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RESEARCH ARTICLE

Urinary heavy metals, phthalates, phenols, thiocyanate, parabens, pesticides, polyaromatic hydrocarbons but not arsenic or polyfluorinated compounds are associated with adult oral health: USA NHANES, 2011–2012

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Abstract Links between environmental chemicals and human health have emerged over the last few decades, but the effects on oral health have been less studied. Therefore, it was aimed to study the relationships of different sets of urinary chemical concentrations and adult oral health conditions in a national and population-based setting. Data was retrieved from the United States National Health and Nutrition Examination Surveys, 2011–2012 including demographics, self-reported oral health conditions and urinary environmental chemical concentrations (one third representative sample of the study population). Chi-square test, *t* test, and survey-weighted logistic and multi-nominal regression modeling were performed. Of 4566 American adults aged 30–80, 541 adults (11.9 %) reported poor teeth health while 1020 adults (22.4 %) reported fair teeth. Eight hundred fifty-five people (19.1 %) claimed to have gum disease, presented with higher levels of urinary cadmium, cobalt and polyaromatic hydrocarbons. Six hundred three adults (13.3 %) had bone loss around the mouth, presented with higher levels of cadmium, nitrate, thiocyanate, propyl paraben and polyaromatic hydrocarbons. Eight hundred forty-five adults (18.5 %) had tooth loose not due to injury, presented with higher level of cadmium, thiocyanate and polyaromatic hydrocarbons. Eight hundred forty-five adults (18.5 %) with higher levels of lead, uranium, polyaromatic hydrocarbons but lower level of triclosan noticed their teeth did not look right. Three hundred fifty-one adults (7.7 %) often had aching in the mouth and 650 (14.3 %) had it occasionally, presented with higher levels of phthalates, pesticides and polyaromatic hydrocarbons. Benzophenone-3 and triclosan elicited protective effects. Regulation of environmental chemicals in prevention of adult oral health might need to be considered in future health and environmental policies.

Keywords Chemicals · Risk factor · Oral health · Gum disease · Self-rated teeth health · Bone loss · Toothache

Introduction

Links between environmental chemicals and human health in American adults including hypertension, cardiovascular disease, food allergy and cognitive function have emerged (Shiue 2013a, b, c, Shiue 2014), but the effects on oral health have been less studied, compared to other health conditions. Previously, research demonstrated hydrochloric acid as the most detrimental chemical to the dental samples while sulfuric acid enacted minimal alterations to the teeth, although some etching and discoloration were also noticeable (Cope and Dupras 2009). In addition, phosphoric acid resulted in variable changes of the organic and inorganic contents of teeth. Lastly, exposure of sodium hydroxide resulted in little to no change (Cope and Dupras 2009). Accidental exposure of children to high amounts of non-halogenated polycyclic aromatic hydrocarbons (PAHs) and halogenated aromatic

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hydrocarbons has been found to be associated with developmental enamel defects and missing permanent teeth (Alaluusua and Lukinmaa 2006). However, these studies had small sample size. Understanding risk effects from environmental chemicals on oral health in later life would seem to be necessary in order to eliminate any potential harmful impact and consequently to maintain and increase quality of life. Following this context, therefore, it was aimed to study the relationships of different sets of urinary chemical concentrations and adult oral health conditions in a national and population-based setting.

Methods

Study sample

As described elsewhere (more details via: http://www.cdc.gov/nchs/nhanes.htm), the United States National Health and Nutrition Examination Surveys (NHANES) has been a national, population-based, multi-year, cross-sectional study since the 1980s. Study samples are representative samples of the civilian, non-institutionalized US population. Information on demographics, lifestyle factors and self-reported health conditions was obtained by household interview using questionnaires. In the current analysis, the 2011–2012 study cohort as the most recent study wave was selected. Informed consents were obtained from participating subjects by the NHAN ES researchers. Only adults aged 30 and above who were asked about their oral health in details were included in the present study (more details via: http://wwwn.cdc.gov/nchs/nhanes/2011-2012/OHQ_G.htm). Questions included "Do you think you might have gum disease", "Have you been told by a dental professional that you have lost bone around your teeth", "Have you had any teeth become loose on their own, without an injury", "During the past 3 months, have you noticed a tooth that does not look right", "How often during the last year have you had painful aching anywhere in your mouth" and self-rated teeth conditions.

Biomonitoring

Urines were only collected in a subsample, being one third of the whole study cohort (still representative), to measure environmental chemical concentrations in urines. To be specific, participants were instructed to collect a partial void in a specimen cup during one morning when they first woke up and to mail it back to the contract laboratory (more details via: http://www.cdc.gov/nchs/nhanes/nhanes2011-2012/labdoc_g.htm). Urine specimens were then processed, stored under appropriate frozen (−20 °C) conditions, and shipped to the Division of Environmental Health Laboratory Sciences, National Center for Environmental Health, Centers for Disease Control and Prevention for analysis.

The inductively coupled plasma-mass spectrometry (ICP-MS) method (Mulligan et al. 1990) was used to measure the following 12 elements of heavy metals in urine: beryllium (Be), cobalt (Co), molybdenum (Mo), cadmium (Cd), antimony (Sb), cesium (Cs), tungsten (W), tin (Sn), strontium (Sr), manganese (Mn) thallium (TI), lead (Pb), and uranium (U). Urine samples are diluted 1+9 with 2 % (*v*/*v*), double-distilled, concentrated nitric acid containing both iridium (Ir) and rhodium (Rh) for multi-internal standardization (more details via: http://wwwn.cdc.gov/nchs/nhanes/2011-2012/UHM_G.htm). In addition, the test principle utilized high performance liquid chromatography-electrospray ionization-tandem mass spectrometry (HPLC-ESI-MS/MS) for the quantitative detection in urine of the following phthalate metabolites: monomethyl phthalate (MMP), mono-ethyl phthalate (MEP), monobutyl phthalate (MBP), mono-isobutyl phthalate (MIBP), mono (3-carboxypropyl) phthalate (MCPP), mono(2-ethylhexyl) phthalate (MEHP), mono-benzyl phthalate (MBzP), mono-isononyl phthalate (MNP), mono(2-ethyl-5-oxohexyl) phthalate (MEOHP), mono(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP), mono(2-ethyl-5-carboxypentyl) phthalate (MECPP), monocarboxyoctyl phthalate (MCOP), monocarboxynonyl phthalate (MCNP), and cyclohexane-1,2-dicarboxylic acid-mono(hydroxy-isononyl) ester (MHNCH) (Silva et al. 2007). Urine samples are processed using enzymatic deconjugation of the glucuronidated metabolites followed by on-line solid phase extraction (SPE) coupled with reversed phase HPLC-ESI-MS/MS. Assay precision is improved by incorporating isotopically labeled internal standards of the phthalate metabolites and MHNCH (more details via: http://wwwn.cdc.gov/nchs/nhanes/2011-2012/PHTHTE_G.htm).

Total and specific urine arsenic concentrations were determined by using inductively coupled plasma-dynamic reaction cell-mass spectrometry (ICP-DRC-MS) (more details via: http://wwwn.cdc.gov/nchs/nhanes/2011-2012/UAS_G.htm). In this case, urine is analyzed because urinary excretion is the major pathway for eliminating arsenic from the mammalian body (Vahter 1988). A sensitive method for measuring two dichlorophenols and several other phenols was developed in 2005 (Ye et al. 2005). The method used on-line solid phase extraction (SPE) coupled to HPLC and tandem mass spectrometry (HPL/CMS/MS) (more details via: http://wwwn.cdc.gov/nchs/nhanes/2011-2012/PP_G.htm and http://wwwn.cdc.gov/nchs/nhanes/2011-2012/EPH_G.htm).

To detect and measure metabolites of PAHs (more details via: http://www.cdc.gov/nchs/data/nhanes/nhanes_11_12/PAH_G_met.pdf), the procedure involved enzymatic hydrolysis of glucuronidated/sulfated OH-polyaromatic hydrocarbons metabolites in urine, extraction, derivatization, and analysis using isotope dilution capillary gas chromatography tandem mass spectrometry (GC-MS/MS). Ion transitions specific to each analyte and carbon-13 labeled internal standards are monitored, and the abundances of each ion are measured. Moreover, solid phase extraction coupled to high performance liquid chromatography-turbo ion spray ionization-tandem mass spectrometry (online SPE-HPLC-TIS-MS/MS) was used for the quantitative detection of perfluorooctane sulfonamide (PFOSA), 2-(N-methyl-perfluorooctane sulfonamido) acetic acid (Me-PFOSA-AcOH), 2-(N-ethyl-perfluorooctane sulfonamido) acetic acid (Et-PFOSA-AcOH), perfluorobutane sulfonate (PFBuS), perfluorohexane sulfonate (PFHxS), perfluorooctane sulfonate (PFOS), perfluoroheptanoate (PFHpA), perfluorooctanoate (PFOA), perfluorononanoate (PFNA), perfluorodecanoate (PFDeA), perfluoroundecanoate (PFUA), and perfluorododecanoate (PFDoA) (more details via: http://wwwn.cdc.gov/nchs/nhanes/2011-2012/PFC_G.htm).

For phenols and parabens that could come from industrial pollution, pesticide use, food consumption, or use of personal care products (more details via: http://wwwn.cdc.gov/nchs/nhanes/2011-2012/EPH_G.htm), a sensitive method for measuring BPA, BP-3, triclosan, and four parabens was developed in 2005 (Ye et al. 2005, 2006). The method uses on-line solid phase extraction (SPE) coupled to HPLC and tandem mass spectrometry (HPLC-MS/MS). While drinking water, milk, and certain plants with high water content can be the main sources of perchlorate intake for humans, nitrate and thiocyanate are polyatomic anions that can disrupt thyroid function by competitively inhibiting iodide uptake, similar to the action of perchlorate (more details via: http://wwwn.cdc.gov/nchs/nhanes/2011-2012/PERNT_G.htm). The laboratory method used was ion chromatography coupled with electrospray tandem mass spectrometry (more details via: and http://www.cdc.gov/nchs/data/nhanes/nhanes_11_12/PERNT_G_met.pdf).

Statistical analysis

Associations of urinary environmental chemical concentrations and adult oral health conditions were examined by *t* test and survey-weighted logistic and multi-nominal regression modeling, with $P<0.05$ considered statistically significant. This type of modeling could be perceived as an efficient and powerful way to analyze the effect of a group of independent variables on a binary outcome by quantifying each independent variable's unique contribution (Stoltzfus 2011). Potential covariates including urinary creatinine, age, sex, ratio of family income to poverty (proxy of socioeconomic status), body mass index and serum cotinine (biomarker of smoking status) were adjusted since they are commonly known for acting as buffers from environmental exposures to health outcomes. Urinary chemical concentrations were highly skewed, and therefore they were all log transformed when performing the statistical analyses. Statistical software STATA version 13.0 (STATA, College Station, TX, USA) was used to perform all the analyses. Since the present study is only a secondary data analysis by extracting data from the NHANES website, no further ethics approval was required.

Results

Of 4566 American adults aged 30–80, 541 people (11.9 %) reported poor teeth health, 1020 adults (22.4 %) reported fair teeth and 2993 adults (65.7 %) reported good teeth health. Characteristics of the adult participants are shown in Table 1.

Eight hundred fifty-five people (19.1 %) claimed to have gum disease, presented with higher levels of urinary

Table 1 Characteristics of American adults in 2011–2012

	N (%)
Age	48.9±17.9
20–39	1957 (35.2 %)
40–59	1812 (32.6 %)
60–80	1791 (32.2 %)
Sex	
Male	2740 (49.3 %)
Female	2820 (50.7 %)
Body mass index	28.8±6.9
<18.5	1103 (1.9 %)
18.5–24.9	1577 (28.4 %)
25–29.9	1684 (30.3 %)
30+	2196 (39.5 %)
Ratio of family income to poverty	
0–4.9	4199 (75.5 %)
5+	1361 (24.5 %)
Education level	
Less than 9th grade	550 (9.9 %)
9–11th grade	782 (14.1 %)
High school graduate or equivalent	1169 (21.0 %)
Some college or AA degree	1657 (29.8 %)
College graduate or above	1397 (25.2 %)
Serum cotinine (ng/mL)	52.1±120.2
Alcohol status	
>12 drinks	3413 (72.8 %)
Less than 12 drinks	1275 (27.2 %)
Physical activity level	
Engaging moderately	2297 (41.3 %)
None	3262 (58.7 %)

Table 2 Associations between urinary environmental chemical concentrations and adult gum disease

(*n*=1255)	No gum disease (*n*=3626, 80.9 %)	Gum disease (*n*=855, 19.1 %)	OR (95% CI)[a]	*P* value
Heavy metals (μg/L)				
Barium	1.6±2.1	2.1±5.8	0.97 (0.78–1.20)	0.751
Cadmium	0.4±0.5	0.5±0.6	**1.43 (1.05–1.94)**	**0.024**
Cobalt	0.4±0.6	0.6±2.0	**1.55 (1.09–2.20)**	**0.018**
Cesium	4.9±3.4	4.9±3.0	1.27 (0.85–1.88)	0.224
Manganese	0.2±0.2	0.2±0.3	1.06 (0.83–1.35)	0.634
Molybdenum	51.4±48.9	54.4±57.2	1.00 (0.66–1.52)	0.988
Lead	0.7±1.0	0.7±0.7	1.02 (0.78–1.32)	0.902
Antimony	0.1±0.2	0.1±0.1	1.18 (0.87–1.60)	0.276
Strontium	110.8±130.4	127.0±108.7	1.16 (0.83–1.63)	0.360
Thallium	0.2±0.1	0.2±0.1	1.03 (0.55–1.94)	0.920
Tin	1.4±3.4	1.4±2.7	1.19 (0.91–1.56)	0.179
Tungsten	0.1±0.2	0.1±0.3	1.12 (0.88–1.42)	0.347
Uranium	0.01±0.03	0.02±0.04	1.13 (0.91–1.39)	0.243
Phenols (ng/mL)				
Benzophenone-3	284.7±1251.1	209.7±1743.2	**0.89 (0.81–0.99)**	**0.030**
Bisphenol A	3.0±8.4	3.0±6.1	1.17 (0.89–1.55)	0.243
Triclosan	96.5±273.7	96.3±304.4	0.97 (0.85–1.10)	0.591
Polyaromatic hydrocarbons (ng/L)				
2-Hydroxyfluorene	528.7±1017.5	827.4±1236.6	**1.45 (1.15–1.84)**	**0.004**
3-Hydroxyfluorene	242.8±529.2	438.2±802.4	**1.42 (1.18–1.71)**	**0.001**
9-Hydroxyfluorene	507.1±938.0	591.6±776.5	1.26 (0.93–1.77)	0.132
1-Hydroxyphenanthrene	196.3±316.2	224.9±225.3	**1.39 (1.02–1.90)**	**0.039**
2-Hydroxyphenanthrene	105.0±163.5	120.1±121.2	1.37 (0.98–1.92)	0.064
3-Hydroxyphenanthrene	114.9±249.1	138.2±166.5	**1.41 (1.02–1.96)**	**0.041**
1-Hydroxypyrene	181.7±325.2	235.1±314.9	1.28 (0.99–1.66)	0.058
1-Hydroxynaphthalene (1-Naphthol)	41,216.3±639,687.2	63,592.9±802,130.5	1.14 (0.91–1.42)	0.246
2-Hydroxynaphthalene (2-Naphthol)	8172.0±11,662.0	9693.4±11,033.1	1.21 (0.97–1.53)	0.092
4-Hydroxyphenanthrene	33.0±53.2	42.1±56.3	**1.39 (1.01–1.91)**	**0.042**

[a] Adjusted for urinary creatinine, age, sex, body mass index, ratio of family income to poverty, serum cotinine, and subsampling weighting

cadmium, cobalt, hydrocarbons but lower level of benzophenone-3 (see Table 2). Six hundred three adults (13.3 %) had bone loss around the mouth, presented with higher levels of cadmium, nitrate, thiocyanate, propyl paraben and PAHs (see Table 3). Eight hundred forty-five adults (18.5 %) had tooth loose not due to injury, presented with higher level of cadmium, thiocyanate, PAHs but lower levels of benzophenone-3 and triclosan (see Table 4). Eight hundred forty-five adults (18.5 %) noticed their teeth did not look right, presented with higher levels of lead, uranium, PAHs but lower level of triclosan (see Table 5). Three hundred fifty-one adults (7.7 %) often had aching in the mouth while 650 (14.3 %) had aching only occasionally.

People who reported fair to poor teeth health were presenting with higher levels of cadmium, cobalt, lead, bisphenol A and PAHs. However, after additionally adjusted for gum disease, urinary cobalt, lead and bisphenol A were no loner significantly associated with self-reported fair to poor self-rated teeth (see Table 6). Compared to rare aching in the mouth in the past year, adults who had occasional to often aching in the mouth in the last year were found to have higher levels of phthalates, pesticides, PAHs but low level of triclosan (see Table 7).

Table 3 Associations between urinary environmental chemical concentrations and adult bone loss around teeth

(*n*=1255)	No bone loss (*n*=3928, 86.7 %)	Bone loss (*n*=603, 13.3 %)	OR (95% CI)[a]	*P* value
Heavy metals (μg/L)				
Barium	1.7±2.1	2.1±6.7	1.03 (0.82–1.29)	0.796
Cadmium	0.4±0.5	0.5±0.7	**1.64 (1.15–2.34)**	**0.009**
Cobalt	0.5±1.1	0.4±0.5	0.95 (0.63–1.44)	0.795
Cesium	4.9±3.5	4.5±2.5	1.07 (0.62–1.83)	0.802
Manganese	0.2±0.2	0.2±0.2	1.01 (0.66–1.54)	0.978
Molybdenum	52.0±47.7	54.0±66.9	1.25 (0.66–2.35)	0.469
Lead	0.7±1.0	0.6±0.6	1.14 (0.79–1.63)	0.459
Antimony	0.1±0.2	0.1±0.1	1.07 (0.83–1.38)	0.584
Strontium	114.8±130.3	109.3±99.8	1.13 (0.86–1.48)	0.355
Thallium	0.2±0.1	0.2±0.1	1.77 (0.94–3.32)	0.073
Tin	1.4±3.4	1.4±2.8	1.12 (0.76–1.64)	0.548
Tungsten	0.1±0.2	0.1±0.1	1.03 (0.66–1.59)	0.897
Uranium	0.01±0.03	0.01±0.04	1.10 (0.82–1.49)	0.500
Perchlorate (ng/mL)	4.6±6.6	4.6±5.2	1.14 (0.83–1.57)	0.393
Nitrate (ng/mL)	54,778.2±52,627.2	53,659.1±44,797.6	**1.47 (1.00–2.17)**	**0.052**
Thiocyanate (ng/mL)	1936.5±3029.8	2234.5±2881.5	**1.31 (1.03–1.68)**	**0.031**
Parabens (ng/mL)				
Butyl	2.2±11.5	2.3±10.8	0.97 (0.82–1.15)	0.688
Ethyl	17.7±62.1	13.4±42.0	1.05 (0.88–1.25)	0.572
Methyl	209.8±449.4	242.7±442.1	1.05 (0.94–1.18)	0.362
Propyl	50.5±142.0	66.5±187.1	**1.09 (1.00–1.20)**	**0.059**
Polyaromatic hydrocarbons (ng/L)				
2-Hydroxyfluorene	572.9±1070.4	704.2±1218.3	**1.36 (1.05–1.76)**	**0.023**
3-Hydroxyfluorene	271.3±596.6	371.2±761.4	**1.34 (1.05–1.70)**	**0.020**
9-Hydroxyfluorene	525.7±941.2	477.1±542.3	1.04 (0.79–1.36)	0.767
1-Hydroxyphenanthrene	201.8±308.1	192.3±233.9	1.17 (0.81–1.67)	0.379
2-Hydroxyphenanthrene	108.2±159.7	98.9±106.1	1.13 (0.82–1.54)	0.435
3-Hydroxyphenanthrene	118.8±244.9	118.6±156.6	1.24 (0.94–1.64)	0.117
1-Hydroxypyrene	190.7±326.5	192.0±297.6	1.27 (0.93–1.74)	0.128
1-Hydroxynaphthalene (1-Naphthol)	51,095.8±721,958.1	7964.7±19,077.0	1.04 (0.91–1.18)	0.560
2-Hydroxynaphthalene (2-Naphthol)	8376.8±11,526.4	8969.3±12,304.5	1.02 (0.73–1.42)	0.902
4-Hydroxyphenanthrene	34.7±55.1	32.7±37.2	1.11 (0.85–1.45)	0.439

[a] Adjusted for urinary creatinine, age, sex, body mass index, ratio of family income to poverty, serum cotinine, and subsampling weighting

Discussion

Previous research

Literature on the relationship of toxins and teeth health could have varied as a result of methodology and specific study outcomes. For example, heavy metals were observed to be associated with tooth type, tooth position within the mouth, caries status, and presence of amalgam fillings inside the mouth in Jordanian (Alomary et al. 2013), Polish, German, Belgian and American children (Barton 2011; Brockhaus et al. 1988; Cleymaet et al. 1991; Arora et al. 2008). Japanese researchers have found that cadmium exposure could develop tooth enamel, and poor catalytic activity of cadmium-binding carbonic anhydrase might hinder the nucleation process (Kakei et al. 2009). Other animal research (female rats) in Brazil also showed that cadmium induced epithelial hypotrophy, indicating a direct action in oral mucosa cells, besides retarded development of the pups (Picoli

Table 4 Associations between urinary environmental chemical concentrations and adult teeth loose without injury

(*n*=1255)	No teeth loose (*n*=3712, 81.5 %)	Teeth loose (*n*=845, 18.5 %)	OR (95% CI)[a]	*P* value
Heavy metals (μg/L)				
Barium	1.7±3.3	1.6±2.5	0.81 (0.61–1.09)	0.159
Cadmium	0.4±0.5	0.6±0.8	**1.98 (1.48–2.64)**	**<0.001**
Cobalt	0.4±0.6	0.6±2.0	1.16 (0.85–1.57)	0.327
Cesium	4.9±3.4	4.8±3.2	1.09 (0.70–1.69)	0.681
Manganese	0.2±0.2	0.2±0.3	1.16 (0.81–1.66)	0.393
Molybdenum	52.4±50.9	51.4±49.6	0.87 (0.53–1.43)	0.566
Lead	0.6±0.9	0.8±1.2	1.22 (0.91–1.63)	0.175
Antimony	0.1±0.2	0.1±0.1	1.14 (0.90–1.45)	0.266
Strontium	113.0±94.2	118.3±215.6	0.83 (0.63–1.10)	0.176
Thallium	0.2±0.1	0.2±0.1	1.26 (0.75–2.11)	0.356
Tin	1.3±3.1	1.8±4.0	1.07 (0.86–1.34)	0.510
Tungsten	0.1±0.2	0.1±0.3	1.01 (0.71–1.43)	0.973
Uranium	0.01±0.03	0.02±0.05	0.95 (0.76–1.20)	0.672
Perchlorate (ng/mL)	4.5±6.0	4.9±8.3	0.95 (0.72–1.24)	0.664
Nitrate (ng/mL)	55,596.4±52,964.1	50,096.8±44,170.1	0.74 (0.46–1.19)	0.204
Thiocyanate (ng/mL)	1843.2±2738.3	2554.8±3923.0	**1.23 (1.00–1.52)**	**0.054**
Bisphenols (ng/mL)				
Benzophenone-3	274.7±1302.3	233.4±1532.7	**0.89 (0.80–0.98)**	**0.023**
Bisphenol A	3.0±8.2	3.0±7.2	0.97 (0.82–1.14)	0.668
Triclosan	105.5±282.5	63.1±273.4	**0.81 (0.70–0.93)**	**0.005**
Polyaromatic hydrocarbons (ng/L)				
2-Hydroxyfluorene	532.7±994.0	843.3±1408.9	**1.51 (1.28–1.78)**	**<0.001**
3-Hydroxyfluorene	249.8±545.8	436.9±861.9	**1.45 (1.27–1.65)**	**<0.001**
9-Hydroxyfluorene	488.9±890.6	664.0±950.1	1.23 (0.95–1.60)	0.115
1-Hydroxyphenanthrene	198.1±311.8	214.4±241.9	1.07 (0.82–1.40)	0.614
2-Hydroxyphenanthrene	105.1±158.9	119.0±142.0	1.22 (0.97–1.52)	0.085
3-Hydroxyphenanthrene	114.4±243.6	141.8±199.1	**1.29 (1.03–1.61)**	**0.030**
1-Hydroxypyrene	181.9±305.8	232.2±384.5	1.26 (0.95–1.66)	0.097
1-Hydroxynaphthalene (1-Naphthol)	41,107.9±648,046.5	61,070.7±749,383.7	1.06 (0.95–1.19)	0.289
2-Hydroxynaphthalene (2-Naphthol)	8022.7±10,998.8	10,312.7±13,819.0	1.19 (0.94–1.49)	0.132
4-Hydroxyphenanthrene	32.7±44.6	42.7±81.6	1.11 (0.89–1.37)	0.326

[a] Adjusted for urinary creatinine, age, sex, body mass index, ratio of family income to poverty, serum cotinine, and subsampling weighting

et al. 2004). Lead has been commonly known for being linked with oral health. In the current analysis, while a few of the heavy metals were associated with various teeth conditions in American adults, urinary lead concentrations were only significantly associated with perception of teeth problems. One reason might be due to the reduction of environment lead levels in USA in recent years.

The link between nitrate and bone loss has not been confirmed yet since many studies have yielded conflicting results (Jamal et al. 2013), and so is the relationship of thiocyanate and bone loss. Moreover, the only paraben element associated with bone loss around the mouth is only borderline. More studies would be needed to confirm or refute these findings in the present study and to compare with previous research as well (Maciejewska et al. 2014). The link between PAHs and oral health including the aching has not ben firmly established, although the toxicology of PAHs was previously described in numerous human diseases already (Tormoehlen et al. 2014). The findings from the present study could be new evidence to provide to the scientific community and the general

Table 5 Associations between urinary environmental chemical concentrations and notice of teeth look in adults

(*n*=1255)	No notice of teeth look (*n*=3712, 81.5 %)	Notice of teeth look (*n*=845, 18.5 %)	OR (95% CI)[a]	*P* value
Heavy metals (μg/L)				
Barium	1.7±3.4	1.7±1.9	1.06 (0.75–1.51)	0.723
Cadmium	0.4±0.5	0.5±0.5	1.41 (0.93–2.15)	0.104
Cobalt	0.5±1.1	0.4±0.6	1.02 (0.69–1.51)	0.911
Cesium	4.9±3.4	4.8±2.9	0.88 (0.57–1.37)	0.552
Manganese	0.2±0.2	0.2±0.3	0.95 (0.70–1.31)	0.757
Molybdenum	51.9±48.4	53.5±60.8	1.29 (0.78–2.14)	0.307
Lead	0.6±0.9	0.8±1.3	**1.41 (1.11–1.79)**	**0.008**
Antimony	0.1±0.1	0.1±0.2	1.26 (0.87–1.82)	0.200
Strontium	113.4±130.6	116.7±102.2	1.00 (0.79–1.28)	0.981
Thallium	0.2±0.1	0.2±0.1	0.95 (0.59–1.53)	0.810
Tin	1.3±2.9	1.8±4.8	1.13 (0.90–1.43)	0.263
Tungsten	0.1±0.2	0.1±0.2	1.30 (0.89–1.90)	0.162
Uranium	0.01±0.03	0.02±0.04	**1.43 (1.10–1.86)**	**0.010**
Phenols (ng/mL)				
Benzophenone-3	273.9±1216.0	234.3±1868.8	0.92 (0.79–1.06)	0.212
Bisphenol A	2.8±7.4	3.7±8.8	1.25 (0.95–1.64)	0.105
Triclosan	100.9±276.1	81.7±305.6	**0.84 (0.75–0.95)**	**0.006**
Polyaromatic hydrocarbons (ng/L)				
2-Hydroxyfluorene	537.6±1034.3	855.6±1305.0	**1.49 (1.17–1.91)**	**0.003**
3-Hydroxyfluorene	256.4±575.7	425.5±797.8	**1.42 (1.17–1.72)**	**0.001**
9-Hydroxyfluorene	501.3±918.5	601.8±760.1	1.18 (0.85–1.64)	0.291
1-Hydroxyphenanthrene	197.4±314.0	214.4±203.7	1.20 (0.83–1.73)	0.311
2-Hydroxyphenanthrene	105.0±160.7	116.5±107.7	1.19 (0.85–1.67)	0.295
3-Hydroxyphenanthrene	115.3±246.1	135.9±161.1	1.26 (0.87–1.82)	0.203
1-Hydroxypyrene	180.5±318.0	242.0±336.8	**1.29 (1.00–1.67)**	**0.049**
1-Hydroxynaphthalene (1-Naphthol)	52,521.6±732,556.2	7178.5±16,239.5	1.07 (0.93–1.23)	0.343
2-Hydroxynaphthalene (2-Naphthol)	7898.0±11,219.8	11,217.3±13,062.5	**1.43 (1.15–1.79)**	**0.003**
4-Hydroxyphenanthrene	33.4±55.0	39.1±40.0	1.26 (0.93–1.70)	0.129

[a] Adjusted for urinary creatinine, age, sex, body mass index, ratio of family income to poverty, serum cotinine, and subsampling weighting

public. On the other hand, the protective effects from benzophenone-3 (known as a sunscreen agent) and triclosan might be owing to the benefits of vitamin D absorption (Millen 2014) and toothpaste use (Dadamio et al. 2013) over time. Unfortunately, it was not possible to have vitamin D levels analyzed because of the current limited dataset.

Strengths and limitations

The present study has a few strengths. First, this study was conducted in a large and nationally representative human sample with mixed ethnicities and socioeconomic status. Second, this is the first time examining the risk effects of different sets of urinary environmental chemical concentrations on adult oral health conditions in detail. Statistically speaking, one needs to be cautious in interpreting the significant associations since they could be by chance or due to multiple comparisons. However, these significant associations appeared more than once with different outcome variables. Of note, all the outcome variables are independent from each other. Therefore, this type of problem could be minimum (Gelman et al. 2012). On the other hand, we would also

Table 6 Associations between urinary environmental chemical concentrations and adult self-rated teeth health

(*n*=1255)	Good teeth health (*n*=2993, 65.7 %) RRR (95% CI)[a]	Fair teeth health (*n*=1020, 22.4 %) RRR (95% CI)[a]	Poor teeth health (*n*=541, 11.9 %) RRR (95% CI)[a]	Poor teeth health (*n*=541, 11.9 %) RRR (95% CI)[b]
Heavy metals (μg/L)				
Barium	1.00	0.97 (0.78–1.21)	0.98 (0.65–1.49)	1.01 (0.62–1.63)
Cadmium	1.00	1.07 (0.75–1.52)	**2.21 (1.39–3.51)**	**2.03 (1.25–3.31)**
Cobalt	1.00	**1.50 (1.06–2.11)**	**1.43 (1.05–1.95)**	1.29 (0.88–1.89)
Cesium	1.00	0.94 (0.66–1.33)	0.73 (0.34–1.58)	0.55 (0.23–1.31)
Manganese	1.00	0.79 (0.58–1.09)	0.77 (0.50–1.19)	0.66 (0.37–1.17)
Molybdenum	1.00	1.22 (0.87–1.71)	0.96 (0.59–1.58)	1.14 (0.74–1.74)
Lead	1.00	**1.32 (1.00–1.74)**	1.19 (0.74–1.91)	1.23 (0.68–2.22)
Antimony	1.00	1.05 (0.75–1.47)	1.44 (0.95–2.20)	1.51 (0.88–2.58)
Strontium	1.00	1.25 (0.92–1.71)	1.07 (0.66–1.75)	1.05 (0.62–1.78)
Thallium	1.00	1.09 (0.76–1.58)	0.69 (0.37–1.31)	0.61 (0.29–1.28)
Tin	1.00	1.05 (0.90–1.21)	1.17 (0.81–1.70)	1.15 (0.83–1.58)
Tungsten	1.00	1.20 (0.85–1.68)	1.14 (0.87–1.50)	1.11 (0.80–1.53)
Uranium	1.00	1.02 (0.77–1.35)	1.32 (0.92–1.88)	1.26 (0.81–1.95)
Bisphenols (ng/mL)				
Bisphenol A[b]	1.00	1.04 (0.86–1.26)	**1.35 (1.03–1.76)**	1.24 (0.98–1.57)
Polyaromatic hydrocarbons (ng/L)				
2-Hydroxyfluorene	1.00	**1.31 (1.05–1.62)**	**2.24 (1.66–3.02)**	**2.05 (1.57–2.67)**
3-Hydroxyfluorene	1.00	**1.23 (1.00–1.52)**	**1.97 (1.63–2.39)**	**1.75 (1.46–2.11)**
9-Hydroxyfluorene	1.00	1.03 (0.79–1.34)	**1.54 (1.12–2.13)**	**1.49 (1.08–2.05)**
1-Hydroxyphenanthrene	1.00	1.12 (0.76–1.64)	**1.71 (1.21–2.41)**	**1.56 (1.01–2.42)**
2-Hydroxyphenanthrene	1.00	1.19 (0.92–1.53)	**1.69 (1.22–2.36)**	**1.62 (1.22–2.13)**
3-Hydroxyphenanthrene	1.00	1.20 (0.91–1.58)	**1.89 (1.39–2.56)**	**1.75 (1.31–2.35)**
1-Hydroxypyrene	1.00	**1.32 (1.02–1.72)**	**1.84 (1.47–2.31)**	**1.79 (1.45–2.20)**
1-Hydroxynaphthalene (1-Naphthol)	1.00	1.06 (0.93–1.22)	**1.30 (1.03–1.64)**	**1.29 (1.04–1.59)**
2-Hydroxynaphthalene (2-Naphthol)	1.00	1.15 (0.92–1.43)	**1.62 (1.09–2.39)**	**1.54 (1.07–2.22)**
4-Hydroxyphenanthrene	1.00	1.09 (0.78–1.52)	**1.66 (1.24–2.24)**	**1.51 (1.15–1.97)**

[a] Adjusted for urine creatinine, age, sex, body mass index, ratio of family income to poverty, serum cotinine, and subsampling weighting

[b] Additionally adjusted for gum disease

need to pay attention to some other non-significant associations but might bring clinical/practical significance since this might be due to sample size issue. For example, there are more PAHs with borderline significance shown already. There are also a few limitations that cannot be ignored. First, there could still be other emerging chemicals from the living environments through different channels/vehicles that we might not yet know and would need future chemical and experimental research to further identify and examine. Moreover, the biologic half-lives of chemicals can vary greatly. It is unclear how they would stay in human bodies and further make impact on human health. During the usual and/or additional dental treatment, there could be minor chemicals releasing to patients, but such information is not available in the current dataset either. Second, it was not possible to examine the duration of dental problems including aching and pains. Third, causality cannot be established in the present study due to the cross-sectional study design in nature. Fourth, since outcome variables were only self-reported, there could be misclassification bias. Therefore, double-checking against medical records would seem to be important in the future research. Future studies with a longitudinal and/or experimental study design to confirm or refute the current findings and, if at all, to understand the persisting risk effects along the life course from those environmental chemicals mentioned above would be suggested.

Table 7 Associations between urinary environmental chemical concentrations and aching in the mouth in the last year

(*n*=1255)	Rare aching (*n*=3561, 78.1 %) RRR (95% CI)[a]	Occasional aching (*n*=650, 14.3 %) RRR (95% CI)[a]	Often aching (*n*=351, 7.7 %) RRR (95% CI)[a]
Phthalates (ng/mL)			
Mono(carboxyoctyl)	1.00	**1.22 (1.03–1.44)**	1.07 (0.80–1.43)
Mono(carboxynonyl)	1.00	1.22 (0.99–1.51)	0.81 (0.54–1.21)
Mono-2-ethyl-5-carboxypentyl	1.00	**1.53 (1.24–1.89)**	1.25 (0.86–1.81)
Mono-n-butyl	1.00	1.11 (0.90–1.37)	**1.27 (1.02–1.58)**
Mono-(3-carboxypropyl)	1.00	**1.26 (1.03–1.54)**	1.04 (0.79–1.37)
Mono-ethyl	1.00	1.02 (0.86–1.22)	0.99 (0.84–1.18)
Mono-(2-ethyl-5-hydroxyhexyl)	1.00	**1.31 (1.08–1.59)**	**1.36 (1.08–1.71)**
Mono-(2-ethyl)-hexyl	1.00	1.06 (0.87–1.30)	0.98 (0.67–1.45)
Mono-isobutyl	1.00	1.16 (0.86–1.56)	1.21 (0.73–2.01)
Mono-n-methyl	1.00	1.05 (0.83–1.32)	0.99 (0.79–1.24)
Mono-isononyl	1.00	1.04 (0.86–1.26)	0.99 (0.72–1.35)
Mono-(2-ethyl-5-oxohexyl)	1.00	**1.37 (1.11–1.69)**	1.30 (0.95–1.77)
Mono-benzyl	1.00	1.22 (0.95–1.57)	**1.27 (1.03–1.58)**
Cyclohexane-1,2-dicarboxylic acid monohydroxy isononyl ester	1.00	0.77 (0.38–1.57)	0.86 (0.44–1.66)
Pesticides (ng/mL)			
Urinary 2,5-dichlorophenol	1.00	1.04 (0.94–1.16)	**1.18 (1.01–1.38)**
Urinary 2,4-dichlorophenol	1.00	1.07 (0.90–1.28)	1.22 (0.94–1.58)
Bisphenols (ng/mL)			
Benzophenone-3	1.00	1.06 (0.97–1.16)	0.94 (0.78–1.14)
Bisphenol A	1.00	1.21 (0.96–1.52)	1.11 (0.70–1.76)
Triclosan	1.00	0.90 (0.81–1.00)	**0.82 (0.70–0.98)**
Polyaromatic hydrocarbons (ng/L)			
2-Hydroxyfluorene	1.00	**1.31 (1.07–1.61)**	**1.48 (1.00–2.04)**
3-Hydroxyfluorene	1.00	**1.34 (1.12–1.61)**	1.21 (0.90–1.62)
9-Hydroxyfluorene	1.00	1.16 (0.91–1.49)	**1.47 (1.09–1.98)**
1-Hydroxyphenanthrene	1.00	1.31 (0.93–1.86)	**1.56 (1.01–2.40)**
2-Hydroxyphenanthrene	1.00	1.17 (0.91–1.50)	1.41 (0.97–2.03)
3-Hydroxyphenanthrene	1.00	1.26 (0.98–1.62)	**1.51 (1.12–2.05)**
1-Hydroxypyrene	1.00	**1.30 (1.10–1.55)**	1.20 (0.85–1.67)
1-Hydroxynaphthalene (1-Naphthol)	1.00	1.05 (0.91–1.22)	1.16 (0.92–1.47)
2-Hydroxynaphthalene (2-Naphthol)	1.00	**1.37 (1.09–1.74)**	1.19 (0.83–1.70)
4-Hydroxyphenanthrene	1.00	1.19 (0.90–1.57)	**1.79 (1.24–2.57)**

[a] Adjusted for urine creatinine, age, sex, body mass index, ratio of family income to poverty, serum cotinine, and subsampling weighting

Conclusion

In sum, urinary heavy metals, phthalates, thiocyanate, parabens, pesticides and PAHs were positively associated with oral health conditions in American adults aged 30–80 while benzophenone-3 and triclosan were negatively associated with oral health conditions. There were no statistically significant associations observed in arsenic or polyfluorinated compounds, although the levels of those urinary concentrations were a little higher in people with oral health conditions as well. For practical implications, Further regulation of environmental chemicals in prevention of adult oral health might need to be considered in future health and environmental policies.

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Conflict of interest None.

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