

Difference between 24-h diet recall and urine excretion for assessing population sodium and potassium intake in adults aged 18–39 y^{1–5}

Carla I Mercado, Mary E Cogswell, Amy L Valderrama, Chia-Yih Wang, Catherine M Loria, Alanna J Moshfegh, Donna G Rhodes, and Alicia L Carriquiry

ABSTRACT

Background: Limited data are available on the accuracy of 24-h dietary recalls used to monitor US sodium and potassium intakes.

Objective: We examined the difference in usual sodium and potassium intakes estimated from 24-h dietary recalls and urine collections.

Design: We used data from a cross-sectional study in 402 participants aged 18–39 y (~50% African American) in the Washington, DC, metropolitan area in 2011. We estimated means and percentiles of usual intakes of daily dietary sodium (dNa) and potassium (dK) and 24-h urine excretion of sodium (uNa) and potassium (uK). We examined Spearman's correlations and differences between estimates from dietary and urine measures. Multiple linear regressions were used to evaluate the factors associated with the difference between dietary and urine measures.

Results: Mean differences between diet and urine estimates were higher in men [dNa – uNa (95% CI) = 936.8 (787.1, 1086.5) mg/d and dK – uK = 571.3 (448.3, 694.3) mg/d] than in women [dNa – uNa (95% CI) = 108.3 (11.1, 205.4) mg/d and dK – uK = 163.4 (85.3, 241.5) mg/d]. Percentile distributions of diet and urine estimates for sodium and potassium differed for men. Spearman's correlations between measures were 0.16 for men and 0.25 for women for sodium and 0.39 for men and 0.29 for women for potassium. Urinary creatinine, total caloric intake, and percentages of nutrient intake from mixed dishes were independently and consistently associated with the differences between diet and urine estimates of sodium and potassium intake. For men, body mass index was also associated. Race was associated with differences in estimates of potassium intake.

Conclusions: Low correlations and differences between dietary and urinary sodium or potassium may be due to measurement error in one or both estimates. Future analyses using these methods to assess sodium and potassium intake in relation to health outcomes may consider stratifying by factors associated with the differences in estimates from these methods. This trial was registered at clinicaltrials.gov as NCT01631240. *Am J Clin Nutr* 2015;101:376–86.

Keywords biomarker, diet, sodium, urine, validation study

INTRODUCTION

Sodium intake has been consistently associated with blood pressure in a direct, positive relation (1–5) and with cardiovascular disease and chronic kidney disease (6, 7). Conversely, dietary potassium intake has been inversely associated with

cardiovascular disease and risk factors such as high blood pressure and stroke (8–11). National estimates show that >95% of American adults consume more than the recommended amount of sodium and <5% consume the recommended amount of potassium (12, 13). National initiatives and recommendations focused on changing population intakes of sodium and potassium in the United States need an accurate assessment of consumption to monitor the impact of their efforts, to monitor adherence to dietary guidelines, and to determine the association of sodium or potassium with health outcomes.

Current national sodium and potassium intake estimates in US adults are subject to bias. These estimates are obtained from 24-h dietary recalls administered as part of the NHANES. Although day-to-day variability in intake can be accounted for through the use of measurement error models with an additional 24-h dietary recall in a subset of the population, differential misreporting may occur by demographic factors such as sex and BMI (14, 15), which are associated with adherence to sodium or potassium consumption guidelines or their related health disparities.

Although sodium and potassium intake estimates from 24-h urine collections are objective measures (16), as opposed to subjective estimates based on self-reported 24-h dietary recalls, these have not previously been collected in US nationally representative surveys. Although current monitoring relies on 24-h

¹ From the Division for Heart Disease and Stroke Prevention, National Center for Chronic Disease Prevention and Health Promotion, Atlanta, GA (CIM, MEC, and ALV); the Division of Health and Nutrition Examination Surveys, National Center for Health Statistics, Hyattsville, MD (C-YW), the Centers for Disease Control and Prevention; National Heart, Lung, and Blood Institute, NIH, Bethesda, MD (CML); the Beltsville Human Nutrition Research Center, Agricultural Research Service, USDA, Beltsville, MD (AJM and DGR); and the Department of Statistics, Iowa State University, Ames, IA (ALC).

² Data collection and laboratory analyses were funded by the CDC.

³ The findings and conclusions in this article are those of the authors and do not necessarily represent the official position of the CDC, the NIH, the USDA, or any other entity of the U.S. government.

⁴ Supplemental Table 1 is available from the “Supplemental data” link in the online posting of the article and from the same link in the online table of contents at <http://ajcn.nutrition.org>.

⁵ Address correspondence to CI Mercado, Centers for Disease Control and Prevention, Mailstop F-72, 4770 Buford Highway NE, Atlanta, GA 30341. E-mail: cmercado@cdc.gov.

Received December 12, 2013. Accepted for publication November 21, 2014.

First published online December 17, 2014; doi: 10.3945/ajcn.113.081604.

dietary recalls and nutrient databases, it is important to assess the accuracy of dietary intake compared with urinary excretion for sodium and potassium within subgroups with potentially different reporting, intake, and excretion. Some studies investigated the accuracy of nutrient intake estimated from 24-h dietary recalls compared with urine excretion from 24-h urine collections and found correlations ranging from 0.14 to 0.59 for sodium (15, 17–21) and from 0.31 to 0.69 for potassium (22, 23). Most of these studies were conducted in other countries, in persons with chronic diseases, or with limited race-ethnic diversity. Furthermore, only a few studies adjusted for day-to-day variability in intake and compared accuracy by possible effect modifiers, including sex, race-ethnicity, age, or BMI; and no studies considered both sodium and potassium in the same study.

The objectives of the current study were to compare estimates of intakes of dietary sodium (dNa)⁶ and potassium (dK) based on 24-h diet recalls with urinary excretion of sodium (uNa) and potassium (uK) based on 24-h urine collections between sex, race, age, and BMI subgroups as well as to determine factors associated with the discrepancies between measures by using a study in young adults, in which 50% of the participants were African American. This trial was registered at clinicaltrials.gov as NCT01631240.

PARTICIPANTS AND METHODS

Participants

Participants were drawn from a calibration study conducted from June to August 2011 by the National Center for Health Statistics and previously described in detail (24). Briefly, participants were recruited from the Washington, DC, metropolitan area. A convenience sample of 500 young adults (18–39 y old) with diverse sodium intakes (assessed by questionnaire) was recruited such that 50% were African American and 50% were women. Participants were excluded if they were pregnant, taking loop diuretics, reported chronic kidney disease, or were prescribed new or recently modified hypertension treatment.

A total of 481 participants were scheduled for an initial visit, and 402 (84%) participants provided at least one complete 24-h urine sample and a 24-h dietary recall. A complete urine sample was defined as follows: 1) a total 24-h urinary volume >500 mL, 2) no menstruation during the collection period, 3) a reported length of collection >20 h, and 4) missing one void ($n = 7$) or less during collection. Both urine collection and dietary recall measured the same 24-h period, with the 24-h dietary recall administered on completion of the 24-h urine collection. Of the 402 participants, 219 were women and 196 were African American. A convenience subsample of 133 participants completed a second dietary recall and a 24-h urine collection 4–11 d after the first measure and not on the same day of the week.

Urine and dietary measures

Values for uNa and uK were estimated from the 24-h urine collection by using an ion-selective electrode Na⁺ and K⁺ assay

(Roche Diagnostics). Estimates of uNa and uK were adjusted for the length of time urine was collected. Further adjustments were made to reflect extrarenal losses of sodium and potassium estimated at 90% (25–27) and 77% (25, 28, 29), respectively, by dividing total daily uNa by 0.90 and uK by 0.77. dNa and dK were obtained from standardized interviewer-administered 24-h dietary recall by using the Automated Multiple-Pass Method (14). Sodium and potassium contents of each food and beverage including water were calculated by using the USDA's Food and Nutrient Database for Dietary Studies, version 5.0 (30). Estimates of intake included salt added in cooking and food preparation as assumed in the nutrient profiles for foods. Discretionary salt used at the table was not included.

Other measurements

Body weight and height were measured by using a standard protocol and used to calculate BMI (in kg/m²). BMI was categorized as follows: normal (18.5 to <25), overweight (25 to <30), or obese (≥ 30). Underweight participants (BMI <18.5; $n = 5$) were excluded from the analysis considering BMI. Race was self-reported as African American or other.

Statistical methods

Usual dNa, dK, uNa, and uK were calculated by using PC-SIDE (Software for Intake Distribution Estimation; Iowa State University), which implements the Iowa State University method to account for day-to-day variation. This method transforms data into the normal scale and allows adjustment for covariates. As long as a subsample has at least 2 repeated measures, a measurement error model that removes the within-person variation from observed measurements can be fitted (31). The estimated usual intakes are then transformed back into the original scale. Because of different distributions of dNa, dK, uNa, and uK for men and women, measurement error models were fitted separately for each sex and adjusted for day of the week and participant age in years. Analytic exclusion included influential outliers for dNa, dK, uNa, and uK estimates ($n = 1$). In PC-SIDE, the best linear unbiased predictors of usual dNa, dK, uNa, and uK were calculated for individuals. Study population percentiles with 95% CIs were also calculated (32). Best linear unbiased predictors of usual total caloric intake and urinary creatinine excretion were obtained as well. These estimates of usual quantities were used in all further analyses.

Spearman's correlation between dNa and dK from 24-h dietary recall compared with uNa and uK from 24-h urine collection and the difference (dNa – uNa and dK – uK) were estimated by using STATA 12.0 (StataCorp). Variations in correlations and differences between measures were calculated by sex and then by race (African American or other race), BMI (normal, overweight, and obese), and age group (18–39 y). Bland-Altman plots were used to examine whether the difference between measures varied across the range of consumption by plotting the difference for each individual against the mean of both measures. In Bland-Altman plots, the 95% limits were calculated by the mean difference $\pm 1.96 \times$ SD. Multiple linear regression was used to evaluate associations between the difference in sodium measures and covariates [race (African American or other races), age (y), and BMI (kg/m²)], urine measures (total 24-h urine volume and urine creatinine), and

⁶Abbreviations used: dK, dietary potassium intake; dNa, dietary sodium intake; uK, urinary potassium excretion; uNa, urinary sodium excretion.

dietary components [total caloric intake, weekend vs. weekday, and percentage of sodium or potassium from food groups (dairy, protein, mixed dishes, grains, fruit and vegetables, beverages, and other foods)], with adjustment for each of the other covariates. Significance was denoted as a 2-sided *P* value <0.05.

Sensitivity analysis

All analyses were repeated after excluding participants with potentially incomplete 24-h urine collection based on creatinine concentrations [i.e., a creatinine ratio (observed:expected) <0.6]. Expected creatinine excretion was calculated by using 2 methods: Joossens and Geboers (33) and Mage et al. (34). In the Joossens and Geboers algorithm, expected 24-h creatinine excretion (mg/d) = $G \times \text{body weight (kg)}$, where $G = 21$ for women and 24 for men. Mage's algorithms are as follows: for men, expected 24-h creatinine (mg/d) = $0.00179 \times [140 - \text{age (y)}] \times [\text{weight (kg)}^{1.5} \times \text{height (cm)}^{0.5}] \times [1 + 0.18 \times (\text{African American} = 1, \text{ other races} = 0)] \times [1.366 - 0.0159 \text{ BMI (kg/m}^2\text{)}]$; for women, expected 24-h creatinine (mg/d) = $0.00163 \times [140 - \text{age (y)}] \times [\text{weight (kg)}^{1.5} \times \text{height (cm)}^{0.5}] \times [1 + 0.18 \times (\text{African American} = 1, \text{ other races} = 0)] \times [1.429 - 0.0198 \text{ BMI (kg/m}^2\text{)}]$. Participants with potentially incomplete 24-h urine collection were defined as having creatinine ratios <0.60 by using one or both methods. Therefore, the sensitivity analysis only included those creatinine ratios ≥ 0.60 from both methods. In addition, for comparison with results using the usual intake/excretion analyses, results from 1-d measures were calculated and are provided in **Supplemental Table 1**.

RESULTS

Demographic, dietary, and biomarker measures for the study participants are presented in **Table 1**. By design, approximately half of the participants were women (54%) or African American (49%). More women (35%) were obese than men (21%). Mean dNa and dK were greater for men (4827 and 3277 mg/d, respectively) than for women (3507 and 2544 mg/d, respectively). Mean dNa was significantly greater than mean uNa in men (4827 vs. 3891 mg/d; $P < 0.0001$) and women (3507 vs. 3399 mg/d; $P = 0.03$). Mean dK was significantly greater than mean uK for men and women ($P < 0.0001$).

Cumulative population percentiles for dNa and uNa as well as dK and uK are shown for men and women in **Figure 1**. Distributions for sodium and potassium measures for women were generally similar because CIs were overlapping throughout the entire distributions. For men, dietary distributions were shifted to the right of, or greater than, their respective urine measures, with 95% CIs only overlapping at the tail ends.

Correlation coefficients and the difference between measures (diet minus urine estimates) are shown in **Table 2**. Correlations between sodium measures were 0.16 ($P = 0.03$) for men and 0.25 ($P < 0.001$) for women. Among men, these correlations were highest for those aged 23–29 y ($\rho = 0.29$) compared with those aged 30–39 y ($\rho = 0.03$). Among women, the correlations between sodium measures were higher for women of other race-ethnicities ($\rho = 0.30$) and lowest among African Americans ($\rho = 0.15$). dNa was, on average, greater than uNa for men, with a mean difference of 936.8 mg/d (95% CI: 787.1, 1086.5 mg/d). This difference did not vary by race ($P = 0.93$) or age group (23–29 vs. 18–22 y, $P = 0.91$; 30–39 vs. 18–22 y, $P = 0.83$) but did

TABLE 1
Demographic characteristics, dietary nutrient intake, and biomarkers by sex: Washington, DC, metropolitan area in 2011¹

| | Men (<i>n</i> = 183) | Women (<i>n</i> = 219) | <i>P</i> |
|--|-----------------------------|-------------------------|---------------------|
| Race, <i>n</i> (%) | | | 0.964 ² |
| African American | 89 (49) | 107 (49) | |
| Other | 94 (51) | 112 (51) | |
| BMI category, ³ <i>n</i> (%) | | | 0.004 ² |
| Underweight | 1 (1) | 4 (2) | |
| Normal | 77 (42) | 86 (39) | |
| Overweight | 66 (36) | 52 (24) | |
| Obese | 39 (21) | 77 (35) | |
| Age category (y), <i>n</i> (%) | | | 0.994 ² |
| 18–22 | 51 (28) | 60 (27) | |
| 23–29 | 72 (39) | 87 (40) | |
| 30–39 | 60 (33) | 72 (33) | |
| Total kilocalories | 2862.5 ± 44.59 ⁴ | 2157.4 ± 33.00 | <0.001 ⁵ |
| Dietary sodium intake, mg/d | 4827.3 ± 73.22 | 3507.3 ± 47.65 | <0.001 ⁵ |
| Adjusted urinary sodium excretion, ⁶ mg/d | 3890.6 ± 31.53 | 3399.0 ± 35.84 | <0.001 ⁵ |
| Dietary potassium intake, mg/d | 3277.0 ± 58.96 | 2544.0 ± 34.00 | <0.001 ⁵ |
| Urinary potassium excretion, mg/d | 2705.7 ± 50.89 | 2380.6 ± 32.84 | <0.001 ⁵ |
| Urinary creatinine excretion, mg/d | 1916.6 ± 30.82 | 1342.4 ± 15.08 | <0.001 ⁵ |

¹Usual dietary intakes from the PC-SIDE (Software for Intake Distribution Estimation; Iowa State University) output are presented for total kilocalories, potassium, and sodium intakes. Usual biomarker excretion was estimated from PC-SIDE and included potassium, sodium, and creatinine excretions.

²Derived by Pearson's chi-square test for differences in proportions between sex groups.

³BMI categories (in kg/m²): underweight (<18), normal (18 to <25), overweight (25 to <30), and obese (≥ 30).

⁴Mean ± SE (all such values).

⁵Derived by unpaired *t* test for differences in means between sex groups.

⁶Sodium excretion measures were corrected to account for 90% excretion of all sodium consumed (26, 35).

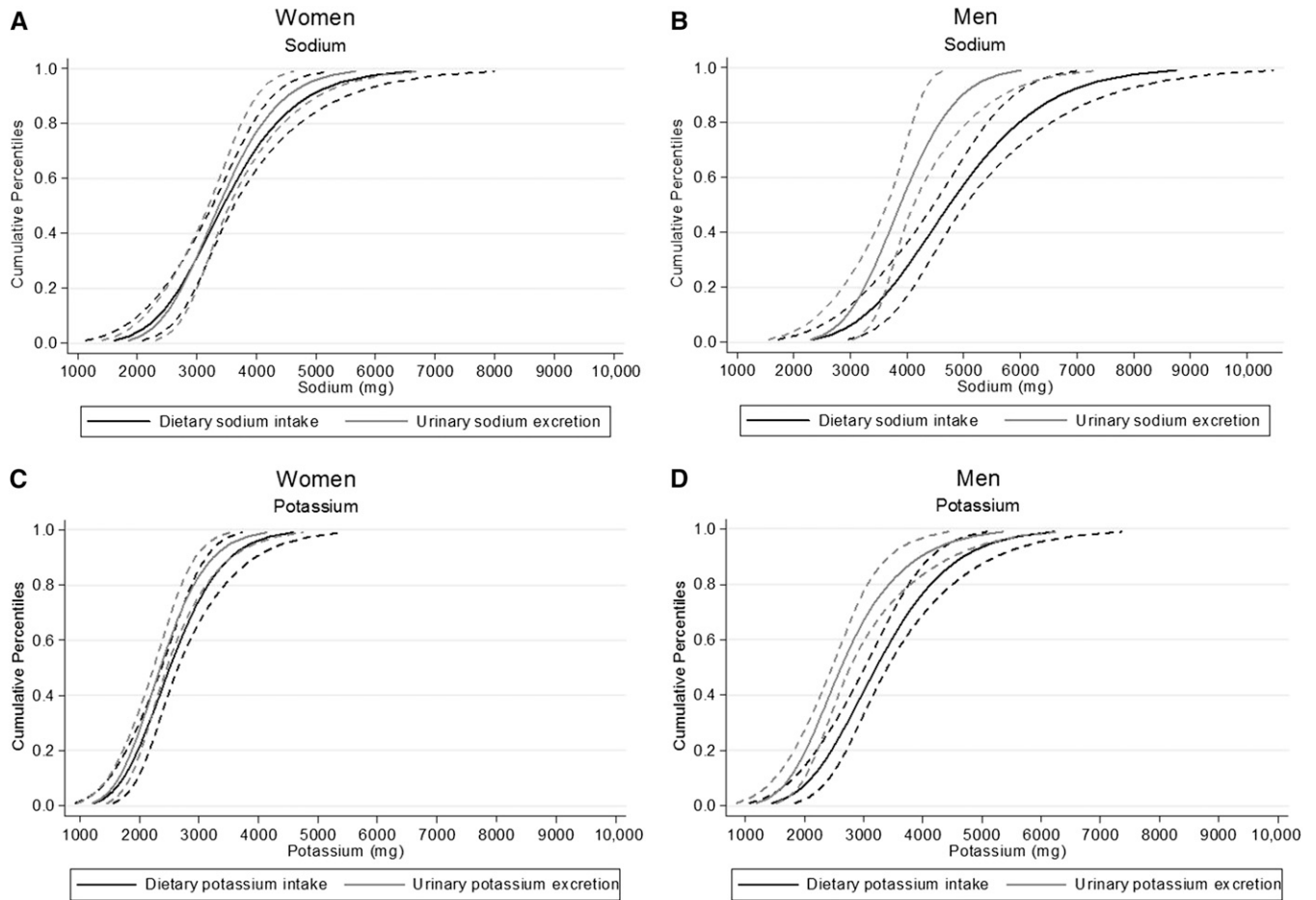


FIGURE 1 Cumulative percentiles of dietary intake and urinary excretion for sodium and potassium: Washington, DC, metropolitan area in 2011. Shown are cumulative percentiles (solid lines) with 95% CIs (dashed lines) of dietary intake and urinary excretion for sodium in women (A) and men (B) and for potassium in women (C) and men (D).

appear to vary by BMI category, with significantly smaller mean differences for obese participants compared with participants with a normal BMI (overweight vs. normal, $P = 0.18$; obese vs. normal, $P = 0.002$). Compared with men, the mean difference was smaller for women at 108.3 mg/d (11.1, 205.4 mg/d). Within race and age, mean differences for women were minimal, with 95% CIs near or crossing zero. Similar to men, there was some variation in the difference by BMI category in women, with overweight women having a significantly smaller difference than those with normal BMI (overweight vs. normal, $P = 0.03$; obese vs. normal, $P = 0.31$).

For potassium, correlations between measures were 0.39 ($P < 0.0001$) for men and 0.29 ($P < 0.0001$) for women (Table 2). For men, correlation coefficients were highest for those who were obese ($\rho = 0.51$) and lowest among African Americans ($\rho = 0.31$). For women, correlations were higher among women of other race-ethnicities ($\rho = 0.44$) and lowest among African Americans ($\rho = 0.10$). On average, dK was greater than uK, with mean differences of 571.3 mg/d (95% CI: 448.3, 694.3 mg/d) for men and 163.4 mg/d (95% CI: 85.3, 241.5 mg/d) for women. In men, this difference varied by race ($P = 0.002$) and BMI (normal vs. overweight, $P = 0.17$; normal vs. obese, $P = 0.04$) but did not vary by age group (23–29 vs. 18–22 y, $P = 0.74$; 30–39 vs. 18–22 y, $P = 0.75$). However, mean differences within subgroups of

race ($P = 0.07$), age (23–29 vs. 18–22 y, $P = 0.40$; 30–39 vs. 18–22 y, $P = 0.61$), or BMI (normal vs. overweight, $P = 0.17$; normal vs. obese, $P = 0.54$) were not significant for women.

The difference in estimated usual individual sodium intake from diet vs. urine excretion was fairly consistent across amounts of sodium and potassium intakes for women (Figure 2A, C). For men, diet measures generally overestimated sodium intake compared with urine measures, and this overestimation was greater at higher intakes, with several individuals falling outside the upper limit of agreement (2948 mg) at an average intake of ~4500 mg or more (Figure 2B). For estimated usual potassium intake, individuals also fell outside the limits of agreement, but diet measures appeared to more consistently overestimate urine measures in the middle of the distribution (Figure 2D).

Demographic characteristics (race and age), BMI, urine measures (total 24-h urine volume and urinary creatinine), and dietary components [total caloric intake, weekend vs. weekday, and percentage of sodium or potassium from food groups (dairy, protein, mixed dishes, grains, fruit and vegetables, beverages, and other foods)] associated with the difference between sodium measures (dNa – uNa) are presented in Table 3. BMI in men was significantly associated with the difference in sodium measures, but race and age were not. Of the urine measures, after all of the covariates were controlled for, urine creatinine was significantly

TABLE 2
Spearman's correlations (ρ) and differences between dietary intake and adjusted urinary excretion of sodium and potassium by sex: Washington, DC, metropolitan area in 2011¹

| | <i>n</i> | Sodium | | | | Potassium | | | | | |
|---------------------------|----------|--------------------------|-------------------------|--------|-------------------------------|-----------------------|--------------|--------------|--------|-------------------------------|-----------------------|
| | | dNa, mg/d | uNa ₂ , mg/d | ρ | Difference, ³ mg/d | <i>P</i> ⁴ | dK, mg/d | uK, mg/d | ρ | Difference, ³ mg/d | <i>P</i> ⁴ |
| Men | 183 | 4827 ± 73.2 ⁵ | 3891 ± 31.5 | 0.16* | 936.8 (787.1, 1086.5) | — | 3277 ± 59.0 | 2706 ± 50.9 | 0.39** | 571.3 (448.3, 694.3) | — |
| Race | | | | | | | | | | | |
| African American | 89 | 4815 ± 105.8 | 3871 ± 50.8 | 0.13 | 943.8 (720.4, 1167.1) | Ref | 3273 ± 88.1 | 2503 ± 60.0 | 0.31** | 770.7 (591.8, 949.5) | Ref |
| Other | 94 | 4839 ± 102.0 | 3909 ± 38.3 | 0.20 | 930.2 (725.5, 1134.8) | 0.93 | 3280 ± 79.3 | 2898 ± 76.3 | 0.50** | 382.5 (219.3, 545.7) | 0.002 |
| Age category (y) | | | | | | | | | | | |
| 18–22 | 51 | 4811 ± 164.9 | 3868 ± 53.9 | 0.13 | 943.3 (610.2, 1276.5) | Ref | 3388 ± 111.7 | 2815 ± 102.1 | 0.39** | 573.3 (320.9, 825.6) | Ref |
| 23–29 | 72 | 4885 ± 104.6 | 3920 ± 51.4 | 0.29* | 965.2 (750.7, 1179.8) | 0.91 | 3174 ± 87.9 | 2651 ± 79.8 | 0.41** | 523.2 (343.9, 702.5) | 0.74 |
| 30–39 | 60 | 4772 ± 122.1 | 3875 ± 58.5 | 0.03 | 897.1 (631.7, 1162.4) | 0.83 | 3306 ± 110.2 | 2678 ± 86.1 | 0.35** | 627.3 (395.7, 858.9) | 0.75 |
| BMI category ⁶ | | | | | | | | | | | |
| Normal | 77 | 4963 ± 121.6 | 3815 ± 46.3 | 0.18 | 1148.3 (903.6, 1393.0) | Ref | 3389 ± 104.9 | 2672 ± 87.2 | 0.35** | 717.0 (492.4, 941.6) | Ref |
| Overweight | 66 | 4756 ± 125.6 | 3844 ± 45.7 | 0.2 | 912.1 (658.6, 1165.6) | 0.18 | 3201 ± 91.0 | 2689 ± 70.8 | 0.32** | 512.7 (330.6, 694.8) | 0.17 |
| Obese | 39 | 4657 ± 117.9 | 4122 ± 77.6 | 0.17 | 534.7 (279.9, 789.5) | 0.002 | 3183 ± 97.8 | 2823 ± 113.0 | 0.51** | 359.6 (156.8, 562.4) | 0.04 |
| Women | 219 | 3507 ± 47.7 | 3399 ± 35.8 | 0.25** | 108.3 (11.1, 205.4) | — | 2544 ± 34.0 | 2381 ± 32.8 | 0.29** | 163.4 (85.3, 241.5) | — |
| Race | | | | | | | | | | | |
| African American | 107 | 3550 ± 72.2 | 3441 ± 50.3 | 0.15 | 109.1 (–39.1, 257.3) | Ref | 2506 ± 53.3 | 2269 ± 41.9 | 0.10 | 236.9 (111.5, 362.3) | Ref |
| Other | 112 | 3466 ± 62.7 | 3359 ± 50.9 | 0.34** | 107.4 (–21.5, 236.3) | 0.99 | 2581 ± 42.7 | 2487 ± 48.3 | 0.44** | 93.2 (–1.6, 188.0) | 0.07 |
| Age category (y) | | | | | | | | | | | |
| 18–22 | 60 | 3470 ± 92.3 | 3341 ± 71.4 | 0.30* | 128.7 (–49.3, 306.7) | Ref | 2512 ± 68.1 | 2360 ± 71.8 | 0.37** | 152.7 (7.2, 298.1) | Ref |
| 23–29 | 87 | 3606 ± 68.0 | 3459 ± 57.1 | 0.33** | 146.5 (5.4, 287.5) | 0.88 | 2604 ± 47.6 | 2377 ± 45.1 | 0.36** | 226.9 (122.6, 331.2) | 0.40 |
| 30–39 | 72 | 3420 ± 90.9 | 3375 ± 60.0 | 0.16 | 45.1 (–151.8, 242.0) | 0.54 | 2498 ± 64.5 | 2402 ± 59.3 | 0.17 | 95.6 (–69.2, 260.4) | 0.61 |
| BMI category ⁶ | | | | | | | | | | | |
| Normal | 86 | 3502 ± 72.1 | 3288 ± 50.9 | 0.18 | 213.7 (59.4, 368.0) | Ref | 2590 ± 55.3 | 2377 ± 53.7 | 0.17 | 213.5 (77.1, 349.8) | Ref |
| Overweight | 52 | 3327 ± 83.6 | 3388 ± 64.1 | 0.28* | –60.7 (–237.4, 116.1) | 0.03 | 2444 ± 73.4 | 2376 ± 64.1 | 0.38** | 67.5 (–87.0, 222.0) | 0.17 |
| Obese | 77 | 3635 ± 91.5 | 3542 ± 69.3 | 0.30** | 93.1 (–87.4, 273.6) | 0.31 | 2561 ± 55.0 | 2405 ± 56.9 | 0.39** | 156.1 (29.6, 282.7) | 0.54 |

¹Best linear unbiased predictors derived from PC-SIDE (Software for Intake Distribution Estimation; Iowa State University) were used for dNa, uNa, dK, and uK in assessing correlations and differences. * $P < 0.05$ and ** $P < 0.01$ (2-sided P values for Spearman's correlation coefficient). dK, dietary potassium intake; Ref, reference; uK, urinary potassium excretion; uNa, urinary sodium excretion.

²Sodium excretion measures were corrected to account for 90% excretion of all sodium consumed (26, 35).

³Difference = dietary intake – urinary excretion.

⁴ P values from t test testing if the mean difference between measures was significantly different within categories of race, age, and BMI.

⁵Mean ± SE (all such values).

⁶BMI categories (in kg/m²): normal (18 to <25), overweight (25 to <30), and obese (≥ 30).

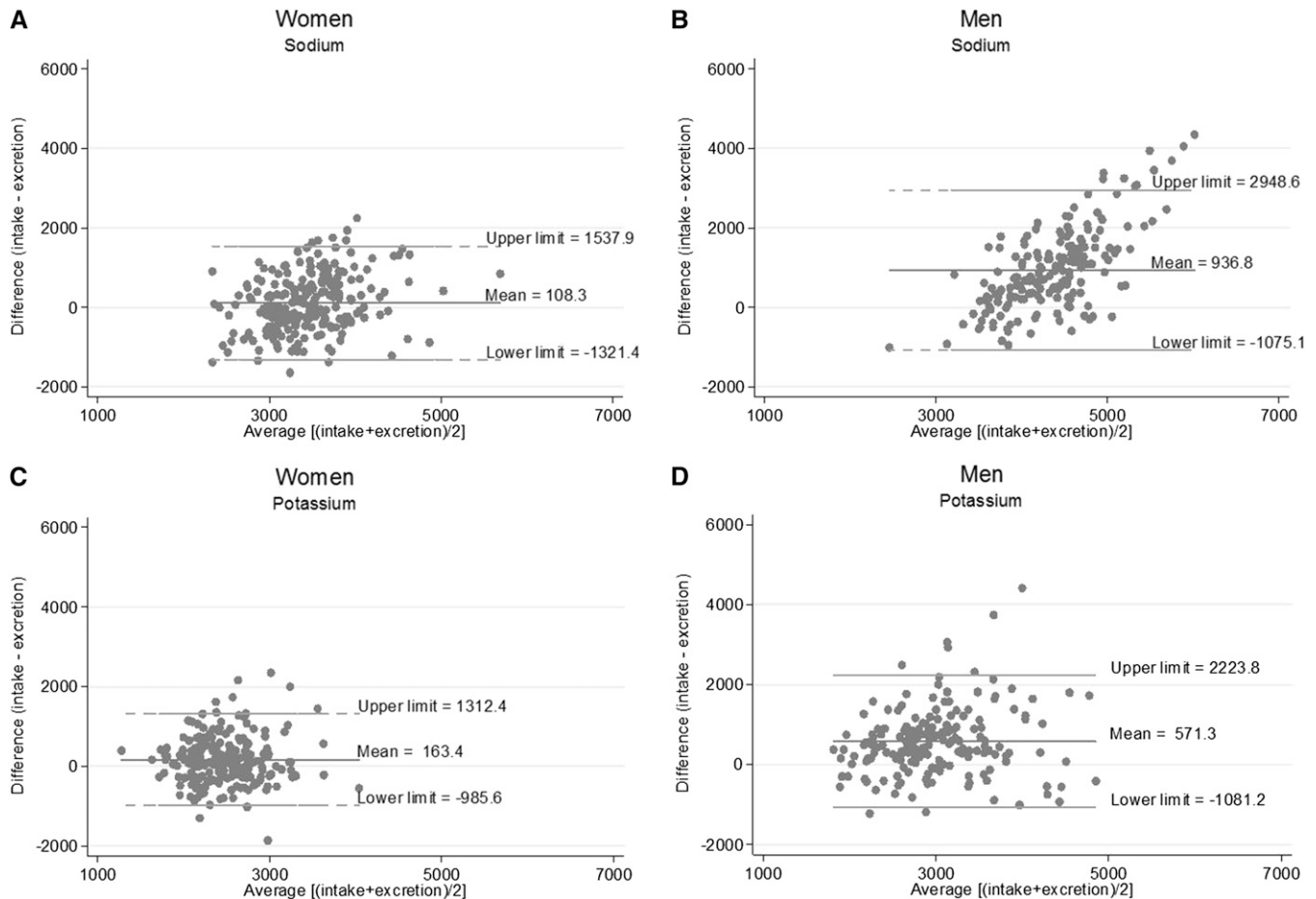


FIGURE 2 Bland-Altman graphs for assessing bias between dietary intake and urinary excretion measures for sodium and potassium: Washington, DC, metropolitan area in 2011. Shown are Bland-Altman graphs with mean differences and 95% limits of agreement (means \pm 1.96 SDs) for sodium in women (A) and men (B) and for potassium in women (C) and men (D).

associated with the difference in men and women as well as urine potassium in men. Most of the dietary components were significantly associated with the mean difference between sodium measures in men and women.

Results from the regression analysis testing the factors associated with the difference between potassium measures (dK – uK) are presented in **Table 4**. In the full model that adjusted for all covariates, measures significantly associated with the difference in potassium measures were race for both sexes and BMI in men. Similar to the sodium analysis, urine creatinine was significantly associated with the difference between potassium measures for men and women as well as with urine sodium for men. Many of the dietary components were significantly associated with the difference between potassium measures for men and women.

In the sensitivity analyses with the removal of all participants with potentially incomplete 24-h urine collections based on creatinine concentrations (31 men and 35 women), the results did not substantially change. Also, the results did not differ when removing those who were missing one void ($n = 7$) in their urine collection.

DISCUSSION

In this study in young adults (18–39 y), dNa and dK from 24-h dietary recalls were significantly greater than uNa and uK from

24-h urine collections. For sodium measures, the difference was small or nonsignificant in most subgroups of women. Sodium differences did not vary by race or age group but did vary by BMI, with greater differences between measures among those with a normal BMI. The differences between potassium measures were smaller than sodium differences for men but not for women. The magnitudes of the correlation coefficients were overall higher between potassium measures than were those for sodium.

Our findings of greater mean dNa and dK than uNa and uK were not anticipated. Although limited studies have compared sodium or potassium estimates from a 24-h dietary recall with 24-h urine collections, most have found mean estimates from urine collection to be greater than those from dietary recall (15, 17, 20, 23, 36–41). We would expect estimates to be greater from a biomarker because these are objective measures that capture nutrients from nondietary sources (water, supplements, and medication), and people are more likely to underreport diet due to recall bias (e.g., misreporting portion size, omitting foods that were consumed or salt added at the table) (42). One study in adults aged 30–69 y (37) using the same dietary method as in this study and another in postmenopausal women aged 50–79 (41) compared dietary estimates with those from 24-h urine collections and found that dNa estimates were <9% lower than uNa estimates. The study in postmenopausal women also considered

TABLE 3

Linear regression coefficients (β) from univariate and multivariate analyses of differences between dietary sodium intake and adjusted urinary sodium excretion according to demographic, diet, and biomarker covariates: Washington, DC, metropolitan area in 2011¹

| Difference as a dependent variable ² | Men (<i>n</i> = 183) | | | Women (<i>n</i> = 219) | | |
|---|-----------------------|----------------|----------|-------------------------|---------------|----------|
| | β | 95% CI | <i>P</i> | β | 95% CI | <i>P</i> |
| Univariate analysis | | | | | | |
| Race ³ | -13.6 | -314.4, 287.2 | 0.93 | -1.7 | -197.0, 193.6 | 0.99 |
| Age, ⁴ y | -3.8 | -31.8, 24.2 | 0.79 | -1.4 | -18.3, 15.5 | 0.87 |
| BMI, ⁴ kg/m ² | -47.7 | -68.9, -26.5 | <0.001 | -7.2 | -22.5, 8.2 | 0.36 |
| Total 24-h urine volume, ⁵ mL | 0.1 | -0.1, 0.3 | 0.34 | -0.05 | -0.2, 0.1 | 0.57 |
| Urinary potassium, mg/d | -0.1 | -0.3, 0.1 | 0.46 | -0.2 | -0.4, 0.03 | 0.09 |
| Urinary creatinine, mg/d | -0.4 | -0.7, 0.03 | 0.07 | -0.6 | -1.1, -0.2 | 0.007 |
| Total kilocalories | 1.2 | 1.0, 1.5 | <0.001 | 0.9 | 0.7, 1.0 | <0.001 |
| Percentage of sodium from ⁶ | | | | | | |
| Dairy | 0.8 | 0.4, 1.1 | <0.001 | 0.6 | 0.2, 0.9 | 0.001 |
| Protein | 0.3 | 0.2, 0.4 | <0.001 | 0.2 | 0.1, 0.3 | 0.001 |
| Mixed dishes | 0.3 | 0.2, 0.4 | <0.001 | 0.2 | 0.1, 0.3 | <0.001 |
| Grains | 0.4 | 0.3, 0.5 | <0.001 | 0.3 | 0.2, 0.4 | <0.001 |
| Fruit/vegetables | 0.4 | 0.1, 0.6 | 0.005 | 0.5 | 0.3, 0.7 | <0.001 |
| Beverages | 1.5 | 1.0, 2.0 | <0.001 | 0.7 | 0.3, 1.2 | 0.002 |
| Other foods | 0.6 | 0.2, 1.1 | 0.004 | 0.3 | -0.03, 0.6 | 0.07 |
| Weekend vs. weekday ⁷ | -119.0 | -427.7, 189.7 | 0.45 | -37.2 | -236.6, 162.3 | 0.71 |
| Full model | | | | | | |
| Race ³ | 23.7 | -107.6, 154.9 | 0.72 | 34.8 | -116.4, 186.0 | 0.65 |
| Age, ⁴ y | 7.7 | -2.6, 17.9 | 0.14 | -4.1 | -15.1, 6.9 | 0.47 |
| BMI, ⁴ kg/m ² | -20.9 | -32.6, -9.2 | 0.001 | -8.6 | -19.5, 2.3 | 0.12 |
| Total 24-h urine volume, ⁵ mL | -0.1 | -0.1, 0.02 | 0.17 | -0.1 | -0.3, 0.03 | 0.11 |
| Urinary potassium, mg/d | -0.2 | -0.3, -0.1 | 0.002 | -0.1 | -0.3, 0.04 | 0.13 |
| Urinary creatinine, mg/d | -0.3 | -0.5, -0.1 | 0.008 | -0.7 | -1.0, -0.3 | <0.001 |
| Total kilocalories | 0.4 | 0.2, 0.6 | <0.001 | 0.4 | 0.2, 0.6 | <0.001 |
| Percentage of sodium from ⁶ | | | | | | |
| Dairy | 0.4 | 0.3, 0.6 | <0.001 | -0.03 | -0.3, 0.3 | 0.85 |
| Protein | 0.3 | 0.3, 0.4 | <0.001 | 0.2 | 0.1, 0.3 | <0.001 |
| Mixed dishes | 0.4 | 0.3, 0.4 | <0.001 | 0.2 | 0.2, 0.3 | <0.001 |
| Grains | 0.4 | 0.4, 0.5 | <0.001 | 0.3 | 0.2, 0.4 | <0.001 |
| Fruit/vegetables | 0.4 | 0.2, 0.5 | <0.001 | 0.4 | 0.3, 0.5 | <0.001 |
| Beverages | 0.002 | -0.2, 0.2 | 0.98 | 0.7 | 0.3, 1.0 | <0.001 |
| Other foods | 0.5 | 0.3, 0.7 | <0.001 | 0.1 | -0.1, 0.4 | 0.29 |
| Weekend vs. weekday ⁷ | -259.6 | -389.8, -129.5 | <0.001 | -148.5 | -285.3, -11.7 | 0.03 |

¹Univariate analyses were linear regression models performed for each covariate (independent variable) and the difference (dependent variable). The multivariate model or the full model was one linear regression model with all covariates included. Best linear unbiased predictors derived from PC-SIDE (Software for Intake Distribution Estimation; Iowa State University) were used for dietary sodium intake (dNa) and urinary sodium excretion (uNa) in calculating the difference and for the covariates: urinary potassium, urinary creatinine, and total caloric intake. Sodium excretion measures were corrected to account for 90% excretion of all sodium consumed (26, 35).

²Difference between sodium measures = dietary sodium intake - urinary sodium excretion.

³The race variable was categorized as African American or other, with African American being the referent group.

⁴Continuous forms of age and BMI were used in the regression models.

⁵Total 24-h urine volume (mL) at the first visit was used in the regression analysis.

⁶Percentage of sodium from each food group (dairy, protein, mixed dishes, grains, fruit/vegetables, beverages, and other foods) was the proportion of total daily sodium from that food group.

⁷Weekend days were Friday, Saturday, and Sunday. Weekdays (Monday through Thursday) represented the referent group.

potassium and found that dK estimates were 12% higher than those of uK (41), a greater overestimation than that observed in the current study (dK estimates were 6% higher than uK among women), possibly due to differences in age and menopausal status of the study populations. The other study corrected for 86% excretion of all sodium consumed and observed greater correlation coefficients between sodium measures ($\rho = 0.18$ –

0.59) (37). The use of 86% excretion rather than the 90% in our study would increase the sodium intake estimates from uNa and therefore decrease the difference between measures in men and possibly increase the absolute difference in measures for women. The percentage of sodium and potassium excreted in urine was estimated from studies conducted >20 y ago with small study samples ($n < 20$) of non-Hispanic whites and did

TABLE 4

Linear regression coefficients (β) from univariate and multivariate analyses of differences between dietary potassium intake and urinary potassium excretion according to demographic, diet, and biomarker covariates: Washington, DC, metropolitan area in 2011¹

| Difference as a dependent variable ² | Men (n = 183) | | | Women (n = 219) | | |
|---|---------------|----------------|--------|-----------------|----------------|--------|
| | β | 95% CI | P | β | 95% CI | P |
| Univariate analysis | | | | | | |
| Race ³ | -388.1 | -628.6, -147.7 | 0.002 | -143.7 | -300.0, 12.5 | 0.07 |
| Age, ⁴ y | 3.7 | -18.2, 25.5 | 0.74 | -1.1 | -15.8, 13.6 | 0.88 |
| BMI, ⁴ kg/m ² | -19.8 | -41.1, 1.4 | 0.07 | -4.7 | -15.3, 5.9 | 0.39 |
| Total 24-h urine volume, ⁵ mL | -0.1 | -0.3, 0.1 | 0.27 | 0.02 | -0.1, 0.2 | 0.79 |
| Urinary sodium, mg/d | -0.6 | -0.9, -0.3 | <0.001 | -0.1 | -0.2, 0.03 | 0.13 |
| Urinary creatinine, mg/d | -0.4 | -0.8, -0.1 | 0.01 | -0.7 | -1.1, -0.4 | <0.001 |
| Total kilocalories | 0.9 | 0.7, 1.1 | <0.001 | 0.7 | 0.5, 0.8 | <0.001 |
| Percentage of potassium from ⁶ | | | | | | |
| Dairy | 0.3 | 0.1, 0.6 | 0.01 | 0.2 | -0.03, 0.4 | 0.09 |
| Protein | 0.4 | 0.2, 0.7 | 0.002 | 0.3 | 0.1, 0.5 | 0.01 |
| Mixed dishes | 0.3 | 0.1, 0.5 | 0.002 | 0.2 | 0.1, 0.3 | 0.003 |
| Grains | 0.3 | -0.03, 0.6 | 0.07 | 0.4 | -0.01, 0.7 | 0.06 |
| Fruit/vegetables | 0.2 | 0.01, 0.4 | 0.04 | 0.4 | 0.3, 0.5 | <0.001 |
| Beverages | 0.5 | 0.3, 0.7 | <0.001 | 0.5 | 0.2, 0.8 | 0.001 |
| Other foods | 0.5 | 0.2, 0.8 | 0.002 | 0.2 | -0.3, 0.7 | 0.41 |
| Weekend vs. weekday ⁷ | -19.7 | -280.8, 241.3 | 0.88 | -75.1 | -235.8, 85.5 | 0.36 |
| Full model | | | | | | |
| Race ³ | -337.3 | -501.8, -172.7 | <0.001 | -234.8 | -351.0, -118.5 | <0.001 |
| Age, ⁴ y | -0.6 | -13.7, 12.6 | 0.93 | -7.1 | -15.9, 1.6 | 0.11 |
| BMI, ⁴ kg/m ² | 17.5 | 2.6, 32.5 | 0.02 | 0.3 | -8.4, 9.0 | 0.95 |
| Total 24-h urine volume, ⁵ mL | 0.0 | -0.2, 0.1 | 0.49 | -0.03 | -0.1, 0.1 | 0.61 |
| Urinary sodium, mg/d | -0.4 | -0.6, -0.2 | <0.001 | -0.1 | -0.2, 0.03 | 0.15 |
| Urinary creatinine, mg/d | -0.5 | -0.8, -0.3 | <0.001 | -1.0 | -1.3, -0.7 | <0.001 |
| Total kilocalories | 0.6 | 0.3, 0.8 | <0.001 | 0.5 | 0.3, 0.6 | <0.001 |
| Percentage of potassium from ⁶ | | | | | | |
| Dairy | 0.3 | 0.1, 0.4 | 0.01 | 0.1 | -0.05, 0.2 | 0.22 |
| Protein | 0.3 | 0.2, 0.5 | <0.001 | 0.2 | -0.04, 0.3 | 0.11 |
| Mixed dishes | 0.3 | 0.1, 0.5 | 0.003 | 0.2 | 0.1, 0.3 | 0.004 |
| Grains | 0.03 | -0.3, 0.3 | 0.86 | 0.05 | -0.2, 0.3 | 0.66 |
| Fruit/vegetables | 0.1 | -0.02, 0.2 | 0.09 | 0.3 | 0.2, 0.4 | <0.001 |
| Beverages | 0.3 | 0.1, 0.5 | 0.002 | 0.3 | 0.1, 0.4 | 0.003 |
| Other foods | 0.4 | 0.2, 0.6 | <0.001 | 0.2 | -0.1, 0.4 | 0.25 |
| Weekend vs. weekday ⁷ | -64.8 | -228.1, 98.5 | 0.43 | -54.3 | -161.0, 52.4 | 0.32 |

¹Univariate analyses were linear regression models performed for each covariate (independent variable) and the difference (dependent variable). The multivariate model or the full model was one linear regression model with all covariates included. Best linear unbiased predictors derived from PC-SIDE (Software for Intake Distribution Estimation; Iowa State University) were used for dietary potassium intake (dK) and urinary potassium excretion (uK) in calculating the difference and for the covariates: urinary sodium, urinary creatinine, and total caloric intake.

²Difference between potassium measures = dietary potassium intake - urinary potassium excretion.

³The race variable was categorized as African American or other, with African American being the referent group.

⁴Continuous forms of age and BMI were used in the regression models.

⁵Total 24-h urine volume (mL) at the first visit was used in the regression analysis.

⁶Percentage of potassium from each food group (dairy, protein, mixed dishes, grains, fruit/vegetables, beverages, and other foods) was the proportion of total daily potassium from that food group.

⁷Weekend days were Friday, Saturday, and Sunday. Weekdays (Monday through Thursday) represented the referent group.

not investigate potential differences in excretion between sex, race, and BMI groups (25, 26, 35). Aside from the adjustment factors used, differences in age, race, and education of participants could explain some of the differences observed between this study and the study by Rhodes et al (36).

We found the difference between sodium and potassium estimates to be greater in men than in women and in those with a normal BMI compared with overweight or obese participants.

Possible explanations for these findings include measurement error in dietary or urine collection and physiologic reasons. Dietary measurement error reflects potential inaccuracy of the nutrient database used in this study to capture sodium or potassium contents of foods consumed by the participants and differential misreporting of dietary intake by sex and BMI. Although the nutrient database used was the most up-to-date one available at the time of the study, the percentages of sodium or

potassium from most of the 7 food groups considered in this study were significantly associated with the difference between measures. Because the source of each food (grocery store, restaurant, fast food, etc.) is not always considered in estimating the sodium content of each food in the nutrient database and ~60% of the sodium and 65% of potassium consumed by these participants were from foods purchased at the grocery store, it is possible that many of the foods were prepared at home or contained less sodium than the estimated amount. In addition, differential misreporting of dietary intake has been found by sex and BMI, with women more accurately reporting total dietary intake than men and overweight and obese participants more often underreporting intake compared with those with a normal BMI (14, 36). This may explain why men showed a much greater difference between measures than did women and the directionality of the difference between BMI categories.

It is also possible that the 24-h urine collections were incomplete, because it is very difficult to collect all urine in a 24-h period and we relied on self-report of urine collection completion from participants. When considering total 24-h urine volume and urinary creatinine as proxies for assessing completeness of 24-h urine collections, urinary creatinine was associated with the difference between sodium as well as potassium measures after adjustment for covariates (Tables 3 and 4). It is possible that we observed better agreement between measures in overweight and obese women because they are more likely to underreport diet along with the potential of incomplete urine collections. However, it is important to note that in our sensitivity analysis the results did not change after excluding those with potentially incomplete urine collections based on creatinine concentrations or when excluding those who reported missing any partial or whole voids.

A physiologic possibility that may explain some of the findings is the potential amount of sodium that could have been lost in sweat. Estimates of the amount of sodium excreted in urine and how much could be lost in sweat are variable (43, 44). A study reported that as much as 33–57% of sodium consumed could be lost in sweat, depending on climate and amount of physical activity (45). This study was conducted during the summer months in the Washington, DC, metropolitan area and a greater than anticipated proportion of sodium could have been lost in sweat, possibly explaining why dNa was greater than uNa. In addition, men and those with a normal BMI in this study might have been more physically active because of occupation or lifestyle than women and those who were overweight or obese (46), accounting for the greater difference between sodium measures observed in these subgroups. Furthermore, differences in the excretion of uK between racial groups were previously documented (47–49), yet differential correction factors for the percentage of extrarenal potassium loss have not been estimated, and in this study we used the same correction factor of 77% of potassium consumed is excreted in urine for all participants.

This study is subject to some limitations. First, dietary recall measured the diet for the same 24-h period during which urine was collected. Because the half-life of sodium in the body is ~24 h (50, 51) and is 16 d for potassium (52), the urinary sodium and potassium collected in this study may not be representative of the dietary sodium measured because measures do not correspond to the same reference period. Furthermore, participants may have changed their eating and drinking patterns during the

measurement period because they knew that their diet and urine would be assessed. Our method attempted to address these issues by calculating usual estimates and only using those assessments. However, the correlation coefficients and mean differences between measures were not greatly different when considering only 1-d measures as opposed to the usual sodium estimates (Supplemental Table 1). On average, correlations and mean differences did not differ greatly between the usual estimates and the 1-d values. Another limitation is the number of repeated measures in this study, which was less than that required to accurately estimate individual intakes. Studies show that ≥ 4 repeated measures are needed to capture individual intake estimates (53). Furthermore, a recent study reported that even at a constant sodium intake, individual day-to-day variability in uNa was large and a 24-h urine collection may not accurately estimate dNa at the individual level (43). Therefore, individual correlations between sodium measures were low due to attenuation that was attributable to measurement error. Also, data on potential confounders for the difference between diet and urine measures, such as physical activity, education attainment, or income, were not collected or considered in this study. In addition, the difference between measures is potentially larger than what was observed in this study due to the unmeasured dietary use of sodium and potassium from supplements or use of salt added at the table. Finally, measurement error from both 24-h dietary recall and urine collection could have influenced the results of this study in other ways.

Strengths of the current study include a racially diverse sample of young adults; the estimation of usual sodium and potassium measures by nutrient distribution estimation software (PC-SIDE), accounting for non-normal distributions and within-person variability in intake; and investigation of factors associated with the difference between sodium and potassium measures through regression modeling. Contrary to previous studies, self-reported sodium and potassium intakes from 24-h dietary recalls were higher than intakes estimated from excretion. Although individual correlations between measures were low, at the population level intake estimates from 24-h dietary recall and urine collection did not differ significantly for women. Although more research is needed to understand differences in measures of sodium and potassium intakes among young adults, future studies should consider stratifying their findings by sex and BMI when assessing sodium consumption as an exposure as well as by race for potassium consumption investigations or include these factors in calibration equations to estimate sodium and potassium intake.

The authors' responsibilities were as follows—CIM, MEC, ALV, C-YW, CML, AJM, DGR, and ALC: designed the study; MEC, C-YW, and CML: designed the sodium calibration study; C-YW: conducted the sodium calibration study research; AJM and DGR: provided essential nutritional coding for dietary data; ALC: provided statistical guidance for this study; and CIM: analyzed the data, wrote the manuscript, and has primary responsibility for the final content. All of the authors read, reviewed, and approved the final manuscript. None of the authors had a conflict of interest.

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