Associations of Sodium and Potassium with Obesity Measures Among Diverse US Hispanic/Latino Adults: Results from the Hispanic Community Health Study/Study of Latinos

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**Objective:** The objective of this study was to evaluate cross-sectional associations of sodium and potassium with BMI, waist circumference (WC), and body fat and to determine whether the nativity and/or duration of United States (US) residence modified these associations.

**Methods:** Sodium and potassium were derived from 24-hour diet recalls from 16,156 US participants of the 2008 to 2011 Hispanic Community Health Study/Study of Latinos (HCHS/SOL) and from 24-hour urine in 447 HCHS/SOL participants. BMI, WC, and body fat were measured.

**Results:** Dietary sodium that was 500 mg/d higher was cross-sectionally associated with a 0.07-kg/m² higher BMI (P < 0.05) and a 0.18-cm larger WC (P = 0.04). Dietary potassium that was 500 mg/d higher was only associated with lower BMI and smaller WC among those who were foreign-born with 10 years in the US (−0.13 kg/m², P < 0.01 and −0.36 cm, P = 0.01, respectively) and among those who were US-born (−0.62 kg/m², P < 0.01 and −1.42 cm, P < 0.01, respectively). Urinary sodium that was 500 mg/d higher was associated with a 0.27-kg/m² higher BMI (P < 0.01) and 0.54 kg more body fat (P < 0.01).

**Conclusions:** Sodium intake was associated with higher BMI, WC, and body fat. Potassium intake was associated with lower BMI and smaller WC among US-born participants and participants with a longer duration of US residence.

**Introduction**

Two of every three adults in the United States (US) have either overweight or obesity (1). The current obesity epidemic in the US has been at least partly attributed to the increasingly processed diet and its composition, which is not only energy dense but also rich in sodium and low in potassium (2). Given the ubiquity of sodium in the US diet (3), coupled with lack of potassium, the sodium-to-potassium (Na/K) ratio has increased over time and is less than ideal (2). Although emerging evidence suggests that sodium intake may be associated with obesity, independently of energy (4-12), the relationships of potassium and Na/K ratio with obesity have not been explored in great detail. Findings from limited studies have

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**Author contributions:** TE conducted the statistical analyses for this study. TE and AZAH interpreted the data and drafted the manuscript. TE, YMR, LVH, MG, DSA, NS, MD, JMB, MML, PAS, GP, HF, and AZAH contributed to the methodological aspects of this study.

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suggested that lower potassium and a higher Na/K ratio are associated with higher rates of obesity (13).

Among ethnic minority populations, such as US Hispanics/Latinos, the relationships among sodium, potassium, Na/K ratio, and obesity are particularly pertinent, and yet they remain underexplored. Hispanics/Latinos have higher dietary sodium intake, lower dietary potassium intake (14), and higher rates of obesity (15) compared with non-Hispanic whites. Further, Hispanics/Latinos have a unique acculturation experience during which their dietary habits and quality tend to worsen with greater duration of residence in the US (16). Thus, understanding how dietary nutrients such as sodium and potassium intake are associated with obesity outcomes among Hispanics/Latinos, one of the fastest-growing segments of the US population, is of great medical and public health interest.

Establishing a direct association between dietary nutrients, sodium in particular, and obesity independent of energy intake is important yet challenging, given the strong correlation between nutrients such as sodium and energy intake. Most prior studies have adjusted for energy intake derived from dietary recall or food frequency questionnaire (4,6,7,9,12,17), both of which are prone to measurement error (18). Fewer studies have explored sodium density (estimated as sodium divided by energy intake) in relation to obesity (8,11), and to our knowledge, no prior study in the US has used the doubly labeled water (DLW) method (19) to objectively calculate energy intake and account for it when examining the associations among sodium, potassium, and obesity outcomes.

Using data from the Hispanic Community Health Study/Study of Latinos (HCHS/SOL), we aimed to examine (1) the associations of dietary sodium, potassium, and Na/K ratio with measures of obesity and (2) whether these associations varied by the duration of US residence. In a subsample, we further examined the associations of 24-hour urinary sodium, potassium, and Na/K ratio with measures of obesity, controlling for DLW-derived energy intake.

Methods

Study population

The HCHS/SOL is a population-based cohort study of 16,415 community-dwelling, self-identified Hispanics/Latinos of diverse heritage. In brief, participants aged 18 to 74 years were recruited between 2008 and 2011 in areas in proximity to four field centers in Bronx, New York; Chicago, Illinois, Miami-Dade, Florida; and San Diego, California. A two-stage area probability sample of households was selected; stratification and oversampling at each stage were utilized to obtain a diverse and representative sample of Hispanics/Latinos (20). Participants were asked to bring in their current medications for review, undergo a clinical examination, have fasting blood samples collected, and answer questionnaires pertaining to their medical history and health behaviors, including two 24-hour diet recalls. After excluding 259 individuals without at least one exposure and outcome measure of interest, our final analytic cross-sectional HCHS/SOL sample was 16,156 (Figure 1). All participants provided informed consent, and the study was approved by each site’s institutional review board. Details have been described elsewhere (20,21).

Study of Latinos: Nutrition & Physical Activity Assessment Study

In 2010 to 2012, within months of completing the HCHS/SOL, a subset of weight stable HCHS/SOL participants enrolled in the Study of Latinos: Nutrition & Physical Activity Assessment Study (SOLNAS) ancillary study (22), designed to assess the measurement error of self-reported energy, protein, sodium, and potassium intake. Spot and 24-hour urine samples were collected at two study visits spanning 12 days. Four hundred eighty-five SOLNAS participants attended visit 1. Participants arrived at the first visit after a 4-hour fast and provided a baseline spot urine sample. Participants then ingested a DLW mixture dosed on the basis of body weight (23) and provided in-clinic post-DLW spot urine samples at 3 and 4 hours. At the end of visit 1, participants received a meal replacement beverage and fluids necessary for the DLW measurement process. Additionally, participants were given 24-
hour urine collection instructions and advised to collect and return the urine at visit 2. At visit 2, the 478 participants who returned provided two more timed spot urine collections for the DLW measurement; seven participants did not return with 24-hour urine samples. Of the 471 24-hour urine samples, a total of 36 were subsequently excluded for the following reasons: a urine sample < 500 ml (n = 5), reporting two or more missed urine collections (n = 18), technical issues with the laboratory assay (n = 1), or the participant has chronic kidney disease (CKD) (n = 12), resulting in a final analytic size of 435 (see Figure 1). The sample included 44 participants who missed one void. All participants provided informed consent.

**Dietary measures**

Self-reported measures of energy, sodium, and potassium. Two 24-hour dietary recalls were collected from the full sample of HCHS/SOL participants within a 3-month period (24). Scores from the two dietary recalls were averaged; 99% of the sample provided at least one recall. Using the Nutrition Data System for Research software, which uses the multiple-pass method (25), values for dietary sodium (milligrams per day), potassium (milligrams per day), and energy (kilocalories per day) were derived. The following measures were further calculated: dietary Na/K ratio as sodium (millimoles) divided by potassium (millimoles), dietary sodium density as dietary sodium intake (milligrams) per 1,000 kcal per day, and dietary potassium density as dietary potassium intake (milligrams) per 1,000 kcal per day.

Biomarker-based measures of energy, sodium, and potassium. From 24-hour urine samples, sodium (millimoles) and potassium (millimoles) levels were determined by using the ion-selective electrode method (Roche Diagnostics, Indianapolis, Indiana) at the central HCHS/SOL laboratory at the University of Minnesota. Samples were normalized to a 24-hour period and values for sodium and potassium were converted into milligrams per day. In brief and described elsewhere (22), DLW, a validated technique known to provide accurate measurement of total energy expenditure (26), was used to estimate total energy intake, which was valid among weight-stable individuals. Deuterium and oxygen-18, two byproducts of the ingested DLW mixture, were measured from each spot urine sample by using mass spectrometry at the Gas-Isotope-Ratio Mass Spectrometry Laboratory, US Department of Agriculture/Agriculture Research Service Children’s Nutrition Research Center, Baylor College of Medicine, Houston, Texas (27,28). Deuterium and oxygen-18 elimination rates were calculated from the multiple timed spot urine specimens collected over the 12-day period; with the difference between these rates proportional to carbon dioxide production. The Weir equation was used to estimate total energy expenditure (expressed in kilocalories per day) from the carbon dioxide production rate (23). The following measures were also derived: Na/K ratio as the ratio of urinary sodium (millimoles per day) to urinary potassium (millimoles per day), sodium density as urinary sodium excretion (milligrams) per 1,000 kcal (derived from DLW) per day, and potassium density as potassium excretion (milligrams per day) per 1,000 kcal (derived from DLW) per day.

**Measures of obesity**

BMI in kg/m² was measured in both the full HCHS/SOL sample and the SOLNAS subsample and was derived from the measured height and weight of participants while they were wearing light clothing (21). Waist circumference (WC) in centimeters was measured during the HCHS/SOL study only using standardized reference points. Additionally, in the SOLNAS subsample, DLW methods, described elsewhere (29), were used to measure body fat in kilograms and percent body fat.

**Other measures**

All study participants reported their language preference (Spanish or English), age, sex, and educational attainment (< high school, high school degree, or > than high school). Individuals also reported their incomes, grouped as <$20,000, $20,000 to $50,000, ≥ $50,000, or missing income. Participants were asked to select a category that best described their Hispanic/Latino heritage, with responses including, Central American, Cuban, Dominican, Mexican, Puerto-Rican, South American, more than one group, or other. Additionally, participants reported their nativity and were classified as US-born or foreign-born (including Puerto Rico). Participants who were identified as foreign-born further reported the duration that they had lived in the US. Nativity/years in the US was classified as follows: foreign-born, < 10 years in the US; foreign-born, ≥10 years in the US; or US-born.

Participants reported their smoking status (never, current, or former) and alcohol consumption (“heavy drinkers” were defined as having > 7 drinks/wk for women and > 14 drinks/wk for men). Physical activity was self-reported by using the modified version of the World Health Organization Global Physical Activity Questionnaire (30). Described elsewhere (31), the Alternative Healthy Eating Index-2010 (AHEI-2010, range from 0 to 110) was used to assess overall diet, with higher scores indicating a more healthful diet. Three seated blood pressure (BP) measurements were taken by using an automatic sphygmomanometer (HEM-907L; OMRON, Hoffman Estates, Illinois), and hypertension was defined as having an average systolic BP ≥ 140 mm Hg, an average diastolic BP ≥ 90 mm Hg, or documented use of antihypertension medication. Use of diuretic medication was also noted. Diabetes status/impaired glucose classification was defined as having a fasting plasma glucose level ≥ 126 mg/dl, a 2-hour postload glucose level ≥ 200 mg/dl, a glycated hemoglobin level ≥ 6.5%, or documented use of hypoglycemic agents (32). CKD was defined as having an estimated glomerular filtration rate < 60 ml/min per 1.73 m² (33). Depressive symptoms were assessed by using the Center for Epidemiologic Studies Depression Scale-10 (range: 0 to 30).

**Statistical analysis**

For our main analysis, among participants of the HCHS/SOL study, demographic and clinical characteristics were assessed along with mean dietary sodium, sodium density, potassium, potassium density, and Na/K ratio across categories of nativity/years in the US. To determine whether means differed by nativity/years in the US, t tests were used. Estimates were age-adjusted to the US 2010 census population.

By using multiplicative interaction terms within linear regression models, we found that nativity/years in the US modified the association of dietary potassium, potassium density, and Na/K ratio with BMI and WC (P values of interactions < 0.05), but not sodium or sodium density, thus resulting in stratified models for potassium, potassium density, and Na/K ratio. Models were adjusted for age, sex, Hispanic/Latino heritage, education, income, language preference, study site, smoking, hypertension, diabetes, CKD, alcohol use,
depression, and physical activity. Models for sodium, potassium, and Na/K ratio were additionally adjusted for dietary energy intake.

For analyses of the SOLNAS subsample, we also assessed demographic and clinical characteristics of the SOLNAS sample (reported in Supporting Information Table S1). We repeated similar linear regression models in the SOLNAS subsample by using the urinary-based biomarkers but did not test for effect modification by nativity/years in the US because of a smaller sample size. Models were adjusted for age, sex, Hispanic/Latino heritage, education, income, language preference, nativity/years in the US, study site, missed urine voids, smoking, hypertension, diabetes, alcohol use, depression, and physical activity. Models for sodium, potassium, and Na/K ratio were additionally adjusted for DLW-derived energy intake. Additionally, we conducted a sensitivity analysis by further excluding participants who missed one urine void (n = 44) or were on diuretic medications, which are known to effect electrolyte excretion (n = 28), for a restricted sample of 363 participants. Analyses were conducted in SUDAAN (Version 11.0.1, Research Triangle Institute, Research Triangle Park, North Carolina) to account for the complex survey design and the sampling weights.

### Results

Overall, mean age was 41 years old (SE: 0.2), and 52.6% (SE: 0.5) were female (Table 1). In total, 34% (SE: 0.7) had less than a high school education, 76% (SE: 0.9) preferred Spanish to English, 25% (SE: 0.5) had hypertension, and 17% (SE: 0.4) had diabetes. Compared with those born in the US, those foreign-born were less likely to have CKD but more likely to have lower educational attainment and lower incomes, prefer Spanish, and have higher AHEI-2010 scores.

Mean dietary sodium differed by nativity/years in the US (Figure 2) and ranged from 3,071 mg/d (SE: 35) among those foreign-born with <10 years in the US to 3,376 mg/d (SE: 47) among those foreign-born with ≥10 years in the US and 3,361 mg/d (SE: 39) among those born in the US.
foreign-born with $< 10$ years in the US. Mean dietary potassium and Na/K ratio, both indicators of diet quality, were least favorable (i.e., lower potassium and higher Na/K ratio) among those born in the US. Results from $t$ tests showed that compared with the US-born, those foreign-born with $< 10$ years had higher dietary potassium (2,512 mg/d, SE: 23 vs. 2,294 mg/d, SE: 33; $P < 0.01$), higher dietary potassium density (1,333 mg/1,000 kcal, SE: 11 vs. 1,198 mg/1,000 kcal, SE: 11; $P < 0.01$), and had lower mean dietary Na/K ratio (2.40, SE: 0.03 vs. 2.56, SE: 0.03; $P < 0.01$).

From fully adjusted linear regression models (Table 2), dietary sodium that was higher by 500 mg/d was associated with a 0.07-kg/m$^2$ higher BMI (95% CI: 0.00-0.15; $P < 0.05$) and a 0.18-cm larger WC (95% CI: 0.00-0.36; $P < 0.05$). Likewise, a dietary sodium density higher by 250 mg/1,000 kcal was associated with a 0.07-kg/m$^2$ higher BMI (95% CI: 0.01-0.14) and a 0.17-cm larger WC (95% CI: 0.01-0.34).

The associations of potassium, potassium density, and Na/K ratio with obesity measures varied by nativity/years in the US (Figure 3 and Supporting Information Table S1). For dietary potassium, a 500-mg/d increment was only associated with lower BMI among the foreign-born with $< 10$ years in the US ($-0.13$ kg/m$^2$, 95% CI: $-0.25$ to 0.00; $P < 0.05$) and among those US-born ($-0.62$ kg/m$^2$, 95% CI: 0.00-0.13).

### Table 2: Associations of dietary sodium and sodium density with BMI and waist circumference, HCHS/SOL

|                      | BMI (kg/m$^2$) | 95% CI          | Waist circumference (cm) | 95% CI          |
|----------------------|----------------|-----------------|--------------------------|-----------------|
| **Sodium**           |                |                 |                          |                 |
| Model 1              | 0.00           | $-0.05$ to 0.05 | 0.11                     | $-0.01$ to 0.24 |
| Model 2              | 0.07*          | 0.00 to 0.15    | 0.18*                    | 0.00 to 0.36    |
| **Sodium density**   |                |                 |                          |                 |
| Model 1              | 0.12*          | 0.05 to 0.18    | 0.31*                    | 0.13 to 0.49    |
| Model 2              | 0.07*          | 0.01 to 0.14    | 0.17*                    | 0.01 to 0.34    |

Model 1 adjusted for age, sex, heritage, education, income, language preference, nativity/years in the US, and study site; Model 2 additionally adjusted for smoking, hypertension, diabetes, chronic kidney disease, alcohol use, depression, physical activity (total METs/wk), and energy intake (in sodium models only). We modeled 500-mg increments of sodium and 250 mg/1,000 kcal units for sodium density.

*Indicates estimate is statistically significant, $P < 0.05$.

METs, metabolic equivalents; HCHS/SOL, Hispanic Community Health Study/Study of Latinos.
For dietary potassium density, an increment of 250 mg/1,000 kcal was associated with higher BMI among the foreign-born with <10 years in the US (0.18 kg/m², 95% CI: 0.03 to 0.34), but not among the foreign-born with ≥10 years in the US (0.01 kg/m², 95% CI: −0.10 to 0.13), and was associated with lower BMI among the US-born (−0.55 kg/m², 95% CI: −0.82 to −0.28). Patterns for WC largely mirrored those of BMI.

For the dietary Na/K ratio, a 0.50-unit increment was associated with higher BMI among the foreign-born with <10 years in the US (0.13 kg/m², 95% CI: 0.08 to 0.22) and among the US-born (0.23 kg/m², 95% CI: 0.11 to 0.35). An increment of 250 mg/1,000 kcal of urinary sodium density was associated with a 0.39 (95% CI: 0.09-0.68) higher percent body fat. Urinary potassium and potassium density were not associated with BMI, body fat, or percent body fat in fully adjusted models. However, a 0.50-increment of the

Demographic and clinical characteristics of SOLNAS participants are shown in Supporting Information Table S2. Among SOLNAS participants, in fully adjusted linear regression models (Table 3), a 500-mg/d higher urinary sodium excretion was associated with 0.27-kg/m² higher BMI (95% CI: 0.08-0.45), 0.54 kg of additional body fat (95% CI: 0.15-0.93), and additional percent body fat of 0.35 (95% CI: 0.11-0.58). An increment of 250 mg/1,000 kcal of urinary sodium density was associated with a 0.39 (95% CI: 0.09-0.68) higher percent body fat. Urinary potassium and potassium density were not associated with BMI, body fat, or percent body fat in fully adjusted models. However, a 0.50-increment of the
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Sodium-to-potassium ratio

Potassium density correlated with energy intake (34). High-sodium diets are also associated with lower body mass index (BMI) and waist circumference (WC) (35). The association of dietary potassium, potassium density, and Na/K ratio with BMI and WC were stronger in the foreign-born with 10 years in the US; among the US-born participants, it was associated with 0.62-km/m² lower BMI and 1.42-cm smaller WC. The magnitude of the associations between urinary-based markers, especially sodium and Na/K ratio, and measures of obesity was much stronger and independent of DLW-derived energy expenditure, suggesting a direct relationship.

Results from the sensitivity analysis restricted to those without any missing urine voids and not on diuretic medications were unchanged (not shown).

Discussion

In the current study of more than 16,000 diverse US Hispanics/Latinos, sodium was associated with measures of obesity, independently of energy intake. Each 500-mg increment of daily dietary sodium was significantly associated with a 0.07-km/m² higher BMI and a 0.18-cm larger WC. The associations of dietary potassium, potassium density, and Na/K ratio with BMI and WC were stronger in magnitude with more years spent in the US. For example, whereas higher dietary potassium was not associated with BMI or WC among the foreign-born with < 10 years in the US, higher dietary potassium was associated with a 0.13-km/m² lower BMI and a 0.36-cm smaller WC among foreign-born with ≥ 10 years in the US; among the US-born participants, it was associated with 0.62-km/m² lower BMI and 1.42-cm smaller WC. The magnitude of the associations between urinary-based markers, especially sodium and Na/K ratio, and measures of obesity was much stronger and independent of DLW-derived energy expenditure, suggesting a direct relationship.

Sodium is ubiquitous in the US food supply (3) and therefore highly correlated with energy intake (34). High-sodium diets are also known to increase fluid intake (35), such as the consumption of sugary drinks (36), which in turn may contribute to weight gain (37). Thus, the sodium-obesity relationship has largely been attributed to indirect downstream processes related to increased energy intake. However, emerging evidence suggests that a direct relationship between sodium and obesity exists independently of energy intake (4-12,17,38,39). For example, in a population-based sample in the United Kingdom that assessed sodium by using 24-hour urine, a sodium level higher by 400 mg/d (or 1 g of salt) was independently associated with greater fat mass in children by 0.73 kg and in adults by 0.91 kg, even after controlling for energy intake by using DLW (39). In agreement with such findings, our study, which was the first of its kind in the US to use objective measures of both sodium and energy, found a strong and direct association between sodium and measures of obesity, independent of energy intake.

Although the biological rationale for this association has not been fully explored, the conventional wisdom that all calories are metabolically equivalent regardless of macronutrient composition is being questioned. For example, a study by Ebbeling et al. (40) showed that isocaloric diets differing in macronutrient composition elicited different declines in resting and total energy expenditure. Similarly, experimental studies in rats showed that high-sodium diets induced higher adiposity compared with rats on isocaloric low-sodium diets (41). Consistent with this animal model, we found that a 500-mg/d higher urinary sodium excretion was significantly associated with 0.54 kg more body fat. Additionally, we found that urinary sodium density, a relative measure, was associated with percent body fat, a measure of body composition, but not absolute body fat in kilograms. Taken together, these results suggest that sodium in itself is

### TABLE 3

| Sodium | Body fat (kg) | Percent body fat |
|--------|--------------|-----------------|
| Model 1 | 0.46* | 0.83* | 0.40* |
| Model 2 | 0.27* | 0.54* | 0.35* |

**Notes:**
- Model 1 is adjusted for age, sex, heritage, education, income, language preference, nativity/years in the US, study site, and missing one urine void; Model 2 is additionally adjusted for smoking, hypertension, diabetes, alcohol use, depression, physical activity (total METs/wk), and energy intake (in sodium, potassium, and sodium to potassium ratio models only).
- We modeled 500-mg increments of sodium and potassium, 250 mg/1,000 kcal–unit increments for sodium density and potassium density, and 0.50-unit increments of sodium-to-potassium ratio (millimoles/millimoles).
- *Indicates estimate is statistically significant, P < 0.05.
- METs, metabolic equivalents; SOLNAS, Study of Latinos: Nutrition & Physical Activity Assessment Study.

**References:**

1. Ebbeling, C. B., et al. (2008). 
2. Elfassy, M., et al. (2018).
associated with increased fat mass, whereas sodium density is associated with body composition. Although we cannot say for sure why this is the case, the authors note that both sodium density and percent body fat are relative measures.

In our study, potassium, a nutrient positively associated with healthfulness of diet (42), was negatively associated with BMI and WC but showed stronger magnitude with longer duration of US residence. In the context of the acculturation process, the current findings may be the consequence of worsening of dietary habits as subjects become more acculturated (as with greater time in the US) (16). Therefore, we speculate that among individuals with fewer years in the US, potassium may not necessarily reflect diet quality and healthfulness to the extent that it does in a diet among individuals with more years spent in the US. This would explain the lack of associations between dietary potassium and measures of obesity among the foreign-born with <10 years in the US. In our study, overall dietary summary scores were indeed higher (i.e., healthier) among Hispanics/Latinos who were foreign-born versus US-born. Consistent with this speculation, adjusted for age and energy, we found that dietary potassium was a weaker predictor of the AHEI-2010 dietary summary score among the foreign-born with <10 years in the US than among the foreign-born with ≥10 years in the US or among the US-born (data not shown). In the SOLNAS subsample, neither urinary potassium nor potassium density was associated with obesity, although we were underpowered to test for effect modification by nativity/years in the US.

Similar to potassium, the associations between Na/K ratio, another indicator of diet quality (42), and measures of obesity also varied by nativity/years in the US, such that the associations were only significant in those with more years in the US. To our knowledge, this has not been previously documented and may again reflect the Na/K ratio, similar to potassium, as being a better indicator of healthfulness of diet in more acculturated US Hispanics/Latinos. Results from the SOLNAS subsample showed a strong positive association among urinary Na/K ratio with all measures of obesity, including BMI, body fat, and percent body fat. For example, we found a 0.50-unit increase in Na/K to be associated with 0.23-kg/m² higher BMI, 0.48 kg more body fat, and additional body fat percent of 0.34. Consistent with our findings, the spot urine Na/K ratio, a more easily available approach to measuring Na/K ratio, was also shown to be independently associated with percent total body fat measured by using dual-energy x-ray absorptiometry in a multiethnic US cohort (5).

The current study is not without limitations. First, given the cross-sectional design, we could not establish temporality. Sodium reduction is often indicated in the treatment of certain chronic conditions, such as hypertension, diabetes, and CKD. Yet we were unable to account for potential dietary modifications made by these individuals because of the cross-sectional design of the study. Further, our main measures of sodium and potassium were derived via 24-hour dietary recall, which is subject to measurement error (22). However, we also found similar associations by using density measures, which are less error prone (22). Further, we were able to repeat our analyses by using objective biomarkers from 24-hour urine in the SOLNAS subsample and found consistent associations that were sometimes stronger in magnitude. However, even the 24-hour urine biomarker measure has limitations (18), as it only reflects sodium intake on 1 day and is not necessarily reflective of habitual sodium intake. Finally, though we used nativity/years in the US as a proxy measure for acculturation (43), we acknowledge that this measure may not accurately reflect the dynamic acculturation process.

Despite such limitations, our study has several notable strengths. To our knowledge, this was the first study of its kind conducted in a population-based sample of diverse US Hispanics/Latinos. The sample was large and comprised mostly immigrants. Thus, we were adequately powered to test for interactions by length of time in the US. Our study included multiple dietary measures, each with differing strengths. For example, although dietary sodium collected via diet recall is prone to measurement error, sodium density is a more accurate marker of true sodium density. In the current sample, dietary sodium density only overestimates urinary sodium density by 6% (44). Likewise, it has been noted that potassium, potassium density, and (particularly) Na/K ratio derived from self-reported measures capture intake quite well (44,45). In addition to our multiple measures of diet, this study also made use of multiple measures of obesity, including BMI, WC, body fat, and percent body fat. In general, our results were robust across multiple nutrient markers: dietary and urinary biomarkers, measures of obesity, and sensitivity analyses.

Conclusion

In the current population-based study of US Hispanics/Latinos, higher sodium intake was associated with higher BMI, WC, and body fat. Lower potassium intake and higher Na/K ratio were more strongly associated with higher BMI and WC with longer duration of US residence. Although the mechanisms underlying such relationships have not been adequately explored, our findings, along with those of other studies, suggest that sodium may be directly related to measures of obesity, above and beyond energy intake. Future studies investigating the longitudinal relationship among intakes of sodium and potassium, the Na/K ratio, and changes in measures of obesity are warranted.

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References

1. Yang L, Colditz GA. Prevalence of overweight and obesity in the United States, 2007-2012. JAMA Intern Med 2015;175:1412-1413.
2. Cordain L, Eaton SB, Sebastian A, et al. Origins and evolution of the Western diet: health implications for the 21st century. Am J Clin Nutr 2005;81:341-354.
3. Mattes RD, Donnelly D. Relative contributions of dietary sodium sources. J Am Coll Nutr 1991;10:383-393.
4. Hallfors LD, Aurell M, Klingberg S, Hallenberg E, Lorentzon M, Ohlsson C. Salt intake in young Swedish men. Public Health Nutr 2010;13:601-605.
5. Jain N, Minhaajuddin AT, Neelands II, Elsayed EF, Vega GL, Hedaya SI. Association of urinary sodium-to-potassium ratio with obesity in a multiethnic cohort. Am J Clin Nutr 2014;99:992-998.
6. Larsen SC, Angquist L, Sorensen TI, Heitmann BL. 24h urinary sodium excretion and subsequent change in weight, waist circumference and body composition. PLoS One 2013;8:e69689. doi:10.1371/journal.pone.0069689.
7. Libuda L, Kersting M, Alexy U. Consumption of dietary salt measured by urinary biomarkers, measures of obesity, and sensitivity analyses. Obesity 2014;26:703-708.
8. Raisanen JP, Silaste ML, Kesaniemi YA, Ukkola O. Increased daily sodium intake on 1 day and is not necessarily reflective of habitual sodium intake. Metabolism 2013;62:703-708.
9. Yi SS, Kansagra SM. Associations of sodium intake with obesity, body mass index, waist circumference, and weight. Am J Prev Med 2014;46:e53-e55.
11. Yoon YS, Oh SW. Sodium density and obesity: the Korea National Health and Nutrition Examination Survey 2007-2010. *Eur J Clin Nutr* 2013;67:141-146.
12. Zhu H, Pollock NK, Kotak I, et al. Dietary sodium, adiposity, and inflammation in healthy adolescents. *Pediatrics* 2014;133:e635-e642.
13. Cai X, Li X, Fan W, et al. Potassium and obesity/metabolic syndrome: a systematic review and meta-analysis of the epidemiological evidence. *Nutrients* 2016;8:183. doi:10.3390/nu8040183.
14. Angell SY, Yi S, Eisenhowder D, et al. Sodium intake in a cross-sectional, representative sample of New York City adults. *Am J Public Health* 2014;104:2400-2416.
15. Daviglus ML, Talavera GA, Aviles-Santa ML, et al. Prevalence of major cardiovascular risk factors and cardiovascular diseases among Hispanic/Latino individuals of diverse backgrounds in the United States. *JAMA* 2012;308:1775-1784.
16. Ayala GX, Baquero B, Klinger S. A systematic review of the relationship between acculturation and diet among Latinos in the United States: implications for future research. *J Am Diet Assoc* 2008;108:1330-1344.
17. Yi SS, Firestone MJ, Beasley JM. Independent associations of sodium intake with measures of body size and predictive body fatness. *Obesity (Silver Spring)* 2015;23:20-23.
18. Cogswell ME, Muggavero K, Bowman BA, Frieden TR. Dietary sodium and cardiovascular disease risk - measurement matters. *New Engl J Med* 2016;375:580-586.
19. Schoeller DA. Recent advances from application of doubly labeled water to measurement of human energy expenditure. *J Nutr* 1999;129:1765-1768.
20. Lavange LM, Kalsbeek WD, Sorlie PD, et al. Sample design and cohort selection in the Hispanic Community Health Study/Study of Latinos. *Ann Epidemiol* 2010;20:642-649.
21. Sorlie PD, Aviles-Santa LM, Wasserteil-Smoller S, et al. Design and implementation of the Hispanic Community Health Study/Study of Latinos. *Ann Epidemiol* 2010;20:629-641.
22. Mossavar-Rahmani Y, Shaw PA, Wong WW, et al. Applying recovery biomarkers to calibrate self-report measures of energy and protein in the Hispanic Community Health Study/Study of Latinos. *Am J Epidemiol* 2015;181:996-1007.
23. Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol* 1949;109:1-9.
24. Siega-Riz AM, Sotres-Alvarez D, Ayala GX, et al. Food-group and nutrient-density intakes by Hispanic and Latino backgrounds in the Hispanic Community Health Study/Study of Latinos. *Am J Clin Nutr* 2014;99:1487-1498.
25. Zhao G, Ford ES, Mokdad AH. Racial/ethnic variation in hypertension-related lifestyle behaviours among US women with self-reported hypertension. *J Hum Hypertens* 2008;22:608-616.
26. Buchowski MS. Doubly labeled water is a validated and verified reference standard in nutrition research. *J Nutr* 2014;144:573-574.
27. Wong WW, Lee LS, Klein PD. Deuterium and oxygen-18 measurements on microliter samples of urine, plasma, saliva, and human milk. *Am J Clin Nutr* 1987;45:905-913.
28. Wong WW, Clarke LL, Laurador M, Klein PD. A new zinc product for the reduction of water in physiological fluids to hydrogen gas for 2H/1H isotope ratio measurements. *Eur J Clin Nutr* 1992;46:69-71.
29. Bhutani S, Racine N, Shriver T, Schoeller DA. Special considerations for measuring energy expenditure with doubly labeled water under atypical conditions. *J Obes Weight Loss Ther* 2015;5(Suppl 5):002. doi:10.4172/2165-7904.S5-002.
30. World Health Organization. Global physical activity surveillance. http://www.who.int/chp/steps/GPAQ/en/. Published 2015. Accessed December 24, 2015.
31. Chiue SE, Fung TT, Rimm EB, et al. Alternative dietary indices both strongly predict risk of chronic disease. *J Nutr* 2012;142:1009-1018.
32. American Diabetes Association. Diagnosis and classification of diabetes mellitus. *Diabetes Care* 33(Suppl 1):S62-S69.
33. National Kidney Foundation. K/DOQI clinical practice guidelines for chronic kidney disease: evaluation, classification, and stratification. *Am J Kidney Dis* 2002;39(2 Suppl 1):S1-S26.
34. Whelton PK, Appel LJ, Sacco RL, et al. Sodium, blood pressure, and cardiovascular disease: further evidence supporting the American Heart Association sodium reduction recommendations. *Circulation* 2012;126:2880-2889.
35. He FJ, Markandu ND, Sagnella GA, MacGregor GA. Effect of salt intake on renal excretion of water in humans. *Hypertension* 2001;38:317-320.
36. Grimes CA, Wright JD, Liu K, Newson CA, Loria CM. Dietary sodium intake is associated with total fluid and sugar-sweetened beverage consumption in US children and adolescents aged 2-18 y: NHANES 2005-2008. *Am J Clin Nutr* 2013;98:189-196.
37. Schulze MB, Manson JE, Ludwig DS, et al. sugar-sweetened beverages, weight gain, and incidence of type 2 diabetes in young and middle-aged women. *JAMA* 2004;292:927-934.
38. Hoffmann IS, Cubeddu LX. Salt and the metabolic syndrome. *Nutr Metab Cardiovasc Dis* 2009;19:123-128.
39. Ma Y, He FJ, MacGregor GA. High salt intake: independent risk factor for obesity? *Hypertension* 2015;66:843-849.
40. Ebbeling CB, Swain JP, Feldman HA, et al. Effects of dietary composition on energy expenditure during weight-loss maintenance. *JAMA* 2012;307:2627-2634.
41. Fonseca-Alaniz MH, Brito LC, Borges-Silva CN, Takada J, Andreotti S, Lima FB. High dietary sodium intake increases white adipose tissue mass and plasma leptin in rats. *Obesity (Silver Spring)* 2007;15:2200-2208.
42. Loftfield E, Yi S, Immerwahr S, Eisenhowder D. Construct validity of a single-item, self-rated question of diet quality *J Nutr Educ Behav* 2015;47:181-187.
43. Thomson MD, Hoffmann-Goetz L. Defining and measuring acculturation: a systematic review of public health studies with Hispanic populations in the United States. *Soc Sci Med* 2009;69:983-991.
44. Mossavar-Rahmani Y, Sotres-Alvarez D, Wong WW, et al. Applying recovery biomarkers to calibrate self-report measures of sodium and potassium in the Hispanic Community Health Study/Study of Latinos. *Am J Hypertens* 2017;31:462-473.
45. Freedman LS, Commins JM, Moler JE, et al. Pooled results from 5 validation studies of dietary self-report instruments using recovery biomarkers for potassium and sodium intake. *Am J Epidemiol* 2015;181:473-487.