Association between Acculturation and Sodium to Potassium Ratio

and

Disparity in Trends by Race/Ethnicity in the U.S.: NHANES 2011-2020

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Abstract

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Introduction: Racial disparity in sodium to potassium ratio (Na/K) has been documented. However, we have a limited understanding of the association between culture and diet. The goal of this study is to assess the trends in the Na/K ratio by race/ethnicity and to explore the association between acculturation and Na/K ratio in the U.S.

Method: We analyzed data from the National Health and Nutrition Examination Survey (NHANES) from 2011 to March 2020 (aged ≥14 years). Trend analyses were conducted for each race/ethnicity group and nativity status. A multivariable linear regression model was used to test the association between the Na/K ratio and acculturation measures, adjusting for race/ethnicity, age, sex, BMI, hypertension, energy intake, and seven social determinants of health (SDoH)-related confounders (employment status, income ratio to poverty, food security, education, access to healthcare, healthcare insurance, and marital status).

Results: A nationally representative sample of 23,057 participants was included. The Na/K ratio increased from 2011 to 2020 in the overall study population, especially among the US-born non-Hispanic White and non-Hispanic Black groups. However, a significant decreasing trend for non-Hispanic Asians, especially Asians who were born outside the U.S. was observed. Non-Hispanic Asians had the highest sodium intake, whereas non-Hispanic Blacks had the highest Na/K ratio compared to other race/ethnicity groups. Findings from the multivariable linear regression model indicated that the duration of residency in the U.S. was associated with an increased Na/K ratio ($p<0.01$). Adjusting for confounders, non-Hispanic Asians had the highest Na/K ratio ($p<0.001$), followed by non-Hispanic Blacks ($p<0.001$), other or multi-racial group ($p<0.05$), and Mexican Americans ($p<0.05$) compared to the non-Hispanic Whites. A higher Na/K ratio was more likely among women, individuals aged 19-30 years, those with suboptimal weight, those with higher energy intake, and those with marginal or lower food security, as well as those with government healthcare insurance or no healthcare insurance. No other significant associations were found between the Na/K ratio and other variables in the regression models.

Conclusion: The Na/K ratio increased in the U.S. from 2011 to 2020. Prolonged exposure to the U.S. food environment has a significant impact on consuming excessive sodium and insufficient potassium. However, the findings also suggest that non-Hispanic Asians might be less prone to adapting their dietary habits compared to other race/ethnicity groups. Multi-faceted interventions

that address the disparity in races/ethnicity and acculturation statuses are needed to reduce the Na/K ratio.

Supplementary: A supplementary file includes a table summarizing study participants aged 14 years and over by NHANES cycle and acculturation measures.

I. Introduction

Excess sodium intake is an important public health concern globally, associated with various health conditions, including hypertension, stroke, heart disease, chronic kidney disease, and stomach cancer.(1–4) Although age-standardized global burden due to high sodium intake is decreasing, it remains much higher than recommended levels. Despite this overall decreasing trend, exposure to excess sodium is reported to be increasing in high-income North American countries.(5) In contrast, the absolute global burden of disease due to high sodium intake is on the rise, driven by demographic changes such as population growth and aging.(5) East Asia, Central Asia, and Eastern European countries have the highest sodium consumption.(6)

Dietary Guidelines for Americans (DGA) 2020-2025 and National Academies of Sciences, Engineering, and Medicine recommend limiting sodium intake to 2300 mg per day and consuming potassium intake of 4700 mg per day.(7–9) However, The World Health Organization (WHO), World Hypertension League (WHL), and other recommendations on sodium are slightly lower, 2000 mg per day.(10–12) In addition, the recommended level of sodium varies by country. According to the dietary reference intakes for Japanese (DRI-JP) in 2020, the recommended sodium intake level was less than 3.0 grams per day for adult males and less than 2.6 grams per day for adult women.(13) Despite these recommendations, meeting the joint sodium and potassium intake targets remains challenging for most populations.(14)

Lower potassium intake and higher sodium to potassium ratio are associated with higher hypertension and CVD.(15–17) The sodium and potassium intake and their impact on health varies by race/ethnicity.(18,19) The National Health and Nutrition Examination Survey (NHANES) has been an important source for studies on sodium and potassium intake across different race/ethnicity groups.(20) NHANES began collecting data on non-Hispanic Asians in 2011. Studies have reported that non-Hispanic Asians have the highest sodium intake compared to other race/ethnicity groups in 2011-2012.(21,22)

Acculturation also affects dietary sodium and potassium intake. Satia-Abouta's conceptual model on dietary acculturation suggests that immigrants adopt to dietary patterns of the host country over time. This process involves changes in psycho-social factors and environmental factors in the host country (Fig 1).(23,24) In this study, we modified this conceptual framework to focus specifically on sodium and potassium intakes. The aim of this study is to examine the trends in the sodium-to-potassium ratio by race/ethnicity and nativity and assess the impact of acculturation on this ratio using NHANES data from 2011 to 2020.

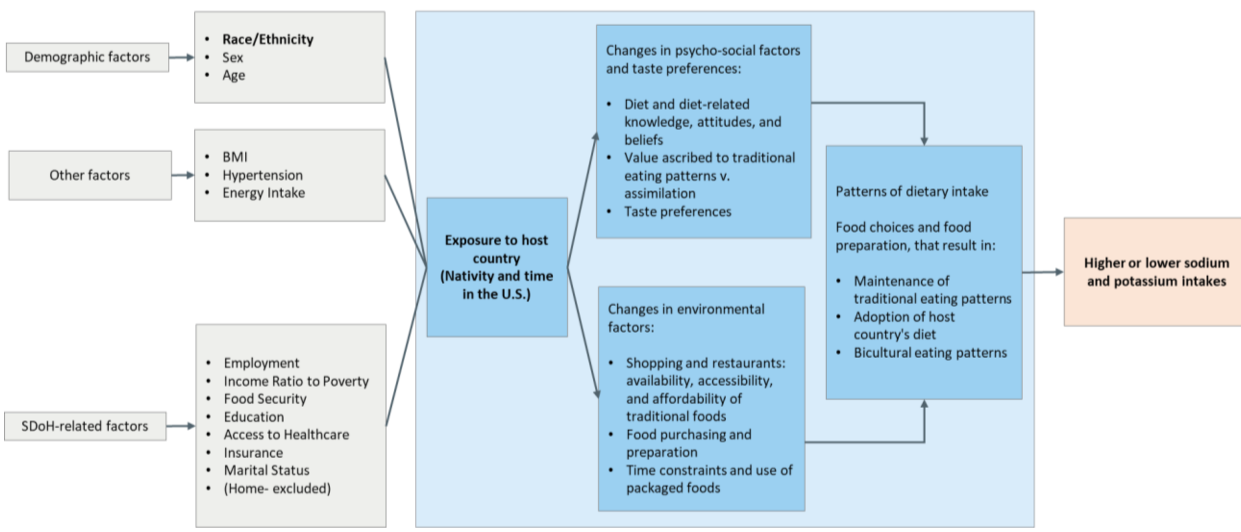


Figure 1. Conceptual Framework of Dietary Acculturation. Modified Version of Satia-Abouta's Model (2002).

II. Methods

Study population.

NHANES is a cross-sectional, nationally representative study that collects detailed data on the demography, health, diet, and nutritional status of the non-institutionalized U.S. population. NHANES uses a complex, multistage sampling design to sample study participants. The detailed NHANES study design and methods were described in a previous publication.(20) The present study utilized data from the 4 consecutive NHANES cycles conducted between 2011 and March 2020. Of the 30,829 participants aged 14 years or older, we excluded participants who had missing values in sodium or potassium intake (N=7,661), country of birth (N=11), and total energy intake questionnaires (N=0), resulting in the final analytic sample of 23,057 participants (Fig 2). The National Center for Health Statistics approved NHANES study protocols and all study participants were provided written informed consent.(20)

Na/K ratio:

Sodium and potassium intakes were determined by using two 24-hour dietary recalls (averaged). Trained interviewers collected detailed information on all foods and beverages consumed by participants in the last 24-hour period.(25,26) The Na/K ratio was calculated by dividing absolute sodium intake by absolute potassium intake.(17)

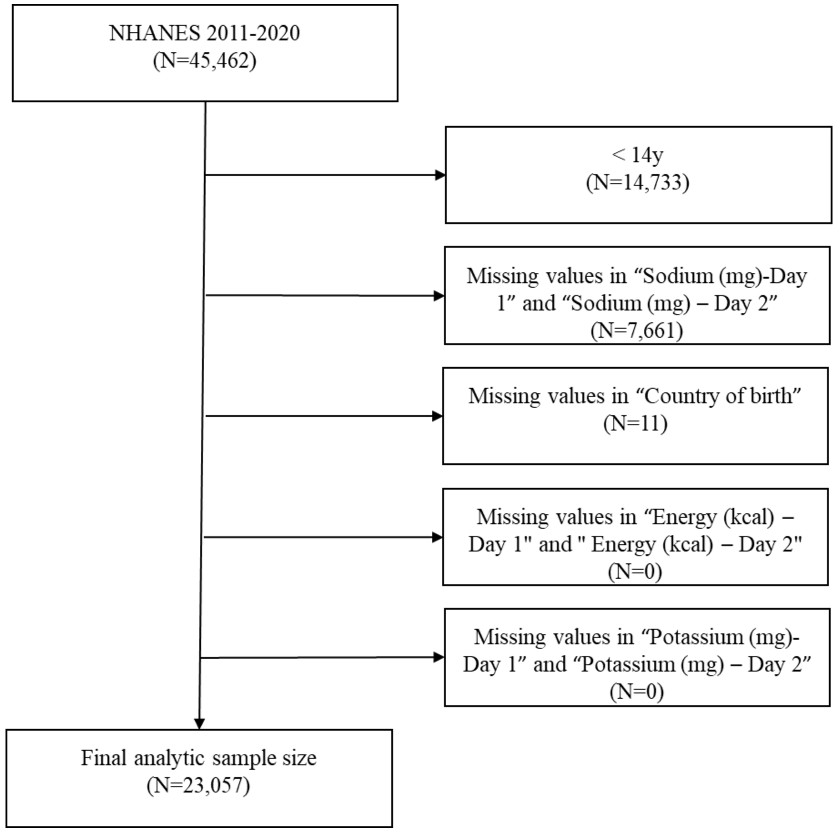


Figure 2. The flow diagram of study participants and the exclusion criteria.

Measures

NHANES uses standardized questionnaires to collect data on key demographic details such as age, gender, and race/ethnicity, including non-Hispanic White, non-Hispanic Black, non-Hispanic Asian, Mexican American, and other or multi-racial. We used seven social determinants of health (SDoH)-related variables that were previously identified in the NHANES framework: employment status, income-to-poverty ratio, food security (questions regarding food unavailability), education level, healthcare access (had routine visits, except an emergency visit), health insurance (private healthcare insurance versus other), and marital status.(27,28) Homeownership status was identified as a possible SDoH variable in the previous study, but it was unavailable in the last survey cycle, 2017-2020. Therefore, homeownership status was not included.

We estimated the cumulative burden of SDoH and each factor was dichotomized into favorable or unfavorable categories, assigning a 0 score for favorable and 1 score for each unfavorable level. An unfavorable SDoH was defined as the level of each SDoH variable that is expected to be associated with higher sodium intake or Na/K ratio. Due to a small proportion of participants who reported having four or more unfavorable SDoH, those groups were aggregated together.(27)

Acculturation was assessed using four different types of acculturation proxy measures including country of birth, nativity and time spent in the U.S., language spoken at home, and acculturation index. The acculturation index score was calculated based on a previous paper.(21,29) For nativity and time in the U.S. measure, participants were first categorized into U.S.-born and foreign-born groups. Then, foreign-born participants were further categorized based on their time spent in the U.S.: <5 years, 5-15 years, 15-30 years, and ≥30 years.

Statistical Analysis

All proportion and prevalence variables were expressed as percentages with 95% confidence intervals (CIs). All analyses were weighted, and CIs of proportion would be estimated by the formula of the Clopper Pearson test using the Korn and Graubard approach for complex survey analysis.(30,31) For continuous variables, the Wald method was used to estimate the 95% CIs.

Design t-test is used to test the difference in means of two continuous variables while the Wald test or modified one-way ANOVA test was used to test the difference in means of three or more continuous variables.(32) The difference between proportions was estimated by the second-order Rao-Scott or F statistic-adjusted chi-squared test for complex survey.(33,34)

We conducted trend analysis to assess the trend of sodium, potassium intake, and Na/K ratio across survey cycle years. The following interval midpoints were used for survey cycles: 2012, 2014, 2016, and 2018.6.(26) We used the Wald test to estimate each trend. In addition, the non-linear trend was assessed with models with quadratic and cubic terms through the forward and backward elimination method.(35,36)

Multivariable linear regression models were used to explore the association between the Na/K ratio and acculturation. For the acculturation variable, we used four different proxies, including birthplace, nativity status and years in the U.S. variable, language spoken at home, and acculturation index (combining the acculturation measures).(6) We studied the associations using three sequentially adjusted models: the first model adjusted for age, gender, and race/ethnicity; the second model was additionally adjusted for BMI, hypertension, and mean energy intake; the third model further adjusted for seven SDoH-related variables: employment status, income ratio to poverty, food security, education, access to healthcare, health care insurance, and marital status. Moreover, we used the cumulative unfavorable SDoH variable in subsequent analyses to identify the dose-response relationship between the Na/K ratio and SDoH, adjusting for other confounders.

All statistical analyses were performed in RStudio version 2024.04.01 (Boston, Massachusetts, USA), and “survey” package version 4.4.2.(33) A two-sided p-value of <0.05 was considered statistically significant.

III. Results

Study Population

Overall, we included 23,057 participants aged 14 years or older, derived from 4 cycles. The sample size per cycle varied, with 5,083, 5,326, 4,914, and 7,734 individuals sampled from the 2011-2012, 2013-2014, 2015-2016, and 2017- 2020 cycles, respectively. The median age of the participants was 44.9 years, with a mean age of 44.2 years for men and 45.6 years for women ($p<0.001$) (Table 1). More than half of the participants were women, approximately 20% of the participants were aged 14-18 years, 8.2% were aged 19-30 years, 46.8% were aged 31-59 years, and 25.2% were aged 60 or over. There were 63.4% non-Hispanic Whites, (5.5%) Mexican Americans, 11.7% other Hispanic Americans, 3.6% non-Hispanic Blacks, 9.4% non-Hispanic Asians, and 6.5% individuals identified as other or multi-racial. Regarding nativity and time spent in years, 84.1% of the participants were born in the U.S. The foreign-born participants were categorized further depending on their time spent in the U.S.: 2% had lived in the U.S. for less than 5 years, 5.4% for 5-15 years, 4.3% for 15-30 years, and 4.2% for more than 30 years.

Table 1: Characteristics of study participants aged 14 years and above by NHANES cycle

	All participants (n=23057)	NHANES cycle				p-value*
		2011-2012 (n=5083)	2013-2014 (n=5326)	2015-2016 (n=4914)	2017-2020 (n=7734)	
Sodium intake (mg)	3423.5 (3392.1-3454.9)	3514.5 (3473.3-3555.6)	3476.5 (3414.4-3538.5)	3442.5 (3372.8-3512.2)	3326.5 (3267.9-3385.2)	<0.001
Potassium intake (mg)	2586.7 (2553-2620.4)	2721.5 (2657.3-2785.6)	2616.5 (2557.1-2675.9)	2556.8 (2474.5-2639.2)	2508 (2449.9-2566.1)	<0.001
Sodium to potassium ratio (mg)	1.403 (1.388-1.419)	1.365 (1.337-1.393)	1.404 (1.377-1.431)	1.420 (1.386-1.455)	1.415 (1.386-1.444)	0.046
Energy intake (calorie)	2071.3 (2053.7-2089)	2113 (2084.4-2141.6)	2082.4 (2040.6-2124.2)	2045.4 (2003-2087.7)	2056.1 (2027.4-2084.9)	0.022
Race/Ethnicity						0.913
Non-Hispanic White	8519 (63.4% [59.9-66.8])	1858 (65.7% [56.7-73.9])	2233 (64.5% [57.1-71.5])	1695 (63.4% [54.2-72])	2733 (61.4% [55.6-66.9])	
Mexican American	3087 (5.5% [4.6-6.5])	543 (8.9% [5.2-14])	787 (10% [6.7-14.1])	856 (9.8% [5.4-16])	901 (9% [6.5-12.1])	
Other Hispanic	2322 (11.7% [9.8-13.8])	484 (6.1% [3.4-9.9])	487 (5.4% [3.6-7.9])	606 (5.8% [3.4-9.2])	745 (7.8% [6.2-9.6])	
Non-Hispanic Black	5723 (3.6% [3.1-4])	1391 (12% [7.2-18.4])	1100 (11.7% [8.2-16.2])	1070 (11.3% [6.9-17.3])	2162 (11.8% [8.8-15.3])	
Non-Hispanic Asian	2435 (9.4% [7.7-11.3])	643 (5.1% [3.5-7.2])	537 (5.2% [3.9-6.9])	483 (5.6% [3.2-8.9])	772 (5.8% [4.3-7.6])	
Othe or Multi-Racial	971 (6.5% [5.5-7.7])	164 (2.3% [1.5-3.3])	182 (3.1% [2.2-4.3])	204 (4% [3-5.3])	421 (4.3% [3.6-5])	
Sex						0.987
Male	11060 (48.4% [47.4-49.4])	2479 (48.5% [47-50])	2494 (48.3% [46-50.7])	2359 (48.6% [46.8-50.4])	3728 (48.2% [46.1-50.4])	
Female	11997 (51.6% [50.6-52.6])	2604 (51.5% [50-53])	2832 (51.7% [49.3-54])	2555 (51.4% [49.6-53.2])	4006 (51.8% [49.6-53.9])	
Age						0.585
14-18 y	2934 (19.8% [18.4-21.2])	648 (8% [6.8-9.4])	734 (8.7% [7.4-10.2])	614 (8.3% [7.2-9.6])	938 (8% [7.1-9])	
19-30 y	3927 (8.2% [7.7-8.8])	961 (20.3% [15.5-26])	924 (20.5% [17.8-23.5])	827 (19.6% [17.1-22.3])	1215 (19% [17.5-20.7])	
31-59 y	9489 (46.8% [45.5-48])	2102 (48.4% [45.2-51.6])	2236 (46.7% [44.4-49])	1998 (46.8% [43.9-49.6])	3153 (45.9% [43.7-48.1])	
≥60 y	6707 (25.2% [23.8-26.7])	1372 (23.2% [20.5-26.2])	1432 (24.1% [22.3-26])	1475 (25.3% [22.1-28.6])	2428 (27% [24-30.3])	
Body mass index						0.006
Normal	6892 (29.9% [28.6-31.2])	1693 (33.4% [29.9-37.1])	1692 (31.1% [28.5-33.8])	1414 (29.1% [26.3-32])	2093 (27.5% [25.3-29.7])	
Underweight	399 (1.5% [1.3-1.8])	109 (1.7% [1.4-2.2])	96 (1.6% [0.9-2.5])	69 (1.3% [0.8-1.8])	125 (1.5% [1.1-2.1])	
Overweight	6749 (30.9% [29.7-32.1])	1489 (31.6% [28.5-35])	1578 (30.9% [28.4-33.6])	1471 (31.3% [29.3-33.5])	2211 (30.2% [28.1-32.3])	
Obese	8743 (37.7% [36.2-39.2])	1716 (33.2% [30.1-36.4])	1907 (36.4% [33.5-39.3])	1903 (38.3% [34.7-42])	3217 (40.8% [38-43.6])	
Hypertension history						0.423
No	14291 (69.1% [67.8-70.4])	3226 (70.3% [67.1-73.3])	3316 (67.2% [64.2-70.2])	3042 (69.8% [67.3-72.2])	4707 (69.1% [66.5-71.5])	
Yes	7537 (30.9% [29.6-32.2])	1587 (29.7% [26.7-32.9])	1715 (32.8% [29.8-35.8])	1606 (30.2% [27.8-32.7])	2629 (30.9% [28.5-33.5])	
Social Determinants of Health (SDoH) measures						
Employment						0.399
Employed, student, retired	16849 (83.6% [82.3-84.8])	3658 (82.2% [79.1-85])	3928 (82.7% [79.3-85.8])	3572 (83.9% [81-86.4])	5691 (84.7% [82.8-86.6])	
Not employed	4013 (16.4% [15.2-17.7])	921 (17.8% [15-20.9])	945 (17.3% [14.2-20.7])	872 (16.1% [13.6-19])	1275 (15.3% [13.4-17.2])	

Family income to poverty ratio						0.191
PIR ≥ 300%	13778 (74.4% [72.5-76.3])	2940 (70.9% [64.7-76.6])	3237 (73.9% [69.6-77.8])	2936 (74.7% [69.5-79.4])	4665 (76.8% [74.5-79])	
PIR < 300%	7677 (25.6% [23.7-27.5])	1892 (29.1% [23.4-35.3])	1819 (26.1% [22.2-30.4])	1639 (25.3% [20.6-30.5])	2327 (23.2% [21-25.5])	
Food security						0.118
Full food security	14453 (72.6% [70.8-74.3])	3375 (74% [69.3-78.3])	3663 (75.8% [72.3-79.1])	2911 (70.2% [65.4-74.6])	4504 (71.2% [68.4-74])	
Marginal, low, or very low	8030 (27.4% [25.7-29.2])	1695 (26% [21.7-30.7])	1622 (24.2% [20.9-27.7])	1873 (29.8% [25.4-34.6])	2840 (28.8% [26-31.6])	
Education						<0.001
High school or more	16338 (83.2% [81.7-84.6])	3516 (78.2% [73.2-82.7])	3787 (79.7% [76.4-82.7])	3482 (80.4% [76.7-83.7])	5553 (90.6% [89.3-91.7])	
Less than high school	5610 (16.8% [15.4-18.3])	1565 (21.8% [17.3-26.8])	1536 (20.3% [17.3-23.6])	1431 (19.6% [16.3-23.3])	1078 (9.4% [8.3-10.7])	
Access to healthcare						0.195
Routine place	18959 (82.6% [81.4-83.8])	4165 (82.8% [80-85.4])	4329 (81.8% [79.7-83.7])	3933 (80.7% [76.7-84.3])	6532 (84.1% [82-86])	
No routine place	4096 (17.4% [16.2-18.6])	918 (17.2% [14.6-20])	997 (18.2% [16.3-20.3])	981 (19.3% [15.7-23.3])	1200 (15.9% [14-18])	
Health insurance						0.002
Private insurance	18989 (85% [83.7-86.4])	3974 (81.6% [78.1-84.7])	4273 (82.3% [79.7-84.7])	4139 (86.9% [83.5-89.9])	6603 (87.6% [84.9-90])	
Government or no insurance	4022 (15% [13.6-16.3])	1100 (18.4% [15.3-21.9])	1047 (17.7% [15.3-20.3])	762 (13.1% [10.1-16.5])	1113 (12.4% [10-15.1])	
Marital status						0.947
Married or with a partner	11539 (37.2% [35.5-38.9])	2454 (62.2% [56.9-67.2])	2696 (63% [59.4-66.5])	2544 (63.6% [59.5-67.6])	3845 (62.6% [60.1-65.1])	
Not married	8076 (62.8% [61.1-64.5])	1851 (37.8% [32.8-43.1])	1779 (37% [33.5-40.6])	1658 (36.4% [32.4-40.5])	2788 (37.4% [34.9-39.9])	
Acculturation measures						
Nativity status and years in the U.S.						0.129
Foreign-born, <5 y	689 (2% [1.6-2.5])	171 (2.1% [1.1-3.7])	110 (1.3% [0.8-1.8])	186 (2.5% [1.5-3.8])	222 (2.1% [1.5-2.9])	
Foreign-born, 5-15 y	1440 (5.4% [4.8-6])	413 (5.5% [3.7-7.7])	351 (4.4% [3.3-5.7])	355 (4.5% [3.1-6.4])	321 (3.2% [2.5-4])	
Foreign-born, 15_30 y	1831 (4.3% [3.9-4.8])	429 (5% [3.9-6.5])	387 (5.4% [3.8-7.4])	399 (4.6% [3.6-5.8])	616 (6% [5.1-7.1])	
Foreign-born, ≥30 y	1673 (4.2% [3.6-4.9])	303 (3.4% [2.7-4.2])	383 (4.2% [3.3-5.2])	394 (4.5% [3.1-6.2])	593 (4.8% [4.1-5.6])	
U.S.-born	17230 (84.1% [82.5-85.6])	3731 (84% [79.5-87.8])	4046 (84.8% [80.8-88.2])	3530 (83.9% [79.5-87.7])	5923 (83.9% [81.6-86.1])	
Acculturation index						0.829
Least acculturated	2994 (84.6% [82.9-86.1])	774 (9.1% [6.4-12.5])	634 (8% [6.2-10.1])	738 (8.6% [6.5-11.2])	848 (8.2% [6.7-9.8])	
Somewhat acculturated	2549 (8.4% [7.5-9.5])	514 (6% [4.5-7.8])	566 (7.2% [5.2-9.6])	636 (7.1% [5.2-9.4])	833 (7.5% [6.3-8.8])	
Most acculturated	17275 (7% [6.3-7.9])	3750 (84.9% [80.1-88.9])	4071 (84.8% [80.6-88.4])	3481 (84.3% [79.9-88])	5973 (84.3% [81.8-86.6])	

Data are mean (95% CI) or n (% [95% CI]); absolute numbers are unweighted; means, percentages, and 95% CIs are weighted. Weighted Cis are estimated by the Korn and Graubard method (1998) for proportion and the Wald-type method for means.

*Second-order Rao and Scott test is used to analyze the difference in proportions; modified one-way ANOVA test for complex survey is used to analyze the difference in means.

Trend Analysis

Among the total participants, the mean sodium intake was 3423.5 mg (95% CI [3392.1-3454.9]), with the lowest mean sodium as 3326.5 mg (3267.9-3385.2) in the 2017 to 2020 cycle and the highest mean sodium as 3514.5 mg (3473.3-3555.6) in 2011-2012 cycle. There was a statistically significant difference in mean sodium intake by NHANES cycles (p value<0.001). The mean sodium intake among the total participants showed a decreasing trend from 2011 to 2020 (p trend<0.001).

The mean potassium intake was 2586.7 mg (95% CI, [2553-2620.4]). The highest potassium intake was in 2011-2012 and the lowest was in 2017-2020. A statistically significant difference was observed by survey cycles (p value<0.001) and a decreasing trend was observed (p trend<0.001).

The overall Na/K intake ratio was 1.403 (95% CI, [1.388-1.419]). The highest Na/K ratio was 1.415 (1.386-1.444) in 2017-2020, while the lowest Na/K ratio was 1.365 (1.337-1.393) in 2011-2012. There was a statistically significant difference in the Na/K ratio by survey cycles (p value<0.05) and an increasing trend was detected (p trend<0.05) (Fig 3A). However, we should note that p values were very close to the alpha of 0.05 in both tests (0.046 and 0.039).

The highest potassium intake was in 2011-2012 and the lowest was in 2015-2016. A statistically significant difference was observed by survey cycles (p value<0.05) and a decreasing trend was identified (p trend<0.05).

In stratified or sub-population analysis, over the study period, trend analysis indicated a general increase in the Na/K ratio among the participants who were born in the U.S. (p trend<0.01) (Fig 3B). This increasing trend was observed among non-Hispanic Whites (p trend <0.05) and non-Hispanic Blacks (p trend<0.05), but a decrease in trend was detected among non-Hispanic Asians (p trend<0.05) (Fig 3C). When stratifying by both nativity and race/ethnicity, increasing trends were observed only in U.S.-born non-Hispanic White (p trend<0.05) and Hispanic Black sub-groups (p trend <0.05), whereas decreasing trends were noted only in foreign-born non-Hispanic Asian (p trend<0.01) and other or multi-racial sub-groups (p trend <0.05) (Fig 3D).

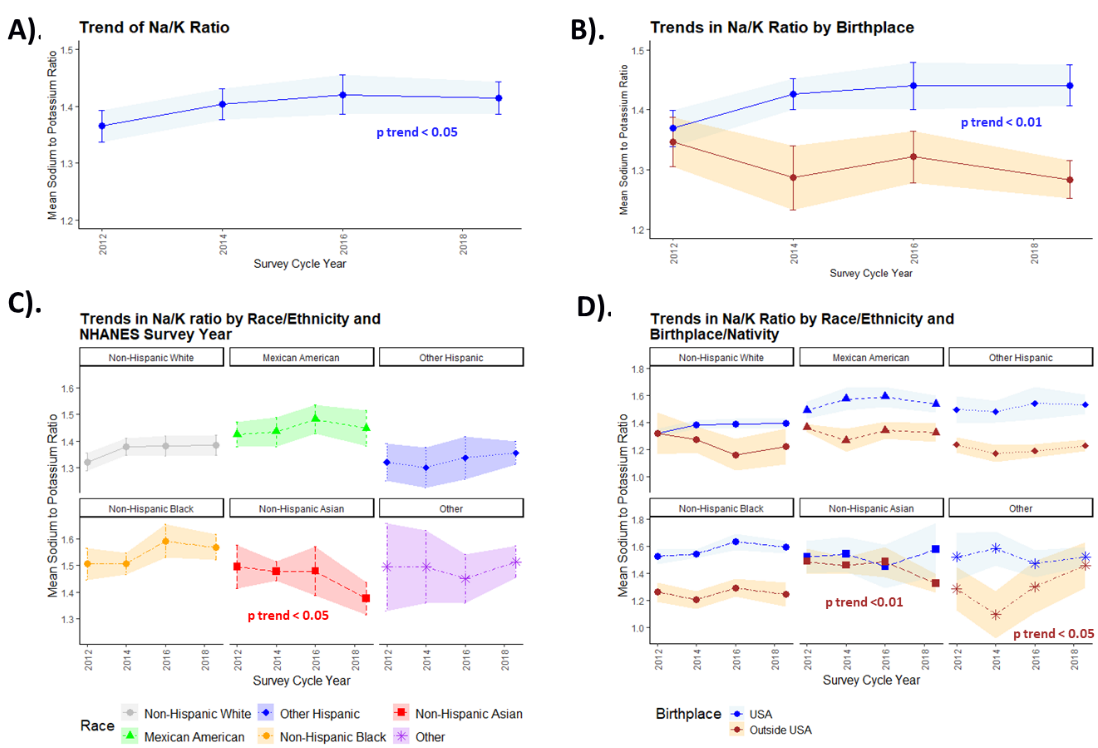


Figure 3. Trends in Na/K ratio by place of birth and race/ethnicity status from 2011 to 2020 (sub-population analysis). A). The overall trend in Na/K ratio, without stratification, B). The trends in Na/K ratio by birthplace. C). The trends in Na/K ratio by race/ethnicity. D. The trends in Na/K ratio by both birthplace and race/ethnicity.

Acculturation and Na/K ratio

We found that the Na/K ratio was lower among less acculturated individuals compared to highly acculturated individuals in regression all models (p value<0.01), except the group who speak mixed language at home in model 3. (Table 2 and Supplementary p1). However, in model 3, participants who spoke in a non-English language at home had a significantly lower Na/K ratio compared to participants who spoke only English in their home (p value<0.001).

Table 2: The association between acculturation measures and sodium to potassium ratio among NHANES study participants aged 14 years and above, 2011-2020.

	Participants, n	Model 1	Model 2	Model 3
Birthplace				
US-born	17,230	Ref	Ref	Ref
Foreign-born	5,827	-0.17 [-0.20, 0.14]***	-0.16 [-0.19, 0.13]***	-0.18 [-0.21, 0.15]***
Nativity status and years in the U.S.				
US-born	17,230	Ref	Ref	Ref
Foreign born, ≥30 y	1,673	-0.12 [-0.16, 0.08]***	-0.11 [-0.15, 0.07]***	-0.13 [-0.17, 0.09]***
Foreign born, 15-30 y	1,831	-0.19 [-0.22, 0.15]***	-0.17 [-0.21, 0.13]***	-0.20 [-0.24, 0.16]***
Foreign born, 5-15 y	1,440	-0.19 [-0.24, 0.15]***	-0.18 [-0.23, 0.14]***	-0.21 [-0.26, 0.17]***
Foreign born, <5 y	689	-0.24 [-0.29, 0.19]***	-0.22 [-0.27, 0.17]***	-0.22 [-0.28, 0.16]***
Acculturation index				
Most acculturated	2,994	Ref	Ref	Ref
Somewhat acculturated	2,549	-0.14 [-0.18, 0.11]***	-0.13 [-0.17, 0.10]***	-0.16 [-0.20, 0.12]***
Least acculturated	17,275	-0.20 [-0.24, 0.17]***	-0.19 [-0.22, 0.16]***	-0.22 [-0.26, 0.18]***
Language spoken at home				
English only	16,533	Ref	Ref	Ref
Mixed	2,404	-0.07 [-0.11, 0.02]**	-0.06 [-0.10, 0.02]**	-0.02 [-0.08 0.03]
Non-English only	4,075	-0.17 [-0.20, 0.13]***	-0.16 [-0.19, 0.12]***	-0.16 [-0.21, 0.12]***

Data are study participants (n) or coefficients [95% CI] from multivariable linear regression models. Model 1 adjusted for race/ethnicity, age, and sex; model 2 additionally adjusted for BMI, hypertension, and mean energy Intake; model 3 additionally adjusted for SDoHs-related variables such as employment status, income ratio to poverty, food security, education, access to healthcare, health care insurance, and marital status. Abbreviation: Ref, reference. *P < 0.05; **P < 0.01; ***P < 0.001 compared with the reference group (least acculturated) within each acculturation measure.

For further analysis, nativity status and years in the U.S. variable was preferred as a primary acculturation proxy due to its ease of interpretation. In the regression models without adjusting for acculturation measures, the Na/K ratio was highest among the non-Hispanic Blacks compared to the non-Hispanic Whites in all three models (p < 0.001), followed by non-Hispanic Asians (p < 0.01). Non-Hispanic Asians also had significantly higher Na/K ratios compared to non-Hispanic Whites in all three models ($p<0.05$, $p < 0.01$, and $p < 0.001$, respectively), whereas the Other Hispanic group had significantly lower Na/K ratios compared to non-Hispanic Whites in all three models ($p < 0.001$) (Table 3).

After adjusting for a nativity status and years in the U.S. variable, non-Hispanic Asians had the highest Na/K ratio was highest compared to the non-Hispanic Whites in all three models ($p < 0.001$), followed by non-Hispanic Blacks ($p < 0.001$), other or multi-racial group, and Mexican Americans (ranging from $p<0.05$ to $p < 0.001$). There was no statistical difference between non-Hispanic Whites and Other Hispanic groups.

Table 3: The association between race/ethnicity and sodium to potassium ratio with or without the adjustment for nativity and time in the U.S. among NHANES study participants aged 14 years and above, 2011-2020.

	Model 1	**Model 2**	**Model 3**
Race/Ethnicity			
Non-Hispanic White	Ref	Ref	Ref
Mexican American	0.01 [-0.02, 0.05]	0.00 [-0.04, 0.04]	-0.03 [-0.07, 0.02]
Other Hispanic	-0.07 [-0.11, -0.04]***	-0.08 [-0.12, -0.04]***	-0.11 [-0.16, -0.07]***
Non-Hispanic Black	0.14 [0.11, 0.18]***	0.13 [0.10, 0.16]***	0.10 [0.07, 0.14]***
Non-Hispanic Asian	0.04 [0.00, 0.08]*	0.07 [0.03, 0.11]**	0.09 [0.05, 0.13]***
Other or Multi-Racial	0.08 [0.03, 0.12]***	0.06 [0.01, 0.11]*	0.04 [0.00, 0.09]
	Model 1 + time in US†	**Model 2 + time in US†**	**Model 3 + time in US†**
Race/Ethnicity			
Non-Hispanic White	Ref	Ref	Ref
Mexican American	0.08 [0.05, 0.12]***	0.07 [0.03, 0.11]**	0.05 [0.01, 0.10]*
Other Hispanic	0.02 [-0.01, 0.06]	0.01 [-0.03, 0.05]	-0.01 [-0.06, 0.03]
Non-Hispanic Black	0.15 [0.12, 0.19]***	0.14 [0.11, 0.17]***	0.11 [0.08, 0.14]***
Non-Hispanic Asian	0.18 [0.13, 0.23]***	0.20 [0.14, 0.25]***	0.24 [0.19, 0.28]***
Other or Multi-Racial	0.10 [0.05, 0.14]***	0.08 [0.03, 0.13]**	0.06 [0.01, 0.11]*

Data are coefficients [95% CI] from multivariable linear regression models. Model 1 adjusted for race/ethnicity, age, and sex; model 2 additionally adjusted for BMI, hypertension, and mean energy Intake; model 3 additionally adjusted for SDoHs-related variables such as employment status, income ratio to poverty, food security, education, access to healthcare, health care insurance, and marital status. Abbreviation: Ref, reference.
† - additional adjustment acculturation (nativity and years in the US variable is chosen as an acculturation proxy).
*P < 0.05; **P < 0.01; ***P < 0.001 compared with the Non-Hispanic White as a reference group.

Adjusting for other covariates in the regression model, women had a lower Na/K ratio (p value<0.001). As we anticipated, individuals aged 31-59 years and individuals aged 60 years or over had a lower Na/K intake ratio (p value<0.001). Additionally, underweight, overweight, and obese individuals had significantly higher Na/K ratios compared to those with normal weight. Mean energy intake was positively associated with the Na/K ratio (Fig 4).

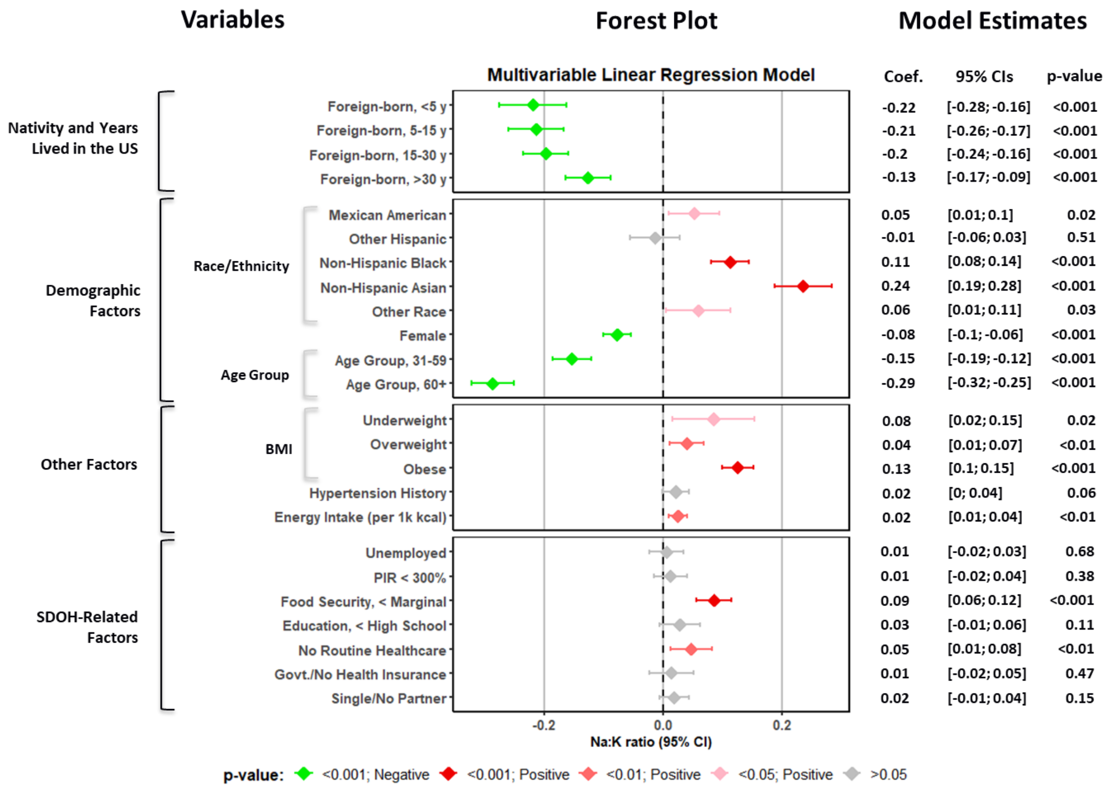
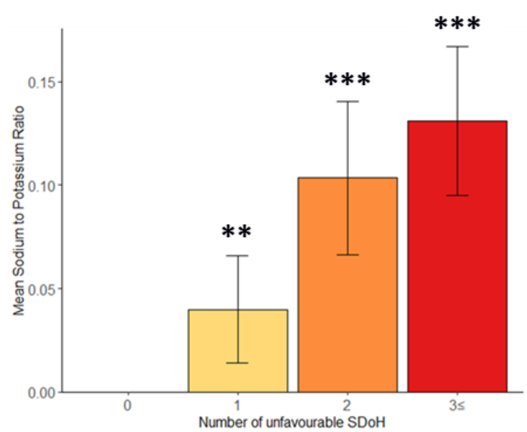


Figure 4. Multivariable linear regression model. Reference group: U.S.-born; Non-Hispanic White; Male; Aged from 21 to 30; Normal BMI; Without hypertension; Employed; PIR> 300%; With full food security; Higher than high school education; With routine healthcare; With private insurance; Married.

Social Determinants of Health

Individuals with marginal or lower food security had a higher Na/K ratio compared to those with full food security or full food availability. Na/K ratio was significantly greater among the people with government health care insurance or without insurance compared to those with private insurance (Fig 4). Dose-response relationships were observed between the Na/K ratio and the cumulative number of unfavorable SDoH. Na/K ratio was 0.04-unit (95% CI; 0.01-0.07) higher for individuals with one unfavorable SDoH, 0.1-unit (0.07-0.14) higher for those with two, and 0.13-unit (0.1-0.17) higher for those with three compared to those with no unfavorable SDoH (Fig 5).



Participant , n	**5452**	**5676**	**4300**	**7572**
Prop. (%)	**23.7%**	**24.7%**	**18.7%**	**32.9%**
Coef.	**Ref.**	**0.04**	**0.1**	**0.13**
95% CIs	**Ref.**	**[0.01; 0.07]**	**[0.07; 0.14]**	**[0.1; 0.17]**
p-value	**Ref.**	**0.003**	**<0.001**	**<0.001**

Figure 5. Sodium to Potassium Ratio by Cumulative Number of Unfavourable SDoH. Constructed by assigning a value of 0 for each favorable and 1 for each unfavorable level, and summing the seven dichotomized SDoH; a higher number indicates the presence of more unfavorable SdoHs (Supplementary p1).

IV. Discussion

Trends of Sodium, Potassium, and Sodium to Potassium Intake Ratio

From 2011 to 2020, the mean sodium and potassium intakes decreased, whereas the overall sodium-to-potassium intake ratio increased. In sub-population analysis, increasing trends were observed only in U.S.-born non-Hispanic Whites and U.S.-born Hispanic Blacks. Interestingly, a decreasing trend in the Na: K ratio was observed in foreign-born Asian Americans.

There were inconsistencies in studies on sodium and potassium intake in the U.S., which can be attributed to differences in study design, data collection period, and measurement methods. In the NHANES study on data from 1999 to 2020, sodium intake slightly increased from 3.24 mg/day to 3.26 mg/day, while potassium intake decreased from 2.65 g/day to 2.50 g/day.(37) There were other studies that reported similar increasing trends,(38) while other studies reported no significant trend changes in sodium excretion(39) and decreasing trends for children and adolescents.(40,41) Other studies sub-population analysis reported Asians had the highest sodium intake and a decrease in sodium intake among non-Hispanic Whites.(42,43)

In Asian countries, decreasing trends in general were observed in sodium intake and the sodium-to-potassium ratio while an increasing trend was seen in potassium intake. In one of the Korean NHANES studies, while mean sodium intake remained stable at around 4.6-4.7 g/day, potassium intake increased significantly from 2.6 to 2.9 g/day, leading to a decrease in the sodium-to-potassium ratio from 1.88 to 1.71. Other studies in South Korea reported similar trends.(44–46) In China, sodium intake decreased from 6.3 g/day to 4.1 g/day and the Na/K ratio decreased from 4.1 to 3.1 between 1991 and 2009 (47). In Japan, a decreasing trend in sodium intake from 1995 to 2016.(48) However, this observed decreasing trend was not common globally. For instance, although a significant decrease in the sodium-to-potassium ratio was observed in Italy, potassium intake also decreased over time.(49) Interestingly, in those Asian countries, the main source of sodium intake came from salt added during home food preparation, with a small but increasing proportion from processed foods.(21,50) Those decreasing trends could be explained by consistent and successful public health campaigns aimed at reducing sodium consumption.(44) Researchers attribute the decreasing trend of sodium intake in Asian countries to government interventions and campaigns, as well as significant improvements in socio-economic factors such as education, income levels, food transportation, and modernization. These advancements have led to a reduction in the consumption of traditional high-sodium preserved foods.(48,50,51)

In the U.S., sodium added to food outside the home is the leading source, accounting for over 70% of total sodium intake, while salt added during home cooking and salt added at the table account for only 11%.(52) In Asia, the primary sodium consumption path is related to added salt during cooking. The main sources of sodium were kimchi, soy sauce, soybean paste, and miso.(44,48,50) Among Non-Hispanic Asians, the primary sources of sodium intake were soup, rice, yeast-bread, stir-fry, or soy-mixed sources, which was significantly different from other race/ethnicity groups: cold cuts or cured meats, meat dishes, eggs or omelets, and cheese.(21) The primary sodium source also depends on age, with older adults consuming more sodium from home-prepared meals, while younger and middle-aged adults consume more sodium from restaurant meals.(45)

Although it is low, processed food intake and eating-out habit were on the rise, especially in urban areas and among higher-income groups in Asia.(47)

Acculturation and Na:K ratio

We found that nativity plays an important role in dietary habits. Compared to the people who were born in the U.S., foreign-born individuals had a lower Na/K ratio. Among those immigrants, the Na/K ratio was greater among highly acculturated individuals, after adjusting for different combinations of confounders for different types of acculturation proxies. Similar findings were observed among adolescents, with better scores for dietary sodium for those who spent less time in the U.S..(53) Generally, several studies reported that higher levels of acculturation were associated with poor diet quality, higher ultra-processed food consumption, and higher risks of obesity.(53–58) Longer duration of residence is linked with lower cardiovascular health scores among non-Hispanic Asians, highlighting the negative impact of dietary acculturation.(56) Those findings can be explained by the concept that less acculturated individuals tend to maintain their traditional food and dietary habits.

In our analysis, we found Non-Hispanic Black participants had the highest Na/K ratio. This aligns with previous reports highlighting that Black Americans have inadequate sources of potassium because they consume fewer servings of fruits and vegetables.(59) In addition, several studies reported that socioeconomic and environmental inequalities among Black Americans might influence their dietary habit.(60) Adjusting for acculturation, non-Hispanic Asian participants had the highest Na/K ratio followed by the Black Americans. To our knowledge, this is the first time we observed this pattern, which suggests they might be less prone to adapting their dietary habits. Among Non-Hispanic Asians, the studies on acculturation were inconsistent depending on the conceptual model and main interest and the impact of acculturation should be carefully interpreted.(61) Although most acculturated non-Hispanic Asians had a lower healthy eating index score (HEI -2015) compared to those who were less acculturated, higher sodium and potassium intakes were reported among the less acculturated group.(58)

However, the impact of acculturation on diet quality can vary depending on specific dietary components. The relationship between acculturation and diet is also multifaceted and influenced by various factors, including race/ethnicity group, socioeconomic status, access to healthy foods, and cultural preferences. We found that those who had no routine healthcare visits and poor food security had a higher Na/K ratio than others. We also found that individuals with a higher number of unfavorable SDoHs had a higher Na/K ratio than those who had no unfavorable SDoHs, which was similar to previous findings.(27) In addition, researchers also noted that participants with lower incomes and education levels tend to have higher sodium intake and lower potassium intake.(57,59)

In this study, we have several limitations. One primary issue is the cross-sectional design of the NHANES survey and we did not control the possible cohort effect. Because we used data from a relatively short period of time, we are constrained to do synthetic cohort groups for acculturation measures. In the future, age, period, and birth cohort effects should be addressed for trend analysis.(62) Additionally, because of the COVID-19 pandemic, we needed to use different midpoints for the 2017-March 2020 NHANES cycles in our trend analysis. Thirdly, the reliance on self-reported dietary recall methods, such as 24-hour recalls, introduces possible recall bias, which can affect the reliability of sodium intake data. Fourth, the generalization of the Asian group into a single category hinders possible differences among various Asian subgroups. Furthermore, we adjusted for energy intake in our regression models, but we selected Na/K ratio and did not examine sodium or potassium density (mg/kcal) as the main variable of interest. Older individuals, women, and those with low socioeconomic status had lower sodium and potassium intake, which was explained by that they were consuming less food or energy.(59) Findings also show that blood pressure rises more steeply with sodium intake at lower energy levels, suggesting that sodium density may be more important than absolute sodium intake for health outcomes.(63) Therefore, further studies are needed to address sodium and potassium density.

V. Conclusion

The Na/K ratio has increased among the overall study population in the U.S. from 2011 to 2020. Prolonged exposure to the U.S. food environment has a significant impact on consuming excessive sodium and insufficient potassium.

Non-Hispanic Asians had the highest Na/K ratio compared to other race/ethnicity groups, after adjusting for confounders. The findings also suggest that they might be less prone to adapting their dietary habits compared to others. Multi-faceted interventions that address the disparity in races/ethnicity and acculturation statuses are needed to reduce the Na/K ratio.

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