Prevalence of Inadequate Hydration Among US Children and Disparities by Gender and Race/Ethnicity: National Health and Nutrition Examination Survey, 2009–2012

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Objectives. We evaluated the hydration status of US children and adolescents.

Methods. The sample included 4134 participants aged 6 to 19 years in the National Health and Nutrition Examination Survey from 2009 to 2012. We calculated mean urine osmolality and the proportion with inadequate hydration (urine osmolality > 800 mOsm/kg). We calculated multivariable regression models to estimate the associations between demographic factors, beverage intake, and hydration status.

Results. The prevalence of inadequate hydration was 54.5%. Significantly higher urine osmolality was observed among boys (+92.0 mOsm/kg; 95% confidence interval [CI] = 69.5, 114.6), non-Hispanic Blacks (+67.6 mOsm/kg; 95% CI = 31.5, 103.6), and younger children (+28.5 mOsm/kg; 95% CI = 8.1, 48.9) compared with girls, Whites, and older children, respectively. Boys (OR = 1.76; 95% CI = 1.49, 2.07) and non-Hispanic Blacks (odds ratio [OR] = 1.34; 95% CI = 1.04, 1.74) were also at significantly higher risk for inadequate hydration. An 8-fluid-ounce daily increase in water intake was associated with a significantly lower risk of inadequate hydration (OR = 0.96; 95% CI = 0.93, 0.98).

Conclusions. Future research should explore drivers of gender and racial/ethnic disparities and solutions for improving hydration status. (*Am J Public Health.* Published online ahead of print June 11, 2015: e1–e6. doi:10.2105/AJPH.2015.302572)

Adequate hydration is essential for health. Water is crucial for the proper function of several physiological processes, including circulatory function, metabolism, temperature regulation, and waste removal.[1] Dehydration, a state in which total body water is inadequate for proper cell, organ, and system functioning, is associated with poor health. Although excessive dehydration is associated with serious health problems, such as impaired renal, immune, and gastrointestinal functioning, confusion, and delirium, even mild dehydration can worsen health and well-being.[2] Mild dehydration is associated with headache, irritability, poorer physical performance, and reduced cognitive functioning among both children and adults.[2–5]

Children's hydration status could have implications for both health and school performance. Two studies have shown that inadequate hydration, defined as urine osmolality of 800 milliosmoles per kilogram or higher, is associated with poorer performance on cognitive tests.[6,7] However, despite a substantial body of research examining children's beverage intake,[8] little is known about children's hydration status and whether it may be a population health concern. Kant et al. found that as of the period 2005 to 2006, US children and adolescents, on average, did not consume adequate water for their age group as defined by the Institute of Medicine,[9] but hydration status was not evaluated. A small study in 2 major US cities using urine osmolality as an indicator of hydration status found that over 60% of a convenience sample of children aged 9 to 11 years were inadequately hydrated and that most children did not consume plain water, putting them at higher risk of inadequate hydration.[10] However, we have identified no study describing children's hydration status nationally. Additionally, although a review of international studies found significant differences in hydration status by age, gender, race/ethnicity, and culture,[11] there is limited evidence about the population distribution of urine osmolality and inadequate hydration among US children, particularly whether disparities in hydration status exist across population groups defined by race/ethnicity, household income, gender, or age. Although small, laboratory-based studies of adults suggest that higher beverage intake is associated with better hydration status (regardless of beverage type),[12,13] preliminary evidence has suggested that plain water may be associated with better hydration status in children.[10] Given that little is known about how consumption of different beverages may affect population hydration status in children, the potential solutions to reducing inadequate hydration are unclear.

Measuring hydration status outside of severe dehydration has proven challenging because the level of fluid in the body is constantly fluctuating. Plasma osmolality, a measure of the amount of solutes in the blood stream, is often used to measure severe dehydration, but it has a very limited range and is tightly regulated by homeostasis, rendering it insensitive to smaller changes in hydration status.[12,14–16] Measures involving urine, such as urine volume or urine osmolality, are more sensitive to less dramatic changes in body water; however, the volume and timing of water intake can bias measurements. If individuals rapidly consume large amounts of water, their urine osmolality will be low and urine volume high as the body rapidly excretes the water, but their hydration status will be unaffected as the body will get rid of the excess water before it has a chance to rehydrate. Twenty-four-hour urine osmolality and 24-hour urine volume may be the most sensitive measures of 24-hour hydration status as time lags are better controlled.[11,14–16] Although a single measure of urine osmolality may not accurately reflect an individual's typical hydration status because of fluctuation in urine osmolality, it may still be useful for estimating population averages. We would expect that observed fluctuations in the population would not be systematically biased above or below the mean.

We examined the prevalence of elevated urine osmolality and its population distribution by age, race/ethnicity, gender, and family income in a nationally representative sample of participants aged 6 to 19 years from the National Health and Nutrition Examination Survey (NHANES), 2009 to 2012,[17] controlling for sample design and time of day the data were collected. We also examined whether consuming different types of beverages on the day before data collection, including water, milk, 100% juice, sugar-sweetened beverages (SSBs), and diet drinks, was associated with urine osmolality in this age group, hypothesizing that increased intake of water (compared with other beverages) would be associated with reduced urine osmolality.

METHODS

NHANES collects nationally representative data annually on health indicators using a complex survey design.[17] NHANES measured urine osmolality in all study participants aged 6 years and older in the 2009–2010 and 2011–2012 waves. Our sample included individuals aged 6 to 19 years with nonmissing urine osmolality, demographic, and body composition data as well as data on dietary intake for the day prior to the NHANES data collection in these waves. Of the 6- to 19-year-old participants (n = 4766) in the study sample, we excluded 632 because of missing data, which resulted in a final sample of 4134.

Measures

Urine osmolality measures the amount of solute particles (in milliosmoles) contained in each kilogram of urine, with higher urine osmolality generally reflecting poorer hydration.[11,14–16] Urine samples were collected and analyzed by NHANES and the time of day of the examination was noted (morning, afternoon, or evening).[18] Consistent with previous studies in children, we used a cutpoint of 800 milliosmoles per kilogram or higher as an indicator of inadequate hydration.[6,7,10] This cutpoint was based on population distributions rather than symptoms, but recent studies have found that children with urine osmolality of 800 milliosmoles per kilogram or higher perform worse on cognitive tests[6,7] and have poorer emotional states.[7] Study participants' age, gender, race/ethnicity (non-Hispanic White, non-Hispanic Black, Mexican American or other Hispanic, and other race, including multiracial), and total household income (operationalized by NHANES as the ratio of income to the poverty level to control for household size) were collected by NHANES via questionnaire. NHANES staff measured body weight and height to calculate body mass index (BMI). Intake of all foods and beverages for the day prior to urine collection was measured by NHANES via one 24-hour recall, with proxy-assisted interviews conducted among children aged 6 to 11 years. From this 24-hour recall, NHANES calculated the total moisture, or water, consumed from all foods and beverages (in grams); the different beverages (in grams) that participants reported were also recorded. We operationalized beverage intake (converted into 8-fl-oz servings) into 6 categories used in previous studies:

1. plain water, including tap water, water from a drinking fountain or water cooler, bottled water, and spring water;
2. SSBs, including calorically sweetened soft drinks, juice drinks that were not 100% juice, sports drinks, flavored waters, and coffee or tea drinks;
3. milk, including cow's milk, soy milk, and rice milk, flavored and unflavored;
4. 100% juice;
5. diet beverages (beverages using noncaloric sweeteners and no-caloric sweeteners); and
6. unsweetened coffee or tea.[19]

We then estimated the total moisture consumed via foods (in grams) by summing total beverage intake in grams and subtracting this sum from total moisture consumed. Although NHANES conducted follow-up 24-hour recalls among many participants, we used the first day only because, theoretically, the prior day's beverages were likely to be a more relevant determinant of urine osmolality at a given time point than beverage intake several weeks later. In addition, using both days would have resulted in the further exclusion of 493 participants, or 12% of the sample.

Statistical Analysis

We estimated population means of urine osmolality and beverage intake using PROC SURVEYMEANS to account for the complex sampling design. We used PROC SURVEYFREQ to estimate the distribution of sociodemographic variables and elevated urine osmolality. We estimated linear regression models, taking into account the complex survey design, using PROC SURVEYREG (SAS version 9.3; SAS Institute, Cary, NC) to determine whether mean urine osmolality differed by age, race/ethnicity, gender, and income, as well as a multivariable adjusted model that also included time of examination (morning vs afternoon or evening), given circadian variations in urine osmolality.[20] We estimated logistic regression models using PROC SURVEYLOGISTIC to evaluate demographic differences in risk of inadequate hydration, also controlling for all variables above. Lastly, we estimated the relationship between beverage intake for the day prior to the examination and urine osmolality using linear regression models, first evaluating the crude relationship between each beverage individually and urine osmolality and then simultaneously adjusting for other beverage and moisture from food intake as well as age, race/ethnicity, gender, income, time of examination, and BMI. We estimated similar logistic regressions modeling the risk of inadequate hydration.

RESULTS

The mean urine osmolality across the population was 755.5 milliosmoles per kilogram (range = 34–1394; SE = 7.4; Table 1). In the adjusted linear model (Table 1), urine osmolality was significantly higher for boys than for girls (difference = +92.0 mOsm/kg; 95% confidence interval [CI] = 69.5, 114.6), for non-Hispanic Blacks than for non-Hispanic Whites (+67.6 mOsm/kg; 95% CI = 31.5, 103.6), and for participants aged 6 to 11 years than for those aged 12 to 19 years (+28.5 mOsm/kg; 95% CI = 8.1, 48.9). Urine osmolality was marginally significantly higher for Hispanics than for non-Hispanic Whites. Family income was not associated with urine osmolality.

Half of the population (54.5%) was inadequately hydrated, defined as having urine osmolality greater than 800 milliosmoles per kilogram (Table 2). In the adjusted logistic

TABLE 1—Crude and Adjusted Mean Urine Osmolality of Participants Aged 6–19 Years, by Socioeconomic and Demographic Characteristics: National Health and Nutrition Examination Survey, United States, 2009–2012

	No. (Weighted %)	Urine Osmolality, mOsm/kg, Mean ±SE (Range)	Difference in Mean Urine Osmolality, mOsm/kg, Crude (95% CI)	P	Difference in Mean Urine Osmolality, mOsm/kg, Adjusted (95% CI)	P
Overall	4134	755.5 ±7.4 (34-1394)				
Age, y						
6–11	2075 (42.9)	775.2 ±10.3 (56-1394)	+34.5 (12.5, 56.6)	.003	+28.5 (8.1, 48.9)	.008
12–19	2059 (57.1)	740.7 ±8.3 (34-1350)	(Ref)		(Ref)	
Gender						
Male	2192 (52.7)	799.1 ±9.9 (56-1394)	+92.1 (68.9, 115.4)	< .001	+92.0 (69.5, 114.6)	< .001
Female	1942 (47.3)	707.0 ±9.1 (34-1339)	(Ref)		(Ref)	
Race/ethnicity						
Non-Hispanic White	1201 (57.2)	735.3 ±12.4 (34-1340)	(Ref)		(Ref)	
Non-Hispanic Black	1057 (14.4)	807.2 ±12.0 (53-1371)	+71.9 (37.7, 106.2)	< .001	+67.6 (31.5, 103.6)	< .001
Hispanic	1404 (20.6)	775.0 ±10.3 (56-1394)	+39.7 (5.5, 73.9)	.02	+33.9 (–2.3, 70.1)	.07
Other race, including multiracial	473 (7.7)	756.7 ±19.5 (55-1269)	+21.4 (–25.7, 64.5)	.36	+17.6 (–28.1, 63.3)	.44
Income[a]						
Higher income	2237 (66.6)	750.6 ±9.9 (34-1371)	(Ref)		(Ref)	
Lower income	1897 (33.4)	765.4 ±8.6 (55-1394)	+14.9 (–10.9, 40.7)	.25	+3.1 (–24.0, 30.3)	.82

Note. CI = confidence interval. Crude models are of each individual demographic characteristic predicting urine osmolality, with no adjustment for covariates. Adjusted model includes all sociodemographic variables (age category, gender, race/ethnicity, income) simultaneously with time of examination.
[a]Lower income was operationalized by the National Health and Nutrition Examination Survey as income below 130% of the poverty line. Higher income was operationalized as income at or above 130% of the poverty line.

model (Table 2), girls were at higher risk than girls (odds ratio [OR] = 1.76; 95% CI = 1.49, 2.07) and non-Hispanic Blacks were at higher risk than non-Hispanic Whites (OR = 1.34; 95% CI = 1.04, 1.74). Although younger children and Hispanics appeared to be at higher risk in unadjusted models, these differences were attenuated in the adjusted model and were no longer statistically significant.

Children and adolescents in this sample consumed 2.9 (SE = 0.1) servings per day of plain water, 2.0 (SE = 0.1) servings per day of SSBs, 1.1 (SE = 0.04) servings per day of milk, and very small amounts of 100% juice, diet beverages, and unsweetened coffee or tea (Table 3). Moisture intake from foods, which averaged 399.3 grams (SE = 9.0) in this population, contributed 21.1% of total moisture, with beverage intake contributing the remaining 78.9%. After adjustment for total moisture from foods (excluding beverages) and for age, race/ethnicity, gender, income, and BMI, consuming 1 more 8-fluid-ounce serving of plain water was associated with an –8.0 milliosmoles per kilogram decrease in urine osmolality (95% CI = –11.7, –4.2), and an additional 1 serving of SSB was similarly associated with lower urine osmolality (–10.0 mOsm/kg; 95% CI = –16.5, –3.5). Intake of milk, 100% juice, diet beverages, and unsweetened coffee or tea was not significantly independently associated with urine osmolality, nor was moisture consumed from foods. Additionally, adjustment for beverage intake and moisture from foods did not substantially alter any of the parameter estimates for sociodemographic factors shown in Table 1, except for gender: urine osmolality was 108.0 milliosmoles per kilogram higher among boys than girls ($P < .001$). Using logistic regression models examining the relationship between beverage type and odds of elevated urine osmolality (Table 3), we found that only water intake was associated with reduced odds of inadequate hydration (OR = 0.96; 95% CI = 0.93, 0.98).

DISCUSSION

This is the first study to document the prevalence of inadequate hydration among US children using nationally representative data. On the basis of elevated urine osmolality levels, more than half of all children were inadequately hydrated. Younger children, boys, and non-Hispanic Blacks had higher urine osmolality than older children, girls, and non-Hispanic Whites. The odds of inadequate hydration were 1.76 times higher among boys than girls and 1.34 times higher among non-Hispanic Blacks than non-Hispanic Whites. Our findings on gender and age differences in urine osmolality echo findings from the 1976 to 1980 waves of NHANES data collection among adults, which also demonstrated significantly higher urine osmolality for men and lower urine osmolality for higher age groups.[21]

We did not identify the reasons for the observed disparities in hydration status in this study. Adjusting for water, other beverages, and food moisture intake as well as BMI did not attenuate the estimates of population differences in urine osmolality according to gender, race/ethnicity, and age, suggesting that these disparities cannot be explained by differences in beverage intake or weight status. Other

TABLE 2—Crude and Adjusted Proportions of Children Aged 6–19 Years Classified as Underhydrated, by Sociodemographic Group: National Health and Nutrition Examination Survey, United States, 2009–2012

Sociodemographic Group	No. (Weighted %)	OR (95% CI), Crude Models	*P*	OR (95% CI), Adjusted Model	*P*
Overall	2298 (54.5)				
Age, y					
6–11	1167 (55.5)	1.15 (1.00, 1.33)	.06	1.11 (0.97, 1.27)	.12
12–19	1131 (52.0)	1.00 (Ref)		1.00 (Ref)	
Gender					
Male	1336 (60.0)	1.75 (1.48, 2.06)	< .001	1.76 (1.49, 2.07)	< .001
Female	962 (46.3)	1.00 (Ref)		1.00 (Ref)	
Race/ethnicity					
Non-Hispanic White	615 (50.8)	1.00 (Ref)		1.00 (Ref)	
Non-Hispanic Black	626 (58.7)	1.38 (1.09, 1.74)	.008	1.34 (1.04, 1.74)	.02
Hispanic	784 (56.7)	1.27 (1.00, 1.61)	.048	1.23 (0.96, 1.57)	.1
Other race, including multiracial	272 (55.7)	1.22 (0.91, 1.64)	.19	1.19 (0.89, 1.62)	.23
Income[a]					
Higher income	1239 (52.7)	1.00 (Ref)		1.00 (Ref)	
Lower income	1059 (55.2)	1.10 (0.96, 1.27)	.17	1.05 (0.90, 1.22)	.54

Note. CI = confidence interval; OR =odds ratio. Underhydrated defined as urine osmolality ≥ 800 mOsm/kg. Crude models are of each individual demographic characteristic predicting urine osmolality, with no adjustment for covariates. Adjusted model includes all sociodemographic variables (age category, gender, race/ethnicity, income) simultaneously with time of examination.
[a]Lower income was operationalized by the National Health and Nutrition Examination Survey as income below 130% of the poverty line. Higher income was operationalized as income at or above 130% of the poverty line.

dietary factors, physical activity,[22] climate differences, and medication use may also play a role. Future research should explore drivers of these disparities and potential public health solutions to reduce disparities.

Higher water intake was associated with significantly lower urine osmolality, as was intake of SSBs. However, only higher water intake was significantly associated with reduced odds of inadequate hydration. Although our results did not demonstrate significant associations between juice, diet beverage, or coffee–tea intake and urine osmolality, this may be because average intake of these beverages in this sample was fairly low. The observed null association between milk intake and urine osmolality in this study mirrors the null association found between moisture from food and urine osmolality; this may be because milk is more similar to food because it contains several other components beyond simply fluid (e.g., protein, salts, sugars). Our results were also similar to the results of a study of children in New York City and Los Angeles, California, which suggested that, compared with consumption of other beverages, water consumption was associated with lower odds of urine osmolality of 800 milliosmoles per kilogram or higher.[10]

Although increased fluid intake is beneficial in general, increased intake of water rather than other beverages may be more important for reducing the prevalence of inadequate hydration. Public health efforts to alleviate inadequate hydration should focus on increasing access to drinking water and promoting consumption of water rather than other beverages such as SSBs, given that water is a low-cost, no-calorie beverage with no negative effects on weight and health, whereas SSB consumption causes worse health, including increased risk of obesity,[8] type 2 diabetes mellitus, and cardiovascular disease.[23] Reducing SSB consumption has been shown to reduce excess weight gain in children and

TABLE 3—Association Between Beverage Type and Hydration Status Among Children Aged 6–19 Years: National Health and Nutrition Examination Survey, United States, 2009–2012

			Mean Urine Osmolality per Serving, mOsm/kg				Inadequate Hydration per 8-fl-oz Serving			
Beverage	No. Consuming Any Amount (Weighted %)	Mean Intake, 8-fl-oz Servings (SE)	Crude Difference (95% CI)	*P*	Adjusted Difference (95% CI)	*P*	Crude OR (95% CI)	*P*	Adjusted OR (95% CI)	*P*
Plain water	3132 (77.6)		−7.4 (−11.8, −3.0)	.002	−8.0 (−11.7, −4.2)	< .001	0.96 (0.94, 0.98)	.001	0.96 (0.93, 0.98)	< .001
Sugar-sweetened beverages	3040 (71.5)	2.0 (0.1)	−6.1 (−11.8, −0.3)	.04	−10.0 (−16.5, −3.5)	.004	0.98 (0.94, 1.02)	.36	0.95 (0.90, 1.01)	.09
Milk	2611 (65.9)	1.1 (0.04)	3.8 (−7.2, 14.8)	.49	−4.5 (−15.4, 6.5)	.41	1.02 (0.94, 1.10)	.69	0.97 (0.90, 1.05)	.44
100% juice	1219 (26.1)	0.3 (0.02)	−5.7 (−35.6, 24.1)	.7	−13.7 (−40.4, 12.9)	.3	1.01 (0.89, 1.15)	.9	0.96 (0.84, 1.10)	.57
Diet beverages	254 (9.1)	0.2 (0.02)	−25.1 (−54.3, 4.2)	.09	−22.0 (−52.1, 8.1)	.15	0.90 (0.75, 1.07)	.22	0.92 (0.77, 1.10)	.34
Coffee or tea (unsweetened)	301 (7.0)	0.1 (0.01)	−22.3 (−49.0, 4.4)	.1	−14.1 (−38.2, 10.0)	.24	0.90 (0.76, 1.06)	.2	0.94 (0.78, 1.13)	.48
Moisture from food, g	4134 (100)	399.3 (9.0)	−0.02 (−0.06, 0.03)	.44	−0.02 (−0.07, 0.03)	.32	1.00 (1.00, 1.00)	.4	1.00 (0.99, 1.00)	.29

Note. CI = confidence interval; OR =odds ratio. Adjusted models are adjusted simultaneously for all other beverages and moisture from food, as well as for age, gender, race/ethnicity, poverty-to-income ratio, body mass index, time of day of examination, and the complex survey design. Crude models adjust for the complex survey design only. The sample size was n = 4134.

adolescents.[24,25] Water consumption among children and adolescents is low[9]; in this sample, nearly a quarter of those aged 6 to 19 years reported no plain water consumption at all. Increasing water consumption may help to lower urine osmolality across the population[26] while having no negative impact on obesity and chronic disease.

Inadequate hydration has implications for children's health and school performance. Drinking water can improve children's performance on cognitive tests.[3,4,7] Two studies have found that children's cognitive performance improved as their urine osmolality decreased.[6,7] Increasing drinking water access in schools may be a key strategy for reducing inadequate hydration and improving student health, because schools reach so many children and adolescents and that they typically provide free drinking water to students. Although schools participating in the National School Lunch Program must provide free drinking water during meals,[27] implementation varies,[28,29] and many school districts struggle with older infrastructure that limits their capacity to provide safe drinking water.[30] Providing servings of between 300 and 500 milliliters (about 10–16.8 fl oz) of water to children during the school day has been shown to improve cognitive performance[4,31] and mood.[7] Recent interventions to improve drinking water access and promote water consumption among students have had promising results, demonstrating increases in water intake[32–34] and reductions in the prevalence of obesity.[34] Similar efforts may help alleviate inadequate hydration.

Limitations

A strength of this study was our use of a nationally representative sample. Previous studies have typically been conducted with convenience samples, limiting the ability to make inferences about the extent to which inadequate hydration is a population health concern. Although urine osmolality is one of many measures of hydration status and may be influenced by rapid fluid intake,[14–16] it can serve as a useful population indicator of hydration status. Future research could evaluate whether these findings would be similar if other measures of hydration status were used. We were unable to evaluate the effects of seasonality and region in this sample, both of which may have played an important role, as climate can affect urine osmolality. However, we did evaluate the relationship between school attendance status (in school vs on vacation) and urine osmolality in the 2009–2010 wave (the variable was not available in the later wave), as a crude measure of seasonality, and found no association in this subset of the data. One 24-hour recall may also not have reflected usual dietary intake, and this measurement error could attenuate observed associations between beverage intake and urine osmolality. We did not fully investigate other drivers of urine osmolality (such as medication use or other dietary variables) in this sample; future research should further explore other potentially modifiable drivers of elevated urine osmolality that could be amenable to intervention to improve children's health.

Conclusions

Inadequate hydration is a prevalent and understudied health problem among US children and adolescents, particularly boys, non-Hispanic Blacks, and Hispanics. Drinking water can reduce the risk of inadequate hydration. Future research should explore strategies to improve overall levels of hydration among children and adolescents, determine the potential reasons for observed disparities, and focus on strategies to reduce gender and racial/ethnic disparities. More information is needed on other predictors of hydration status, such as diet, that may also be modified to improve hydration. ■

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Contributors

E. L. Kenney, the lead author, helped develop the research question and conducted the main analyses. M. W. Long provided input on the analysis and conceptual framework and reviewed the article for important intellectual content. A. L. Cradock reviewed the article for important intellectual content. S. L. Gortmaker helped develop the research question, provided input on the analytic strategy, and reviewed the article for important intellectual content.

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