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Blood Lead Levels and Dental Caries in U.S. Children Who Do Not Drink Tap Water

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Abstract

Introduction—This study's purpose is to determine whether non-consumption of tap water is associated with lower prevalence of elevated blood lead levels and higher prevalence of dental caries in children and adolescents.

Methods—Cross-sectional data from the National Health and Nutrition Examination Survey 2005–2014 recorded drinking water source (*n*=15,604) and blood lead levels (*n*=12,373) for participants aged 2–19 years, and dental caries experience for the 2011–2014 subset (*n*=5,677). The threshold for elevated blood lead level was ≥3 μg/dL. A binary outcome indicated presence or absence of dental caries experience. Multivariable generalized linear models estimated adjusted prevalence ratios with 95% confidence limits.

Results—In analysis conducted in 2017, 15% of children and adolescents did not drink tap water, 3% had elevated blood lead levels ≥3 μg/dL, and 50% had dental caries experience. Children and adolescents who did not drink water were less likely than tap water drinkers to have an elevated blood lead level (adjusted prevalence ratios=0.62, 95% confidence limits=0.42, 0.90). Non-consumers of tap water were more likely to have dental caries (adjusted prevalence ratios=1.13, 95% confidence limits=1.03, 1.23). Results persisted after adjustment for other covariates and using a higher threshold for elevated blood lead level.

Conclusions—In this nationally representative U.S. survey, children and adolescents who did not drink tap water had lower prevalence of elevated blood lead levels and higher prevalence of dental caries than those who drank tap water.

INTRODUCTION

A groundswell of criticism from the scientific community challenges the safety of America's public drinking water, its regulatory oversight, and its aging infrastructure.[1–4] The U.S. Environmental Protection Agency (EPA) concedes "… the drinking water sector faces a

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growing array of challenges that, if left unaddressed, can pose serious risks to public health" (p3).[5]

The public also voices mistrust about drinking water safety. The majority of respondents to a national poll believed that the lead-contaminated water crisis in Flint was a sign of a more widespread problem.[6] Even before the Flint water crisis, one in seven white and one in four black and Hispanic youth respondents to a national survey disagreed that their local tap water was safe to drink.[7] Environmental injustice is one explanation for greater mistrust among black and Hispanic groups. Communities with higher proportions of low income and black and Hispanic residents are more likely to live near agricultural or industrial waste sites that contaminate water supplies.[8,9]

Tap water has health benefits for the two thirds of Americans connected to public water systems that contain fluoride at or near the optimal level of 0.7 mg/L.[10] Water fluoridation is the controlled addition of a fluoride compound to drinking water to a level sufficient to prevent dental caries without increasing risk of unwanted effects. According to the Centers for Disease Control and Prevention (CDC), fluoride has dramatically decreased dental caries prevalence over the past 70 years.[11] Nonetheless, dental caries remains widespread. In 2011–2012, the disease affected the primary teeth of 23% of U.S. preschoolers.[12]

These groups at elevated risk of tooth decay are also less likely to drink tap water. From 2005 to 2010, odds of drinking tap water in the U.S. were twice as high among children from homes of a college graduate as among children from homes of a high school graduate.[13] Very few U.S. studies have examined whether non-consumption of tap water protects against waterborne contaminants. One exception was a 1988–1994 National Health and Nutrition Examination Survey (NHANES) analysis of 3,325 Mexican American children. The study found that those who primarily drank tap water had more than twice the odds of elevated blood lead levels than those who primarily drank bottled water.[14]

The aims of this analysis are to examine whether non-consumption of tap water is associated with lower prevalence of elevated blood lead levels and higher prevalence of dental caries.

METHODS

Study Sample

In 2017, the authors analyzed cross-sectional data from NHANES covering the decade 2005–2014. The National Center for Health Statistics used a complex, multistage, probability sampling design, in which racial and ethnic minorities as well as people living in poverty were over-sampled to increase the reliability of estimates. Following an in-home interview, participants attended the mobile examination center where they donated a blood sample, completed a dietary interview, and received a dental examination.

Participation in the mobile examination center ranged from 68.5% in 2013–2014 to 77.4% in 2005–2006. In each 2-year cycle, mobile examination center participation rates were higher among minors (aged from birth to 19 years) than among adults.

Measures

Age was categorized as 2–5, 6–11, and 12–19 years. These age groups correspond to phases of dentition development commonly assessed in dental caries examinations. Self-identified race-ethnicity was classified as Mexican American, other Hispanic, non-Hispanic white, non-Hispanic black, and other/multiple. The derived income-to-poverty ratio divided total family income by the family size specific poverty threshold. Four categories were: below the poverty threshold, near poverty, not in poverty, and 500% of the poverty threshold. An additional missing value category avoided potential bias arising from different tap water drinking patterns among people with nonreported income.

Interviewers asked about the primary source of drinking water. A binary variable distinguished children who did not drink tap water from children who drank from a city water supply well, rain cistern or spring. The dietary interview also determined the amounts of water of all types consumed during the 24 hours prior to the interview. This enabled assessment of whether children who did not drink tap water compensate by drinking greater volumes of bottled water. The authors also computed a variable that recorded the amount of bottled water consumed divided by the child's body weight.

Venous samples of whole blood were collected by phlebotomy following a standard protocol, frozen and shipped to the National Center for Environmental Health. After thawing, lead concentrations were determined using inductively coupled plasma mass spectrometry. The limits of detection were 0.25 μg/dL in 2005–2012, and 0.07 μg/dL in 2013–2014. A binary variable was computed in which an elevated blood lead level was defined as ≥3 μg/dL versus <3 μg/dL. This is lower than the threshold of ≥5 μg/dL recommended by CDC based on blood lead levels in 2007–2010. However, the Council on Environmental Health now recognizes that there is no blood lead level without deleterious effects.[15] Furthermore, only 1.5% of children had blood lead levels of ≥3μg/dL in the 2013–2014 NHANES. This same blood lead threshold of ≥3μg/dL was used in a recent NHANES analysis of young children.[16]

Caries experience is the presence of either untreated or treated tooth decay. During 2005–2010, NHANES did not conduct comprehensive dental examinations. Hence, this analysis uses NHANES 2011–2014 when dentists conducted tooth surface-level dental examinations of the primary and permanent dentitions. A binary variable classified children with any finding of carious or filled tooth surface as having dental caries experience. The remainder had no dental caries experience.

The authors investigated whether greater consumption of sugar-sweetened beverages might account for the relationship between non-consumption of tap water and dental caries. Following the methods of Rosinger et al.,[17] the authors computed a variable measuring kilocalories of sugar-sweetened beverage from NHANES 2011–2014 to coincide with the years in which dental caries examinations were conducted.

Statistical Analysis

Analyses conducted using Stata/SE, version 14 took account of the complex sample survey design. Sampling weights that accounted for differential probabilities of selection, nonresponse, noncoverage, and sample design, produced representative estimates of the non-institutionalized U.S. population. A subpopulation analysis computed the correct point and variance estimation for the subset of NHANES participants who were aged 2 to 19 years.

Analysis omitted participants missing source of drinking water (*n*=3,188) to yield a sample size of 15,604 children aged 2 to 19 years. Of these, 12,373 had data on blood lead level and 5,677 had dental caries examination data.

Descriptive statistics quantified consumption of tap water for each level of the demographic and socioeconomic characteristics. Overall differences within groups of categorical variables were compared using Pearson’s chi-square test. Regression analysis computed mean values and 95% confidence limits (CL) of bottled water consumed for drinkers versus non-drinkers of tap water. In multivariable models, covariate adjusted prevalence ratios (APR) estimated the strength and direction of association between sociodemographic characteristics and non-consumption of drinking tap water. APR along with corresponding 95% CL were derived from generalized linear models for survey estimation, specifying binomial distribution with log link function and reporting estimates as exponentiated coefficients. When the outcome is not rare, the prevalence ratio is preferable to the OR, as the OR overestimates the strength of association.[18] Multivariable analyses adjusted for the potential confounding of NHANES cycle and sociodemographic characteristics of sex, age, race/ethnicity, and income to poverty ratio.

Four sensitivity analyses tested uncertainties in the models. The first, using NHANES 2005–2014, substituted the threshold of elevated blood lead levels to 5.0 μg/dL, as is the current threshold recommended by the CDC. The second sensitivity analysis, also modeling prevalence of elevated blood lead levels, additionally adjusted for year that the house was built (pre-1978 versus 1978 or later) as a proxy for exposure to lead-based paint. This analysis was restricted to NHANES 2005–2010, because age of house was not assessed after 2010. The third sensitivity analysis, using NHANES 2005–2004, omitted participants whose water source was a well or rain cistern (*n*=1,237) or a spring (*n*=275). The fourth sensitivity analysis, using NHANES 2011–2014, modeled prevalence of dental caries with adjustment for sweetened beverage consumption measured in the 24-hour dietary recall.

As this study analyzed unidentifiable publicly available data it was deemed exempt from review by the University of North Carolina at Chapel Hill IRB.

RESULTS

Analysis of NHANES 2005–2014 showed that 15% of U.S. children and adolescents on average did not drink tap water. One in five preschoolers (21.3%) did not drink tap water compared with one in ten adolescents (11.2%). A striking fourfold variation in non-consumption of tap water among racial/ethnic groups ranged from 8.0% among non-Hispanic white children to 32.2% among Mexican Americans. As depth of poverty increased, so too did non-consumption of tap water. More than one in four children living below the poverty threshold (22.6%) did not drink tap water.

Prevalence of elevated blood lead levels decreased across successive NHANES cycles (Table 1). Overall, the geometric mean blood lead level was 0.875 μg/dL (95% CL=0.865, 0.885) and 2.9% of children had blood lead levels ≥3 μg/dL. By 2013–2014, only 1.5% of children exceeded this threshold (Table 1). Prevalence of elevated blood lead levels was significantly higher among boys than girls, among preschoolers than older children, among African Americans than non-Hispanic whites, and among children from homes with low versus high income.

Although the univariate relationship between tap water consumption and blood lead levels was not statistically significant, in age-stratified analysis (Appendix Table 1), preschool children who did not drink tap water had significantly lower prevalence of elevated blood lead levels than preschoolers who drank tap water.

One in every two children (49.8%) had dental caries (Table 1). Prevalence was greatest among Mexican Americans followed by African Americans. Dental caries prevalence followed a pronounced inverse income gradient. Although univariate analysis did not reveal differences in dental caries experience based on tap water consumption, statistically significant differences were evident in age-stratified analysis (Appendix Table 1). Among preschool children, prevalence of dental caries experience was 20.5% among those who drank tap water compared with 31.8% among those who did not drink tap water (p=0.003).

The significant associations observed in univariate analysis of non-consumption of tap water persisted after adjustment for potential confounding (Table 2). As anticipated, children who did not drink tap water drank more bottled water than children who drank tap water (Appendix Table 2).

When modeling blood lead levels in multivariable analysis (Table 3), children and adolescents who drank tap water had significantly higher prevalence of elevated blood lead levels than children who did not drink tap water (APR=0.62, 95% CL=0.42, 0.90). In sensitivity analysis where the threshold for elevated blood lead levels was set to ≥5 μg/dL, non-consumers of tap water showed significantly lower prevalence of elevated blood lead levels (Appendix Table 3).

Sensitivity analysis conducted for 2005–2010 added the covariate that distinguished between dwellings built after versus before 1978. Although living in houses built before 1978 was positively associated with elevated blood lead levels, non-consumption of tap water remained significantly protective against elevated blood lead levels (Appendix Table 4).

Analysis that omitted participants who reported that their main source of drinking water was a well or rain cistern (n=1,237) or a spring (n=275) showed that the associations did not meaningfully differ (not tabulated).

When modeling dental caries experience in multivariable analysis, children and adolescents who did not drink tap water had significantly higher prevalence of dental caries experience than those who drank tap water (Table 4). Adjusted prevalence estimates were 55.3% and 49.0%, respectively (APR=1.13, 95% CL=1.03, 1.23). Even when adjusted for sugar-sweetened beverage consumption, non-consumption of tap water remained significantly associated with higher prevalence of dental caries experience (Appendix Table 5).

DISCUSSION

In the decade studied, there was no linear trend in the proportion of U.S. children and adolescents who avoided tap water, refuting the notion that public trust in tap water safety declined during this period. However, these findings predate the environmental public health crisis that has since unfolded in Flint, Michigan. That crisis and the attendant intense scrutiny heightened public awareness of the hazard of lead-contaminated drinking water and will likely undermine public trust in public drinking water.[19]

One in four preschoolers did not drink tap water. One in three Mexican American children did not drink tap water. Even after accounting for household income, prevalence of non-consumption of tap water was elevated approximately threefold among Mexican Americans and twofold among non-Hispanic black children, compared with non-Hispanic white children. One in four children living in poverty did not drink tap water. Because any alternative to tap water incurs a financial cost, this decision not to consume it may impose a burden on the food budgets of these most impoverished households. In this study, half the children had dental caries experience, with prevalence in children aged 2–5 years and 6–19 years. Non-consumption of tap water was associated with less lead in children's blood, but more decay in their teeth.

Children and adolescents who drank tap water had significantly greater prevalence of elevated blood lead levels than those who did not, and the effect was strongest among the youngest children. This extends an earlier finding among Mexican American children and adolescents, of an association between tap water consumption and elevated blood lead levels.[14] It also builds on findings of a study conducted in Washington DC in which lead service lines carrying tap water were associated with elevated blood lead levels in children, even when water supplies met Environmental Protection Agency standards for lead content in water.[20] Although blood lead levels have decreased substantially in the past 40 years in response to the amendments to the Safe Drinking Water Act and the Lead and Copper Rule,[21,22] these measures fall short of protecting against lead in older household water pipes, or corrosion of older pipes connecting a dwelling to the main water pipe in the street. One consequence of reduced prevalence is that, although the protective association between non-consumption of tap water and elevated blood lead levels is pronounced in relative terms (APR=0.62), it equates to a small net difference in prevalence (i.e., 1.9 compared with 3.1%).

Social differences in tap water consumption coincide with contextual risk factors of the built environments. Factors such as inadequate maintenance of water infrastructure, poorly enforced regulation, and substandard housing limit access to piped potable water[23] compounding health risks for disadvantaged groups lacking opportunity to relocate to safer, more desirable residential areas. Not unexpectedly these factors are strongly correlated with elevated blood lead levels.[19]

Aversion to tap water consumption among Mexican American children is noteworthy. One explanation is the legacy of experiences in Mexico where rapid industrial development and urbanization produced high levels of environmental pollution and unsafe drinking water.[24]

CDC's decision to use ≥5 μg/dL as a reference blood lead level in 2007–2010 NHANES cycles was based on the 97.5th percentile of blood lead distribution in children aged 1–5 years. CDC intends to reassess this reference value using more recent data. Because <1% of children had a blood lead level of ≥5 μg/dL of blood in this study, it was hard to argue the population relevance for such as small group.

The groups least likely to drink tap water suffered a disproportionate burden of dental caries.[12,25] However, caries prevalence was high, and therefore the hazardous association between non-consumption of tap water and caries was not pronounced (APR=1.13), the net difference in prevalence was (55.3% compared with 49.0%). Furthermore, studies conducted in England, Australia, and Canada have raised the intriguing possibility that the protective effect of water fluoridation is greater among those with most dental caries and fewest socioeconomic resources.[26–28] Water fluoridation is the archetypal primary prevention strategy, being independent of compliance or personal expenditure. Although prevalence of dental caries among children decreased for several decades, it remains high in the group aged 2 to 5 years, especially children in families with low income.[25]

The large sample composed of multiple NHANES cycles drawn with probability sampling, reduces the bias of estimates and ensures that findings accurately represent the U.S. child and adolescent population. Since 1976, NHANES has been the primary source of blood lead levels surveillance data in the U.S. population. In addition, NHANES is the sole national source of examiner-determined dental caries data. These results are timely given mounting concern about public water infrastructure and safety.

Limitations

These findings are subject to two major limitations. First, the possibility cannot be ruled out of confounding from unmeasured lead exposures such as lead laden paint chips and dust, gasoline, and solder that could confound the relationship between tap water and blood lead level. On the other hand, the association between tap water consumption and elevated blood level persisted after adjustment for age of house, although that probably constitutes over-adjustment, because older houses are the ones more likely to receive water from pipes containing lead. A better approach would be to adjust for other environmental sources of lead, although that was not possible in this study. Second, the fluoridation status of participants' tap water is not known. Therefore, the observation that drinking tap water has a protective association with dental caries may be an underestimate of fluoride's caries protective effect.

CONCLUSIONS

Non-consumption of tap water is associated with a sizable relative reduction in the probability of blood lead exposure, although at a population level, the net reduction in prevalence of such exposure is small, and the serious health consequences of lead exposure emerge only after years. By contrast, dental caries causes immediate and tangible problems for children's teeth and it is highly prevalent. Non-consumption of tap water is associated with a sizable net increase in its prevalence in the population, though the relative increase in its probability of occurrence is small for individuals.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Characteristics Associated With Outcome Among U.S. Children Aged 2–19 Years[a,b,c]

Characteristics	Does not drink tap water	*p*-value	Blood lead level ≥3 μg/dL	*p*-value	≥1 Tooth with dental caries	*p*-value
Total	3,259 (14.8)		507 (2.9)		2,774 (49.8)	
NHANES cycle						
2005–2006	761 (13.5)	0.143	207 (5.3)	**<0.001**	*d*	
2007–2008	720 (17.3)		124 (3.4)		*d*	
2009–2010	697 (17.6)		85 (1.9)		*d*	
2011–2012	615 (13.3)		55 (2.1)		1,408 (51.1)	0.359
2013–2014	466 (12.4)		36 (1.5)		1,366 (48.4)	
Sex						
Male	1,538 (13.5)	**<0.001**	293 (3.6)	**<0.001**	1,432 (50.7)	0.343
Female	1,721 (16.3)		214 (2.2)		1,342 (48.7)	
Age group, years						
2–5 preschool	1,134 (21.3)	**<0.001**	247 (6.3)	**<0.001**	378 (22.5)	**<0.001**
6–11	1,113 (15.1)		163 (2.8)		1,179 (54.7)	
12–19 adolescence	1,012 (11.2)		97 (1.5)		1,217 (59.8)	
Race/ethnicity						
Mexican American	1,341 (32.2)	**<0.001**	116 (2.4)	**<0.001**	693 (60.6)	**<0.001**
Other Hispanic	418 (26.9)		44 (4.1)		287 (46.8)	
Non-Hispanic white	423 (8.0)		114 (2.3)		644 (47.0)	
Non-Hispanic black	854 (21.5)		199 (5.7)		753 (52.5)	
Other/Multiple	223 (12.4)		34 (2.0)		397 (46.4)	
Income-to-poverty ratio						
<1 (below poverty threshold)	1,227 (22.6)	**<0.001**	259 (5.1)	**<0.001**	1,058 (57.4)	**<0.001**
1 to <2.5 (near poverty)	1,116 (16.1)		150 (2.9)		876 (52.9)	
2.5 to <5 (not poor)	499 (10.3)		43 (1.8)		468 (44.6)	
5 (500% above threshold)	127 (6.4)		13 (1.1)		165 (36.7)	
Income not reported	290 (20.4)		42 (3.4)		207 (54.6)	
Tap water consumption						
Drinks tap water	*d*		413 (3.0)	0.389	2,219 (49.1)	0.057

Characteristics	Does not drink tap water	*p*-value	Blood lead level ≥3 μg/dL	*p*-value	≥1 Tooth with dental caries	*p*-value
Does not drink tap water	*d*		94 (2.5)		555 (54.1)	

Notes: Data presented as unweighted n (weighted %).

[a]Tap water consumption and blood lead level data are from NHANES 2011–2014.

[b]Dental caries data are restricted to NHANES 2011–2014 as dental caries was not assessed in 2005 to 2010.

[c]Not tabulated, but included in this analysis are children and adolescents who: drank tap water (n=12,345), had non-missing BLL >3 (n=12,067) and no caries experience (n=2,903).

[d]Not assessed or not applicable.

NHANES, National Health and Nutrition Examination Survey; BLL, blood lead level

Table 2

Adjusted Prevalence Ratios[a] for Non-Consumption of Tap Water

Characteristics	Prevalence ratio (95% CL)
Sex	
Male	ref
Female	1.17 (1.07, 1.27)
Age group, years	
2–5	1.73 (1.54, 1.94)
6–11	1.29 (1.13, 1.4)
12–19	ref
Race/ethnicity	
Mexican American	3.31 (2.65, 4.14)
Other Hispanic	2.81 (2.22, 3.55)
Non-Hispanic white	ref
Non-Hispanic black	2.25 (1.75, 2.88)
Other/Multiple	1.42 (1.06, 1.89)
Family income to poverty ratio	
<1 (below poverty threshold)	1.95 (1.42, 2.69)
1 to <2.5 (near poverty)	1.73 (1.24, 2.40)
2.5 to <5	1.37 (0.99, 1.90)
5 (500% above threshold)	ref
Income not reported	2.06 (1.45, 2.92)
Intercept	0.04 (0.03, 0.05)

[a]Values are for children and adolescents aged 2 to 19 years, 2005–2014 National Health and Nutrition Examination Survey, n=15.

CL, confidence limits

Table 3

Adjusted Prevalence of Blood Lead Level ≥3 μg/dL

Characteristics	Adjusted prevalence	Prevalence ratio (95% CL)
Tap water consumption		
Drinks tap water	3.1	ref
Does not drink tap water	1.9	0.62 (0.42, 0.90)
NHANES cycle		
2005–2006	5.6	ref
2007–2008	3.6	0.63 (0.41, 0.96)
2009–2010	2.0	0.35 (0.21, 0.58)
2011–2012	2.0	0.36 (0.18, 0.74)
2013–2014	1.2	0.22 (0.12, 0.42)
Age in years	*b*	0.88 (0.85, 0.91)
Sex		
Male	3.6	ref
Female	2.1	0.58 (0.45, 0.74)
Race/ethnicity		
Mexican American	2.1	0.83 (0.52, 1.32)
Other Hispanic	3.5	1.42 (0.77, 2.61)
Non-Hispanic white	2.5	ref
Non-Hispanic black	4.9	1.90 (1.24, 2.90)
Other/Multiple	2.0	0.78 (0.43, 1.41)
Family income to poverty ratio		
<1 (below poverty threshold)	4.9	4.20 (1.76, 10.03)
1 to <2.5 (near poverty)	2.8	2.42 (0.97, 6.04)
2.5 to <5	1.8	1.53 (0.58, 4.07)
5 (500% above threshold)	1.2	ref
Income not reported	4.2	3.63 (1.18, 11.15)
Intercept	*b*	0.09 (0.03, 0.23)

[a]Values are for children and adolescents aged 2–19 years, 2005–2014 NHANES (n=12,373)

[b]Not applicable

NHANES, _ National Health and Nutrition Examination Survey _

Table 4

Adjusted Prevalence of Dental Caries[a,b]

Characteristics	Adjusted prevalence	Prevalence ratio (95% CL)
Tap water consumption		
Drinks tap water	49.0	ref
Does not drink tap water	55.3	1.13 (1.03, 1.23)
Age in years	*c*	1.06 (1.05, 1.07)
Sex		
Male	51.0	1.00
Female	48.5	0.95 (0.87, 1.04)
Race/ethnicity		
Mexican American	56.6	1.16 (1.03, 1.31)
Other Hispanic	45.7	0.93 (0.82, 1.07)
Non-Hispanic white	48.9	1.00
Non-Hispanic black	48.7	1.00 (0.90, 1.10)
Other/Multiple	48.0	0.98 (0.85, 1.13)
Family income to poverty ratio		
<1 (below poverty threshold)	57.0	1.49 (1.11, 2.00)
1 to <2.5 (near poverty)	52.9	1.39 (1.08, 1.79)
2.5 to <5	44.4	1.16 (0.87, 1.56)
5 (500% above threshold)	38.2	1.00
Income not reported	51.6	1.35 (0.97, 1.88)
Intercept	*c*	0.20 (0.16, 0.26)

[a]Dental caries experience defined as ≥1 tooth surface/s in the primary or permanent dentition that is decayed, extracted or filled because of dental caries

[b]Values are for children and adolescents aged 2–19 years, 2011–2014 NHANES (n=5,585)

[c]Not applicable

NHANES, National Health and Nutrition Examination Survey