchers as "established" use or "experimentation/infrequent" use based upon the number of days of use [23]. The cut-points to define established use are also not well established although 0; 1–5; 6–29; and 30 days of use during the previous 30 days was recommended in one study [23]. Additionally, e-cigarette aerosol exposure varies by the type of device; presence or absence of nicotine and/or flavorings in the e-cigarette fluid [24]; and, previous, current, or dual use of other tobacco products. All of these factors influence research results.

In a study involving the body burden of heavy metals and e-cigarettes, the participants who self-reported e-cigarette use (n=34) were all former smokers [12]. They had the highest concentrations of selenium, silver, arsenic, nickel, and vanadium compared with non-smokers and current smokers. However, the frequency of e-cigarette use was not defined in the paper. In the U.S. Population Assessment of Tobacco and Health (PATH) Study, e-cigarette use was measured as: "ever" use; the frequency of use (every day, somedays, or not at all); and any use during the previous 30 days (yes, no) [25]. Researchers concluded that never users (n=1655) had significantly less urinary lead and cadmium than e-cigarette-only users (n=247) [15].

In addition, the quality control in the manufacturing of e-cigarette devices has been called into question [10], as has the quality control for e-cigarette liquids, both of which can affect research results. For example, e-cigarette liquid was found to be labeled as having no nicotine when, in fact, it did have nicotine [26]. Additionally, many off-market, black market devices and e-cigarette liquids are available online or through the mail with questionable sourcing. Those e-cigarette liquids can have tetrahydrocannabinol (THC), unregulated flavorings, excessive vitamin E, and impurities that may be related to hundreds of severe lung illnesses confirmed or suspected to be linked to e-cigarette use.

Other factors, such as using creatinine correction in data analysis, also influence research results. Researchers disagree whether adjustment for creatinine improves the model analyzing the association between the exposure dose of e-cigarette and metals [27,28]; or whether such an adjustment is unnecessary and may, in fact, worsen the result [29,30].

Although there are significant data about the content of e-cigarette aerosols, there is scant information about the body burden of metals from e-cigarette aerosol. There are concerns about the nanoparticles of metals from the aerosol entering into the body as “their toxicological impact could be significant” [31]. Nanoparticles have the ability to enter alveolar sacs [32,33]. As the emphasis of the public health concern is upon organic compounds in e-cigarette liquids, the generation of metals by the e-cigarettes, and their body burden has received less research.

The complexity of e-cigarette use patterns, variabilities in brands [34], devices, and e-cigarette liquids are limitations for research. Another limitation of this study is the lack of data for metal exposures from other sources, such as occupational exposure. A better understanding of health effects of e-cigarettes needs to be ascertained. Lack of data on frequency of smoking (both e- and combustible cigarettes) is also a study limitation.

Conclusion

In this study, blood lead levels, and urinary cadmium, barium, and antimony levels were similar between participants who ever-used e-cigarettes and participants who did not, and therefore, e-cigarette use was not a major source of heavy metals. It is important to regularly monitor the patterns of e-cigarette use and other potentially harmful exposures from e-cigarettes. Such surveillance and assessment can provide evidence for public health guidelines and standards for Food and Drug Administration to set regulations.

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Table 1

Blood lead (μg/dL) geometric means and unadjusted Odds Ratios (95% confidence intervals)

	Geometric Mean for lead, [95% CI]	**OR [95%CI] unadjusted**[a]	***p*-value**
Overall blood lead (μg/dL)	0.82 μg/dL [0.77, 0.87]		
E-cigarette use/cigarette use			
Neither E-cigarette nor cigarette use	0.63 μg/dL [0.44, 0.91]	reference	NA
Smoking history (including dual use with e-cigarettes)	1.00 μg/dL [0.93, 1.08]	1.43 [1.30, 1.57]	<.0001
Only E-cigarette use (current or former)	0.70 μg/dL [0.64, 0.77]	0.90 [0.65, 1.25]	.5123
Sex			
Female	0.70 μg/dL [0.64, 0.77]	reference	NA
Male	0.94 μg/dL [0.86, 1.02]	1.33 [1.21,1.47]	<.0001
Age in years			
18–25	0.55 μg/dL [0.52, 0.59]	reference	NA
26–44	0.96 μg/dL [0.64, 0.76]	1.26 [1.13, 1.40]	.0003
45–65	1.06 μg/dL [0.97, 1.16	1.92 [1.77, 2.07]	<.0001
Race/ethnicity			
Non-Hispanic white	0.79 μg/dL [0.71, 0.87]	reference	NA
Non-Hispanic black	0.85 μg/dL [0.74, 0.97]	1.08 [0.96, 1.21]	.6147
Mexican American	0.77 μg/dL [0.72, 0.82]	0.98 [0.88, 1.08]	.1642
Other	1.00 μg/dL [0.92, 1.08]	1.26 [1.13, 1.41]	.0004
Federal Poverty Level			
≤200%	0.83 μg/dL [0.77, 0.91]	1.05 [0.96, 1.15]	.2996
>200%	0.80 μg/dL [0.73, 0.87]	reference	NA

[a]Odds ratios and *p*-values provided are based upon 1,899 participants in unadjusted linear regression on log-transformed blood lead levels. Relative standard error of mean blood lead and e-cigarette use/cigarette use <30%.

Abbreviations: NA, not applicable

Table 2

Urinary cadmium (μg/L) geometric means and Odds Ratios (95% confidence intervals)

	Geometric Mean for cadmium, [95% CI]	OR [95%CI] unadjusted[a]	*p*-value
Overall urinary cadmium (μg/L)	0.14 μg/L [0.13, 0.16]		
E-cigarette use/cigarette use			
Neither e-cigarette nor cigarette use	0.12 μg/L [0.11, 0.14]	reference	NA
Smoking history (with dual use e-cigarettes)	0.23 μg/L [0.20, 0.27]	1.86 [1.53, 2.26]	<.0001
Only e-cigarette use (current or former)	0.11 μg/L [0.08, 0.14]	0.86 [0.61, 1.20]	.3491
Sex			
Female	0.17 μg/L [0.14, 0.20]	reference	NA
Male	0.15 μg/L [0.14, 0.16])	0.88 [0.77, 1.01]	.0719
Age in years			
18–25	0.10 μg/L [0.08, 0.11]	reference	NA
26–44	0.14 μg/L [0.12, 0.15]	1.41 [1.25, 1.60]	<0001
45–65	0.21 μg/L [0.19, 0.25]	2.22 [1.83, 2.70]	<.0001
Race/ethnicity			
Non-Hispanic white	0.14 μg/L [0.13, 0.16]	reference	NA
Non-Hispanic black	0.23 μg/L [0.20, 0.27]	1.53 [1.36, 2.85]	<.0001
Mexican American	0.15 μg/L [0.14, 0.17]	1.07 [0.93, 1.24]	.2996
Other	0.18 μg/L [0.16, 0.21]	1.29 [1.11, 1.49]	.0027
Federal Poverty Level			
≤200%	0.16 μg/L [0.14, 0.18]	1.04 [0.90, 1.19]	.5976
>200%	0.16 μg/L [0.14, 0.17]	reference	NA
		Creatinine-adjusted OR [95%CI]	
Overall urinary cadmium (μg/L)	0.17 μg/L [0.16, 0.19]		
E-cigarette use/cigarette use			
Neither e-cigarette nor cigarette use	0.14 μg/L [0.13, 0.15]	reference	NA
Smoking history (with dual use e-cigarettes)	0.23 μg/L [0.21, 0.27]	1.63 [1.42, 1.88]	<.0001
Only e-cigarette use (current or former)	0.09 μg/L [0.08, 0.11]	0.65 [0.55, 0.77]	<.0001
Sex			
Female	0.22 μg/L [0.20, 0.25]	reference	NA
Male	0.13 μg/L [0.13, 0.14]	0.60 [0.55, 0.96]	<.0001
Age in years			
18–25	0.09 μg/L [0.08, 0.10]	reference	NA
26–44	0.15 μg/L [0.13, 0.16]	1.66 [1.48, 1.85]	<.0001
45–65	0.26 μg/L [0.23,0.28]	2.94 [2.57, 3.97]	<.0001
Race/ethnicity			
Non-Hispanic white	0.17 μg/L [0.15, 0.19]	reference	NA
Non-Hispanic black	0.17 μg/L [0.14,0.19]	0.98 [0.83, 1.16]	.8324

	Geometric Mean for cadmium, [95% CI]	OR [95%CI] unadjusted[a]	*p*-value
Mexican American	0.16 μg/L [0.15, 0.18]	0.95 [0.85, 1.07]	.4063
Other	0.23 μg/L [0.20, 0.27]	1.37 [1.12, 1.67]	.0045
Federal Poverty Level			
≤200%	0.18 μg/L [0.16, 0.20]	1.04 [0.88, 1.22]	.6495
>200%	0.17 μg/L [0.15, 0.19]	reference	NA

The first part of each table contains unadjusted association between urinary cadmium levels and each factor. The second part of each table contains association between urinary cadmium levels and the specific metal adjusted for sex, race/ethnicity, age, and poverty level.

[a]Odds ratios and *p*-values are based upon 1,302 participants in unadjusted/or creatinine-adjusted linear regression on log-transformed urinary cadmium levels. Relative standard error of mean urinary cadmium and e-cigarette use/cigarette use <30%.

Abbreviations: NA, not applicable.

Table 3

Urinary barium (μg/L) geometric means and Odds Ratios (95% confidence intervals)

	Geometric Mean for barium, [95% CI]	**OR [95%CI] unadjusted[a]**	***p*-value**
Overall urinary barium (μg/L)	1.15 μg/L [1.08, 1.22]		
E-cigarette use/cigarette use			
Neither E-cigarette nor cigarette use	1.08 μg/L [0.99, 1.19]	reference	NA
Smoking history (with dual use e-cigarettes)	1.15 μg/L [1.03, 1.28]	1.06 [0.93, 1.21]	.3476
Only E-cigarette use (current or former)	1.65 μg/L [1.05, 2.60]	1.52 [0.98 to 2.32]	.0510
Sex			
Female	0.99 μg/L [0.88, 1.12]	reference	NA
Male	1.31 μg/L [1.17, 1.48]	1.32 [1.12, 1.56]	.0027
Age in years			
18–25	1.23 μg/L [0.99, 1.53]	reference	NA
26–44	1.17 μg/L [1.04, 1.32]	0.95 [0.78, 1.17]	.6390
45–65	1.06 μg/L [0.97, 1.17]	0.86 [0.69, 1.08]	.1868
Race/ethnicity			
Non-Hispanic white	1.22 μg/L [1.08, 1.39]	reference	NA
Non-Hispanic black	1.00 μg/L [0.83, 1.20]	0.82 [0.67, 1.00]	.0582
Mexican American	0.96 μg/L [0.85, 1.08]	0.78 [0.65, 0.94]	.0126
Other	1.10 μg/L [0.92, 1.30]	0.90 [0.75, 1.08]	.2341
Federal Poverty Level			
≤200%	1.00 μg/L [0.87, 1.16]	084 [0.74, 0.95]	.0080
>200%	1.20 μg/L [1.10, 1.31]	reference	NA
		Creatinine-adjusted OR [95%CI]	
Overall urinary barium(μg/L)	1.23 μg/L [1.11, 1.36]		
E-cigarette use/cigarette use			
Neither e-cigarette nor cigarette use	1.26 μg/L [1.14, 1.40]	reference	NA
Smoking history (with dual use e-cigarettes)	1.19 μg/L [1.09, 1.27]	0.93 [0.87, 1.00]	0.0427
Only e-cigarette use (current or former)	1.45 μg/L [0.97, 2.16]	1.15 [0.81, 1.62]	0.4020
Sex			
Female	1.30 μg/L [1.17, 1.44]	reference	NA
Male	1.17 μg/L [1.04, 1.32]	0.90 [0.81, 0.99]	.0681
Age in years			
18–25	1.12 μg/L [0.94, 1.32]	reference	NA
26–44	1.25 μg/L [1.09, 1.44]	1.12 [0.99, 1.27]	.0737
45–65	1.28 μg/L [1.15, 1.42]	1.14 [0.95, 1.38]	.1449
Race/ethnicity			
Non-Hispanic white	1.44 [μg/L 1.33, 1.60]	reference	NA
Non-Hispanic black	0.72 μg/L [0.59 to 0.89]	0.50 [0.42, 0.61]	<.0001

	Geometric Mean for barium, [95% CI]	OR [95%CI] unadjusted[a]	*p*-value
Mexican American	1.01 µg/L [0.88 to 1.15]	0.70 [0.59, 0.83]	.0005
Other	1.39 µg/L [1.19 to 1.60]	0.96 [0.78, 1.17]	.6396
Federal Poverty Level			
≤200%	1.10 µg/L [0.95 to 1.27]	0.84 [0.72, 0.97]	.0241
>200%	1.32 µg/L [1.18 to 1.46]	reference	NA

The first part of each table contains unadjusted association between urinary barium levels and each factor. The second part of each table contains association between urinary barium levels and the specific metal adjusted for sex, race/ethnicity, age, and poverty level.

[a]Odds ratios and *p*-values are based upon 1,302 participants in unadjusted/or creatinine-adjusted linear regression on log-transformed urinary barium levels. Relative standard error of mean urinary barium and e-cigarette use/cigarette use <30%.

Abbreviations: NA, not applicable.

Table 4

Urinary antimony (μg/L) geometric means and Odds Ratios (95% confidence intervals)

	Geometric Mean for antimony, [95% CI]	OR [95%CI] unadjusted[a]	*p*-value
Overall urinary antimony (μg/L)	0.09 μg/L [0.09, 0.10]		
E-cigarette use/cigarette use			
Neither E-cigarette nor cigarette use	0.10 μg/L [0.09, 0.11]	reference	NA
Smoking history (with/without e-cigarette use)	0.09 μg/L [0.09, 0.09]	1.02 [0.86, 1.12]	.9384
Only E-cigarette use (current or former)	0.10 μg/L [0.08, 0.13]	1.06 [0.82, 1.39]	.5292
Sex			
Female	0.09 μg/L [0.09, 0.11]	reference	NA
Male	0.09 μg/L [0.08, 0.09]	0.92 [0.77, 1.10]	.3393
Age in years			
18–25	0.09 μg/L [0.08, 0.10]	reference	
26–44	0.10 μg/L [0.09, 0.11]	1.09 [0.96, 1.23]	.1008
45–65	0.09 μg/L [0.08, 0.10]	0.98 [0.81, 1.19]	.6372
Race/ethnicity			
Non-Hispanic white	0.10 μg/L [0.09, 0.11]	reference	NA
Non-Hispanic black	0.09 μg/L [0.07, 0.11]	0.94 [0.77, 1.15]	.5491
Mexican American	0.08 μg/L [0.07, 0.09]	0.81 [0.71, 0.93]	.0061
Other	0.11 μg/L [0.10, 0.14]	1.18 [0.98, 1.42]	.0774
Federal Poverty Level			
≤200%	0.09 μg/L [0.08, 0.10]	0.94 [0.85, 1.03]	.1654
>200%	0.09 μg/L [0.09, 0.11]	reference	NA
		Creatinine-adjusted OR [95%CI]	
Overall urinary antimony (μg/L)	0.10 μg/L [0.09, 0.11]		
E-cigarette use/cigarette use			
Neither e-cigarette nor cigarette use	0.11 μg/L [0.10, 0.13]	reference	
Smoking history (with/without e-cigarette use)	0.10 μg/L [0.09, 0.11]	0.86 [0.68, 0.93]	.1632
Only e-cigarette use (current or former)	0.09 μg/L [0.06, 0.13]	0.81 [0.54, 1.21]	.2751
Sex			
Female	0.13 μg/L [0.10, 0.16]	reference	NA
Male	0.08 μg/L [0.07, 0.09]	0.63 [0.49, 0.80]	.0010
Age in years			
18–25	0.86 μg/L [0.07, 0.10]	reference	NA
26–44	0.11 μg/L [0.10, 0.12]	1.28 [1.10, 1.48]	.0030
45–65	0.11 μg/L [0.10, 0.13]	1.30 [1.05, 1.62]	.0198
Race/ethnicity			
Non-Hispanic white	1.44 μg/L [1.33, 1.60]	reference	NA

	Geometric Mean for antimony, [95% CI]	**OR [95%CI] unadjusted[a]**	***p*-value**
Non-Hispanic black	0.72 µg/L [0.59, 0.89]	0.50 [0.42, 0.61]	<.0001
Mexican American	1.01 µg/L [0.88, 1.15]	0.70 [0.59, 0.83]	.0012
Other	1.38 µg/L [1.19, 1.60]	0.96 [0.79, 1.65]	.0847
Federal Poverty Level			
≤200%	0.10 µg/L [0.09, 0.11]	0.94 [0.80, 1.10]	.3951
>200%	0.11 µg/L [0.10, 0.12]	reference	

The first part of each table contains unadjusted association between urinary antimony levels and each factor. The second part of each table contains association between urinary antimony levels and the specific metal adjusted for sex, race/ethnicity, age, and poverty level.

[a]Odds ratios and *p*-values are based upon 1,302 participants in unadjusted/or creatinine-adjusted linear regression on log-transformed urinary antimony levels. Relative standard error of mean urinary antimony and e-cigarette use/cigarette use <30%.

Abbreviations: NA, not applicable.

Table 5

Odds Ratios [95%CI] for the adjusted association of heavy metals and electronic cigarette

	Lead **OR [95%CI]** ***p*-value**	**Cadmium** **OR [95%CI]** ***p*-value**	**Barium** **OR [95%CI]** ***p*-value**	**Antimony** **OR [95%CI]** ***p*-value**
Adjusted for sex, race/ethnicity, age, and poverty level				
Neither E-cigarette nor cigarette use	reference	reference	reference	reference
Smoking history (including dual use with e-cigarettes)	1.32 [1.21, 1.45] <.0001	1.81 [1.49, 2.20] <.0001	1.05 [0.92, 1.20] .4643	1.10 [0.94, 1.28] .2262
Only E-cigarette use (current or former)	1.12 [0.85, 1.48] .3899	1.17 [0.82, 1.68] .3654	1.38 [0.96, 1.98] .0770	1.31 [0.91, 1.83] .1008
Adjusted for creatinine, sex, race/ethnicity, age, and poverty level				
Neither E-cigarette nor cigarette use	NA	reference	reference	reference
Smoking history (including dual use with e-cigarettes)	NA	1.62 [1.44, 1.82] <.0001	0.94 [0.88, 1.01] .0737	0.91 [0.71, 1.17] .4282
Only E-cigarette use (current or former)	NA	0.97 [0.81, 1.16] .7194	1.14 [0.81, 1.60] .4210	0.88 [0.58, 1.33] .5118

Lead n=1,899 participants; Other metals n=1,302.