Trends in Sodium Intake in Children and Adolescents in the US and the Impact of US Department of Agriculture Guidelines: NHANES 2003-2016

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Objective To examine trends in sodium intake and the impact of nutritional guidelines in the US pediatric population.
Study design Sodium intake data collected between 2003 and 2016 in the US National Health and Nutrition Examination Surveys (NHANES) were analyzed. Trends in intake for individuals aged 4-17 years and subgroups based on age, sex, and race and ethnicity were examined. Adherence to US Department of Agriculture guidelines was assessed.
Results A total of 16 013 individuals (50.6% male) were included in the analysis. The median sodium intake was 2840 mg/day (95% CI, 2805-2875 mg/day), decreasing from 2912 mg/day (95% CI 2848-2961 mg/day) in 2003-2004 to 2787 mg/day (95% CI, 2677-2867 mg/day) in 2015-2016 ($P = .005$). Intake increased with age (2507 mg/day for individuals aged 4-8, 2934 mg/day for those aged 9-13 years, and 3124 mg/day for those aged 14-17 years; $P < .001$) and was greater in males than in females (3053 mg/day vs 2624 mg/day; $P < .001$). Caucasians, Hispanics, and African Americans consumed 2860, 2733, and 2880 mg/day, respectively ($P < .001$). Population adherence to US Department of Agriculture recommendations was 25.0% in 2003-2010 and 25.5% in 2011-2016 ($P = .677$). No age, sex, or racial/ethnicity subgroup had an adherence rate >30% after implementation of pediatric guidelines in 2010.
Conclusions Sodium intake remains elevated in all pediatric population segments, and guideline adherence is poor. A greater effort to reduce sodium consumption is needed to mitigate future cardiovascular disease risk. *(J Pediatr 2020;225:117-23)*.

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Excess sodium intake has been linked to an increased prevalence of cardiovascular morbidity and mortality.[1,2] Higher levels of sodium consumption have been associated with higher systolic and diastolic blood pressure.[3] Furthermore, worse cardiovascular outcomes have been attributed to the direct effect of hypertension; this association has been validated in multiple populations.[4-9] In the pediatric population, higher sodium intake and hypertension have been associated with increased arterial stiffness and left ventricular hypertrophy.[10-13] Children with hypertension or high-normal blood pressure have accelerated retinal microvascular disease and greater artery stiffness compared with normotensive peers.[14] Childhood sodium intake is related to higher blood pressure and prevalence of hypertension in children, which predisposes to a greater risk of hypertension in adults.[15-18]

Due to the connection between childhood dietary sodium intake and adult cardiovascular disease, the United States Department of Agriculture (USDA) has implemented recommendations to encourage moderation of sodium consumption in both the adult and pediatric populations. Poor adherence to these guidelines in the adult population has been reported.[19,20] Beginning in 2010, the USDA released pediatric age group-specific guidelines after previous iterations only suggested reduction and moderation.[21,22] The 2010 guidelines recommended limiting sodium intake to 1500 mg/day for children aged 1-3 years, 1900 mg/day for those aged 4-8 years, 2200 mg/day for those aged 9-13 years, and 2300 mg/day for those aged 14-17 years, which is the same as for the general adult population, and there were no changes in the 2015 version.[23,24]

Previous work has shown excess childhood sodium intake in international populations and in earlier analyses of the National Health and Nutrition Examination Survey (NHANES), but recent trends in sodium intake and the impact of the USDA guidelines have not been reported to date.[25-31] To address these knowledge gaps, we analyzed NHANES data to identify trends in sodium intake in the pediatric population from 2003 to 2016 with demographic subgroups by age, sex, and race and ethnicity, as well as sodium intake before and after the 2010 USDA recommendations.

Methods

The National Center for Health Statistics has administered the cross-sectional NHANES at periodic intervals since 1971 to evaluate health and nutritional

NHANES	National Health and Nutrition Examination Surveys
USDA	United States Department of Agriculture

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markers for adults and children in the US. The surveys are designed to compose a scientifically selected sample representative of the population and include data on demographics, physical examination and laboratory test results, and detailed interviews regarding lifestyle, diet, and health status. NHANES data have been converted to downloadable public-use datasets available from the Centers for Disease Control and Prevention (www.cdc.gov/nchs/nhanes). For our present analysis, NHANES datasets available in 2-year cycles from 2003-2004 to 2015-2016 (the most recent available cycle) were used; we excluded 1999-2002, as recommended by NHANES, owing to a variation in sodium intake collection techniques.[32] We limited the analysis to children aged 4-17 years and specified age subgroups to correspond with USDA recommendations: 4-8, 9-13, and 14-17 years. Children aged <4 years were excluded due to limited independent food choices in that age group and to maintain congruence with USDA-recommended age groups. Race and ethnicity were categorized as non-Hispanic white, non-Hispanic black, Hispanic, and other (including multiracial).

Sodium Intake

Dietary sodium intake data were derived from nutrition interviews conducted by trained interviewers. The validity of this interview-based sodium intake measurement has been verified against 24-hour urinary sodium excretion.[33,34]

Statistical Analyses

NHANES data were retrieved from https://www.cdc.gov/nchs/nhanes/using the RNHANES package in R (R Foundation for Statistical Computing, Vienna, Austria). Specialized survey functions were used for all estimates and *P* values, accounting for survey design using appropriate variable weights provided by the NHANES database. Mean and median sodium intakes (mg/day) were calculated for the entire population and within demographic subgroups, both overall and within 2-year cycles. The groups (age, sex, race/ethnicity) and time trends (cycles) were compared using generalized linear models for survey design. The models for demographic groups were adjusted for survey cycle. To account for non-normal distribution of the sodium variable, Box-Cox power transformation was used in the models. The proportion of individuals adherent to USDA sodium recommendations was calculated and expressed as a percentage. To evaluate the impact of USDA recommendations on population behavior, we defined 2 time periods: 2003-2010, reflecting the period with no specific recommendations, and 2011-2016, reflecting the period with specific pediatric guidelines. Sex and race/ethnicity subgroups were analyzed based on age group-appropriate sodium level recommendations to account for variations in the recommended level of sodium intake across age groups. Differences in adherence to guidelines was evaluated using the χ^2 test, adjusted for survey design. A *P* value of <.05 was considered statistically significant. All analyses were performed using R version 3.6.

Human Studies

This study was evaluated by the Human Research Protection Office at Washington University and Barnes-Jewish Hospital in St. Louis, Missouri. Because the study involves analysis of deidentified publicly available data, formal approval by the Institutional Review Board was waived.

Results

A total of 16 013 individuals were included over 7 cycles. The sample sizes per cycle ranged from 2836 to 3755. The distribution by age group was 5589 in the 4-8 year (34.9%), 5669 in the 9-13 year group (35.4%), and 4756 in the 14-17 year group (29.7%). There were 8119 males (50.7%) and 7894 females (49.3%). There were 6234 Hispanic Americans (35.1%), 4991 non-Hispanic whites (28.1%), 4866 non-Hispanic blacks (27.4%), and 1687 other or multiracial individuals (9.5%). There were 9608 subjects with a normal BMI (60.0%), 2754 overweight individuals (17.2%) and 3651 (22.8%) obese individuals. **Table I** provides demographic data by 2-year NHANES cycles.

Sodium Intake and Trends Over Time

Median sodium intake for the population and demographic subgroups overall and by cycle is shown in **Table II**. As shown in **Figure 1**, A, total median sodium intake was 2840 mg/day (95% CI, 2805-2875 mg/day), decreasing from 2912 mg/day in 2003-2004 (95% CI 2848-2961 mg/day) to 2787 mg/day in 2015-2016 (95% CI 2677-2867 mg/day) ($P = .005$). Median sodium consumption was greater in males compared with females (3053 mg/day [95% CI, 2994-3109 mg/day] vs 2624 mg/day [95% CI, 2811-2905 mg/day]; $P < .001$) (**Figure 1**, B). As shown in **Figure 1**, C, median intake was 2507 mg/day (95% CI, 2464-2551 mg/day) in the 4-8 year group, 2934 mg/day (95% CI, 2890-2981 mg/day) in the 9-13 year group, and 3124 mg/day (95% CI 3047-3214 mg/day) in the 14-17 year group ($P < .001$ for all comparisons). Among racial and ethnic subgroups, non-Hispanic black individuals consumed a median of 2880 mg/day (95% CI, 2826-2928 mg/day), non-Hispanic white individuals had a median intake of 2860 mg/day (95% CI, 2811-2905 mg/day), and Hispanic individuals consumed a median of 2733 mg/day (95% CI, 2811-2905 mg/day) ($P = .507$ non-Hispanic black vs white; $P = .012$ Hispanic vs non-Hispanic black; $P < .001$ Hispanic vs non-Hispanic white) (**Figure 1**, D). There was no difference in sodium intake across BMI categories adjusted for age and cycle ($P = .384$) (**Table II**).

Temporal trends in median sodium intake are shown in **Figure 1** for the total population and the analyzed subgroups. For the total population, there was a modest but statistically significant decrease in median sodium intake over time ($P = .01$). Males did not show a meaningful trend in sodium intake ($P = .08$), but the trend in sodium intake among females was statistically significant ($P = .02$). Among the age subgroups, there was a marginally significant

Table I. Sociodemographic data overall and by NHANES cycle

Variables	Overall (N = 16 013)	2003-2004 (N = 2728)	2005-2006 (N = 2799)	2007-2008 (N = 2253)	2009-2010 (N = 2331)	2011-2012 (N = 1963)	2013-2014 (N = 1984)	2015-2016 (N = 1955)
Age group, %								
4-8 y	34.9	26.8	30.1	39.7	37.9	40.7	36.0	37.0
9-13 y	35.4	34.9	35.1	34.6	35.6	35.9	35.9	36.1
14-17 y	29.7	38.3	34.8	25.7	26.6	23.5	28.1	26.9
Sex, %								
Female	49.4	49.9	51.1	48.4	48.5	49.0	48.3	49.9
Male	50.6	50.1	48.9	51.6	51.5	51.0	51.7	50.1
Race/ethnicity, %								
Black	30.2	36.8	33.2	27.5	21.3	35.2	30.0	25.9
White	30.9	28.3	28.5	32.9	35.8	27.6	30.4	34.1
Hispanic	38.8	34.9	38.3	39.6	42.9	37.2	39.6	40.0
Body mass index category, %								
Normal	60.0	59.9	61.5	60.9	60.1	60.4	58.5	57.8
Overweight	17.2	18.6	15.8	16.1	17.0	16.9	18.2	18.4
Obese	22.8	21.5	22.7	23.0	22.9	22.7	23.2	23.8
Reference person education level, %*								
Less than high school	30.4	33.5	32.2	31.2	30.7	30.5	26.2	26.2
High school or General Educational Development (GED) tests	23.5	25.5	23.1	24.8	22.7	23.4	23.6	21.0
More than high school	45.7	40.6	44.1	43.7	46.3	45.9	49.9	52.4
Unknown	0.4	0.4	0.5	0.3	0.3	0.2	0.3	0.4
Reference person marital status, %*								
Married/with partner	67.4	63.9	67.5	67.4	68.3	65.7	69.7	70.5
Never married	13.1	14.4	12.3	12.8	11.6	16.4	12.6	11.9
Unknown	0.9	1.0	0.8	0.9	0.8	1.4	0.9	1.0
Widowed/divorced/separated	18.5	20.8	19.4	18.9	19.3	16.5	16.8	16.5

*Reference person refers to the adult individual who consented to and completed the NHANES surveys.

decrease in median sodium intake in the 9-13 year group ($P = .05$) but no significant trends in the other age groups (4-8 years, $P = .28$; 14-17 years, $P = .34$). Of the race/ethnicity subgroups, only non-Hispanic white individuals had a statistically significant downward trend in sodium intake ($P = .01$), whereas non-Hispanic black individuals ($P = .53$) and Hispanic individuals ($P = .44$) did not.

Impact of USDA Sodium Guidelines

Figure 2 shows adherence rates to the USDA recommended level of sodium intake before (2003-2010) and after (2011-2016) publication of the 2010 guidelines by age group (Figure 2, A), sex (Figure 2, B), and race and ethnicity (Figure 2, C). During the 2003-2010 period, the overall population adherence rate was 25.0%, which was essentially unchanged at 25.5% in 2011-2016 ($P = .677$). Similarly, there were no significant changes in adherence rates across age groups; from 25.2% to 24.6% in the 4-8 year group ($P = .756$), from 24.0% to 25.6% in the 9-13 year group ($P = .338$), and from 26.0% to 26.3% in the 14-17 year group ($P = .884$). Males showed an improvement in adherence from 18.6% to 21.5%, which was statistically significant ($P = .04$), whereas females had a nonsignificant decrease in adherence, from 31.6% to 29.6% ($P = .217$). There were no significant changes in adherence rates for any of the race/ethnicity subgroups (all $P > .50$). Adherence decreased from 26.4% to 26.3% in non-Hispanic black subjects, increased from 23.5% to 24.4% in non-Hispanic white subjects, and decreased from 28.6% to 27.6% in Hispanic subjects. Both head of household education level and marital status were analyzed for relationships to sodium intake, and neither was found to be significant (data not shown).

A multivariable model was developed to identify factors associated with adherence to the USDA guidelines for sodium intake. Overall caloric intake was positively associated with sodium intake, but other macronutrients (fat, carbohydrates, and protein) were not significantly associated with sodium intake after adjustment for caloric intake. The overall predictive value of the model was low, indicating that other factors influence sodium intake in this population (data not shown).

Discussion

Our data show that sodium consumption in the US pediatric population has remained persistently above USDA recommendations from 2003-2004 to 2015-2016 despite focused efforts to reduce high levels of dietary sodium intake. Although there has been a modest reduction in median sodium intake over this period (~125 mg/day), current levels remain well above the goal for all identified subgroups. Males had a statistically significant improvement in adherence to current USDA guidelines, but this was counterbalanced by lower adherence in females. The median sodium intake also varied

Table II. Median (95% CI) sodium consumption overall and by NHANES cycle

	Overall	2003-2004	2005-2006	2007-2008	2009-2010	2011-2012	2013-2014	2015-2016
All	2840 (2805-2875)	2912 (2848-2961)	2932 (2843-3036)	2733 (2634-2831)	2816 (2721-2905)	2917 (2813-3022)	2739 (2662-2855)	2787 (2677-2867)
Age group								
4-8 y	2507 (2464-2551)	2621 (2487-2850)	2550 (2390-2697)	2425 (2312-2508)	2524 (2421-2646)	2542 (2435-2666)	2399 (2235-2564)	2472 (2377-2554)
9-13 y	2934 (2890-2981)	2927 (2777-3101)	3131 (2932-3226)	2890 (2687-3061)	2816 (2710-2927)	2972 (2924-3022)	2926 (2829-3037)	2944 (2828-3036)
14-17 y	3124 (3047-3214)	3171 (2980-3336)	3285 (2982-3510)	3029 (2803-3196)	3276 (3084-3481)	3271 (3065-3501)	2949 (2729-3254)	2975 (2763-3123)
Race								
Black	2880 (2826-2928)	2929 (2833-3007)	2893 (2808-3019)	2761 (2561-2910)	2939 (2763-3071)	2869 (2691-2996)	2848 (2708-2961)	2917 (2726-3037)
White	2860 (2811-2905)	2938 (2862-2986)	2975 (2880-3132)	2803 (2611-2924)	2798 (2692-2924)	2942 (2833-3063)	2717 (2586-2876)	2758 (2598-2905)
Hispanic	2733 (2683-2787)	2754 (2606-2916)	2706 (2566-2910)	2579 (2485-2696)	2728 (2656-2842)	2874 (2627-3059)	2759 (2617-2904)	2742 (2663-2831)
Sex								
Female	2624 (2578-2680)	2756 (2649-2828)	2689 (2578-2786)	2526 (2436-2635)	2544 (2440-2694)	2803 (2604-2926)	2541 (2454-2635)	2588 (2490-2702)
Male	3053 (2994-3109)	3090 (2969-3218)	3209 (3062-3350)	2921 (2816-3031)	3032 (2923-3224)	3137 (2981-3253)	3008 (2835-3283)	2963 (2876-3062)
BMI								
Normal	2833 (2083-3811)	2915 (2148-3966)	2912 (2107-3857)	2710 (2013-3788)	2784 (2097-3837)	2926 (2183-3891)	2731 (2000-3716)	2751 (2021-3642)
Overweight	2835 (2110-3766)	2911 (2234-4033)	2957 (2171-3653)	2738 (1978-3314)	2756 (2126-3653)	2839 (2207-3881)	2736 (1945-3807)	2846 (2152-3844)
Obese	2887 (2072-3965)	2887 (2015-3912)	3033 (2180-4192)	2813 (1922-4047)	2931 (2294-3926)	2928 (2129-3960)	2810 (1908-3894)	2762 (2060-3780)

Data are in milligrams.

significantly by age group, sex, and race and ethnicity across all NHANES cycles.

The NHANES has been used to evaluate sodium intake previously; however, contemporary long-term trends in sodium consumption patterns have not been reported.[6,29,30] Rosner et al showed that in NHANES III (1988-1994) and in NHANES from 1999-2008, sodium intake was persistently elevated in the pediatric population.[17] Our work updates these findings and shows no substantial improvement in sodium intake despite the introduction of USDA guidelines for the pediatric population in 2010, modifications to food labeling, and widespread public education aimed at reducing sodium consumption.[17] Other analyses have shown similar results for pediatric populations in other countries, but these findings have only limited generalizability to the US population given differences in public policy and dietary habits.[7,26,27,31] This study also provides new insight into adherence rates to USDA recommendations in the pediatric population; the data indicate a persistence of sodium overconsumption with low adherence rates to dietary guidelines and no substantial improvement in adherence since 2010.

The health benefits of reducing sodium intake are well established and extend to multiple populations, including children. Previous cohort analyses have shown that elevated childhood blood pressure predicts adult hypertension, and that reducing sodium consumption can lower childhood blood pressure.[15,18,35] The link between childhood sodium intake and adult hypertension, which increases the risk of cardiovascular disease substantially, evinces the importance of targeting the pediatric population for sodium moderation. Notably, 62% of strokes and 49% of myocardial infarctions have been attributed to hypertension.[36] Furthermore, the highest proportion of estimated diet-related cardiometabolic deaths in adults is related to high sodium intake (66 508 individuals, or 9.2% of all cardiometabolic deaths in 2012).[37]

Population-level clinical and economic benefits of attenuating sodium intake have been reported previously in the adult population. These analyses have concluded that a reduction in sodium intake to currently recommended levels would save more than $10 billion in healthcare costs annually while reducing the prevalence of hypertension and the incidence of coronary artery disease and stroke.[38,39] Although these reports focused on the adult population, the clearly established connection between childhood sodium overconsumption and adult cardiovascular disease suggests that similar benefits might be obtained by improving adherence to pediatric sodium intake guidelines. To our knowledge, this type of analysis has not been conducted in the US pediatric population and is a potential target for future study. However, family-based interventions to reduce sodium intake focused on nutritional education for children have yielded substantial improvements in blood pressure and have been shown to be highly cost-effective public health interventions in other countries.[40,41]

The importance of sodium moderation should be considered within the context of promoting healthy dietary behaviors more broadly, given that high sodium intake has been

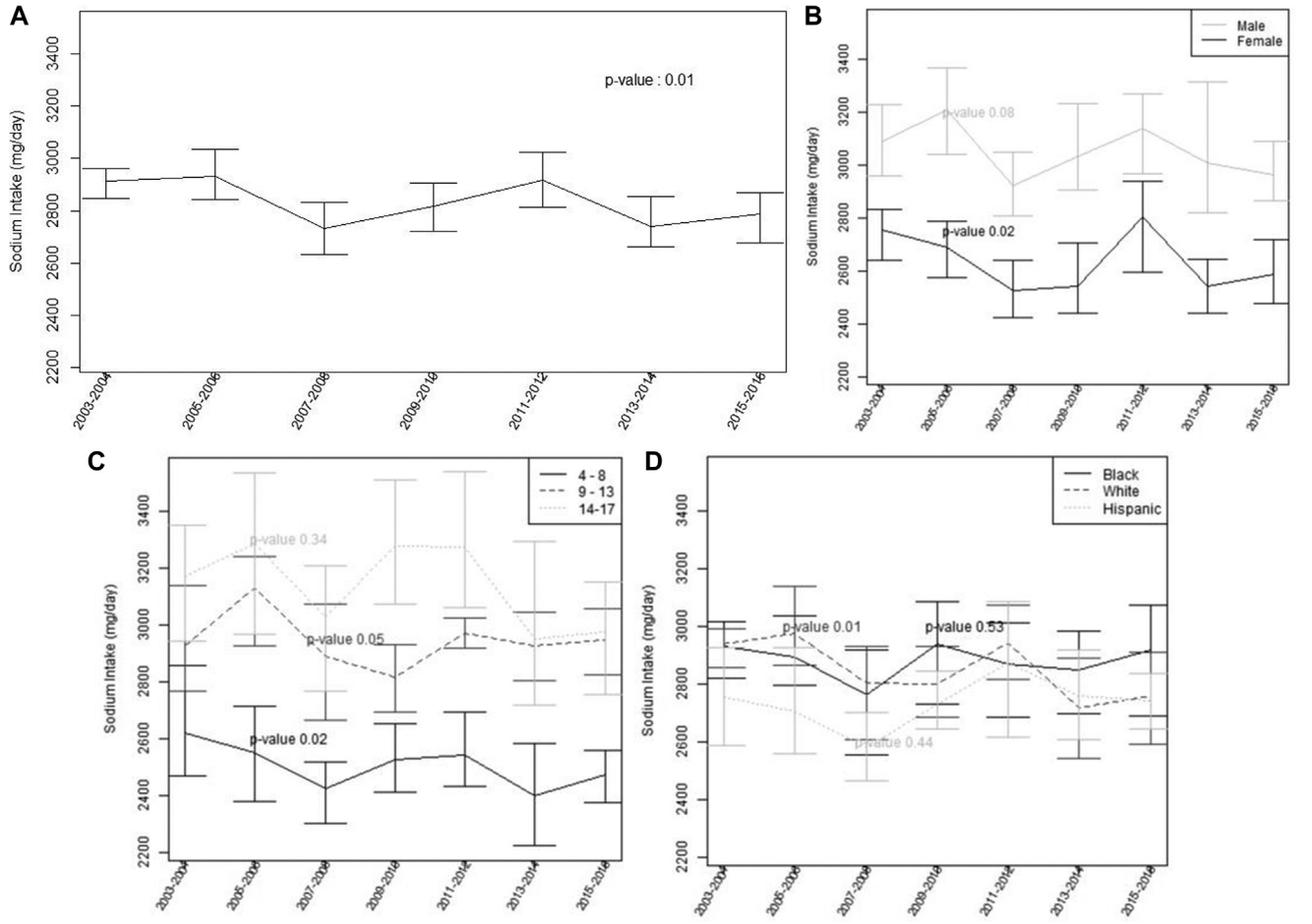

Figure 1. Trends in sodium intake from NHANES 2003-2016 data. Median sodium intake is displayed as milligrams per day. **A,** Overall pediatric population. **B,** By sex. **C,** By age group. **D,** By race/ethnicity.

associated with additional unhealthy dietary behaviors. In one study, higher levels of fast-food consumption along with higher caloric intake, regular soda consumption, and increased fat and sugar intake were all associated with higher levels of sodium consumption.[42] Similarly, an analysis of NHANES data from 2005-2008 showed that dietary sodium was positively associated with sugar-sweetened beverages after adjustment for sociodemographic factors.[43] In adults, adherence to a Mediterranean diet has been associated with reductions in cardiovascular events[44]; although it is likely that such a diet would prove beneficial in a pediatric population as well, additional study is needed. However, the Greek Childhood Obesity (GRECO) study showed that sodium intake can remain elevated with the Mediterranean diet, owing to sodium added to manufactured and processed foods.[45] This suggests that policies focused on manufacturing processes will be necessary to improve adherence to sodium guidelines and enhance overall diet quality.

An important target for sodium reduction specific to children is the national school lunch program. As of 2016, 12 million children ate school breakfasts and 31 million children ate school lunches.[46] In 2010, the Healthy, Hunger-Free Kids Act was enacted, which established policies for improving nutritional standards for school meals with a 12-year phased timeline.[46] This legislation calls for an approximate 50% reduction in added sodium in school meals by 2022.[46] Efforts have been made in Congress to impede or halt enforcement of these increasingly stringent nutrition standards, which has delayed full implantation of the program.[46] Ongoing vigilance and advocacy will be needed to facilitate meaningful changes through policy legislation, particularly in light of the persistence of sodium overconsumption shown by our data.

This study has several limitations. Due to the observational and cross-sectional structure of the NHANES data, causation cannot be inferred. Clinical outcomes and cardiovascular imaging data are not collected in NHANES; thus, we were unable to analyze associations between sodium intake and clinical markers, such as left ventricular hypertrophy and arterial thickness. Importantly, food labeling changes implemented by the Food and Drug Administration that took effect beginning in 2016 are not reflected in the existing data. Future surveys will allow for greater assessment of the impact of these changes.[36,47] In addition, the full impact of the

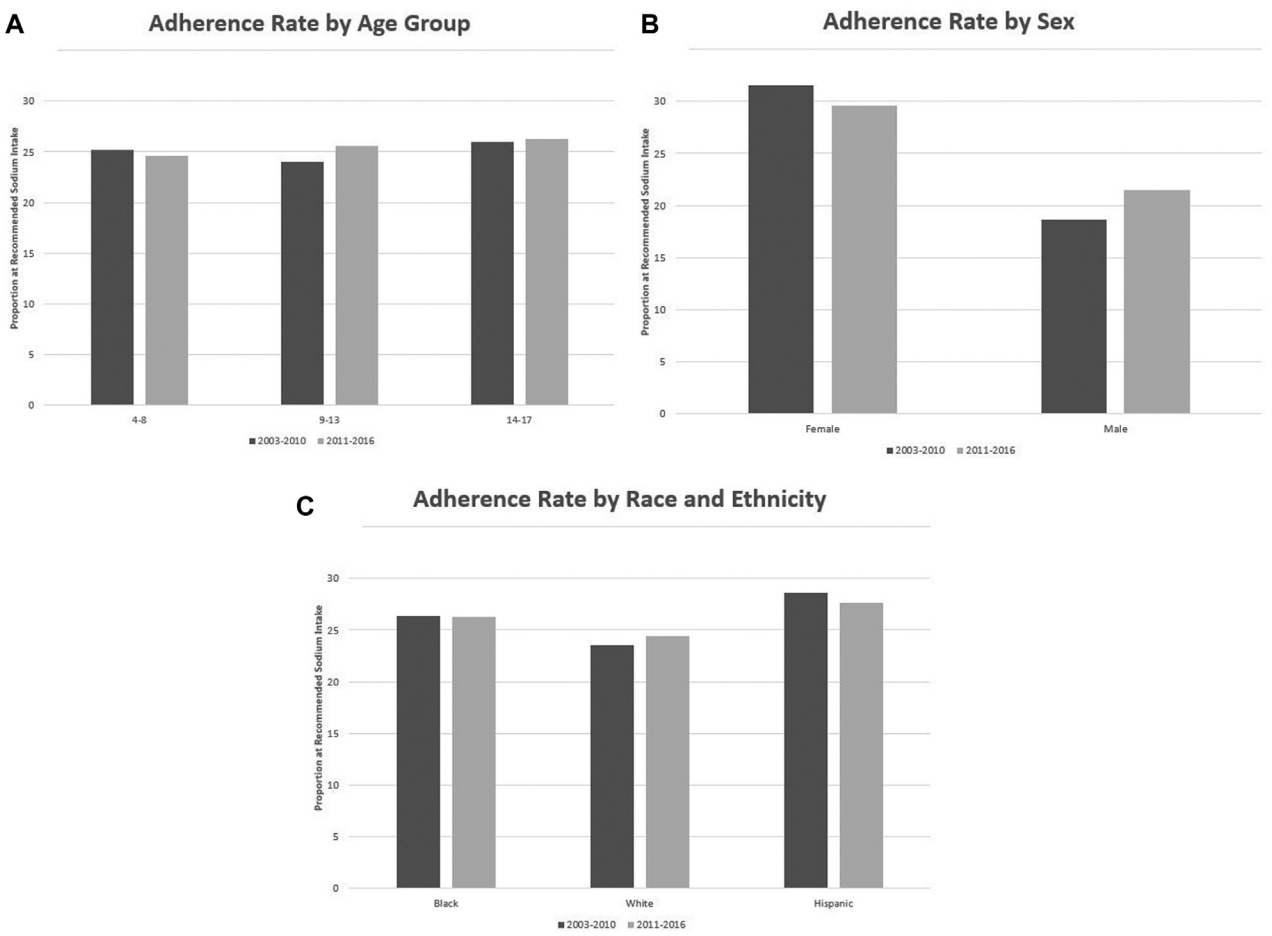

Figure 2. **A-C,** Adherence to USDA dietary sodium recommendations, data from 2003-2016 NHANES. In 2010, the USDA recommended <1900 mg/day in children aged 4-8 years, consume, <2200 mg/day in children aged 9-13 years, and <2300 mg/day in children aged 14-17 years.

Healthy, Hunger-Free Kids Act is not reflected in our data, as this ongoing initiative is currently set to conclude in 2022.[46] Future studies will be needed to evaluate the effectiveness of this intervention. Further initiatives to decrease sodium intake will be required through national policy efforts to reduce the impact of excess sodium consumption on health outcomes and costs in both the pediatric and adult populations. ■

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