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Estimating the Population Distribution of Usual 24-Hour Sodium Excretion from Timed Urine Void Specimens Using a Statistical Approach Accounting for Correlated Measurement Errors[1–4]

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Abstract

Background: High US sodium intake and national reduction efforts necessitate developing a feasible and valid monitoring method across the distribution of low-to-high sodium intake.

Objective: We examined a statistical approach using timed urine voids to estimate the population distribution of usual 24-h sodium excretion.

Methods: A sample of 407 adults, aged 18–39 y (54% female, 48% black), collected each void in a separate container for 24 h; 133 repeated the procedure 4–11 d later. Four timed voids (morning, afternoon, evening, overnight) were selected from each 24-h collection. We developed gender-specific equations to calibrate total sodium excreted in each of the one-void (e.g., morning) and combined two-void (e.g., morning + afternoon) urines to 24-h sodium excretion. The calibrated sodium excretions were used to estimate the population distribution of usual 24-h sodium excretion. Participants were then randomly assigned to modeling (n = 160) or validation (n = 247) groups to examine the bias in estimated population percentiles.

Results: Median bias in predicting selected percentiles (5th, 25th, 50th, 75th, 95th) of usual 24-h sodium excretion with one-void urines ranged from −367 to 284 mg (−7.7 to 12.2% of the observed usual excretions) for men and −604 to 486 mg (−14.6 to 23.7%) for women, and with two-void urines from −338 to 263 mg (−6.9 to 10.4%) and −166 to 153 mg (−4.1 to 8.1%), respectively. Four of the 6 two-void urine combinations produced no significant bias in predicting selected percentiles.

Conclusions: Our approach to estimate the population usual 24-h sodium excretion, which uses calibrated timed-void sodium to account for day-to-day variation and covariance between measurement errors, produced percentile estimates with relatively low biases across low-to-high sodium excretions. This may provide a low-burden, low-cost alternative to 24-h collections in monitoring population sodium intake among healthy young adults and merits further investigation in other population subgroups. This study was registered at clinicaltrials.gov as NCT01631240. *J Nutr* doi: 10.3945/jn.114.206250.

Keywords: sodium, population distribution, nutrition survey, calibration, 24-hour urine collection, timed urine void, usual sodium intake

Introduction

High sodium intake increases the risk of cardiovascular diseases (1), the leading cause of death in the United States (2). Reducing average daily US population sodium consumption by approximately one-third is projected to avert up to 92,000 deaths and save up to 24 billion health care dollars annually (3). Federal and private sector efforts toward this goal (4) necessitate a feasible and accurate method to monitor sodium in the US population across the distribution of low-to-high intakes. The Institute of Medicine and the Pan American Health Organization recommend

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[3] The findings and conclusions in this manuscript are those of the authors and do not necessarily represent the official position of the CDC, the NIH, or any other entity of the US government.
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[4] Supplemental Methods, Supplemental Tables 1 and 2, and Supplemental Figures 1–6 are available from the "Online Supporting Material" link in the online posting of the article and from the same link in the online table of contents at http://jn.nutrition.org.

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the measurement of a single 24-h sodium excretion as the gold standard for assessment of mean population sodium intake (5, 6), but collecting 24-h urine in population surveys is logistically complex, burdensome, and costly. Furthermore, unaccounted within-person variation in individual sodium intake from day-to-day can lead to biased estimates of the prevalence of high sodium intake at the population level (1, 7). Estimating sodium intake from timed urine voids could provide a less burdensome and lower cost option. Yet, data are limited on the validity of this approach, particularly among blacks, who may have different diurnal patterns of sodium excretion compared with whites (8, 9). Most previous studies focus on the correlation between a single 24-h urine and spot urine measurements at an individual level, or the spot urine's utility in estimating population mean sodium intake. Using timed urine voids to monitor population distributions and percentiles of usual sodium excretion accounting for day-to-day variability in intake has not been explored (10).

We previously reported the day-to-day variation in 24-h and single-void sodium excretion and the correlations between them from a study among adults aged 18–39 y living in the Washington, DC, metropolitan area (11, 12). Based on data from this study, we also evaluated the validity of published equations for predicting group mean 24-h sodium excretion (12). One of the main objectives of the study was to develop calibration equations to estimate the population distribution of usual 24-h sodium excretion with use of timed urine voids. To address this objective, here we *1*) modeled the expected usual 24-h sodium excretion with use of data from 1 or 2 timed urine voids, *2*) evaluated the utility of the calibrated sodium excretion in estimating the population distribution of usual 24-h sodium excretion by gender and timing of urine void collections, and *3*) examined the performance of using more than one urine void per day in estimating the distribution over low-to-high percentiles of sodium intake. We also conducted validation analyses to further assess this approach.

Methods

Study participants and setting. In 2011 500 volunteers aged 18–39 y living in the Washington, DC, metropolitan area were screened for participation in a study requiring 24-h urine collection. We stratified recruitment by gender and race to yield an equal number of men and women and ~50% blacks within each gender. Questions were asked in an attempt to recruit an enhanced sample of 50 participants with a low sodium intake and 50 with a high sodium intake. We excluded persons for whom sodium excretion might be altered because of physiologic factors or disease status, including pregnant women or women trying to get pregnant, and persons who reported taking loop diuretics, with chronic kidney disease, or with new or modified hypertension treatment in the past 2 wk. Of those screened, 481 were scheduled for an initial visit and 407 completed urine collection. We defined completion as a total urine volume >500 mL, a recorded collection length of ≥20 h, and no reports of spilling urine nor missing void more than once during the collection. Among participants with a complete 24-h urine collection, 133 (33%) completed a second 24-h urine collection 4–11 d later. A detailed description of the study design and characteristics of the participants are published elsewhere (11). The study protocol was approved by the National Center for Health Statistics Ethics Review Board. All participants gave written informed consent.

On the morning of the starting day, upon rising, participants were asked to discard the first void and then collect each subsequent urine void over the next 24-h period. They were encouraged to follow their usual daily routine and were not required to pass urine at any specific time. Participants were instructed to collect each void using a separate container and to record the time of each void. Urines were kept cold until portioned into aliquots. A composite 24-h urine sample was prepared by taking a proportional aliquot from each void. In addition, 4 timed urine voids were selected: *1*) a morning specimen, the first void collected between 0830 and 1230, *2*) an afternoon specimen, the first void between 1231 and 1730, *3*) an evening specimen, the first void between 1731 and 2359, and *4*) an overnight specimen, the first void after the longest period of sleep and between 0400 and 1200 the next morning. These times parallel the timing of urine specimens currently collected in the NHANES (13), the primary data system used to monitor health and nutritional status in the United States.

A 1-mL aliquot was taken from the composite 24-h urine sample and from each of the 4 timed urine void specimens. All aliquots were shipped frozen on dry ice within 7 d of collection to the CDC's National Center for Environmental Health for analysis. Sodium was analyzed with use of ion-selective electrodes and the Cobas ion-selective electrode/Na^+, K^+, Cl^- assay on the Hitachi Modular P clinical analyzer (Roche Diagnostics). Creatinine was analyzed with use of the Roche Creatinine Plus enzymatic assay on the Hitachi Modular P clinical analyzer. Each analytical run included 100 study samples and 2 levels of commercially prepared urine quality-control materials measured at the beginning and end of the run bracketing the study samples. The between-run measurement imprecision for sodium was 0.8–0.9% and 1.1–1.5% for creatinine (11).

Black participants were identified by the question "Do you consider yourself to be black or African American?" during screening. No information on other races or ethnicities was collected; participants of races other than black were grouped as "other races" in the analysis. Weight and height were measured with use of the standard NHANES protocol (14) and were used to calculate BMI as weight in kilograms divided by squared height in meters.

Statistical analysis. We calculated the amount of sodium and creatinine in each urine specimen by multiplying the individual concentrations of each specimen by the corresponding volume. The volume of the 24-h urine collection was adjusted for self-reported collection time [(total volume collected/self-reported collection time) × 24].

Gender-specific equations were developed to calibrate an individual's sodium excretion from a timed urine void to the person's expected usual 24-h sodium excretion with use of Fuller's error-in-the-equation measurement error model (EEM) (15). We assumed the observed 24-h sodium excretion (Y_{ij}) and timed-void sodium excretion (X_{ij}) for person i on the jth day were equal to the person's usual 24-h sodium excretion (y_i) or usual sodium excretion from the same urine void (x_i) plus an error term for that individual on that day, so that

$$Y_{ij} = y_i + u_{ij} \quad (1)$$

and

$$X_{ij} = x_i + q_{ij}, \quad (2)$$

Where u_{ij} and q_{ij} represented the deviations of the observed short-term measurements from their expected usual values. We assumed that these 2 error terms were jointly normally distributed as the following:

$$\begin{bmatrix} u_{ij} \\ q_{ij} \end{bmatrix} \sim N_2\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_{uu} & \sigma_{uv} \\ \sigma_{uv} & \sigma_{vv} \end{bmatrix}\right) \quad (3)$$

Here, σ_{uu} and σ_{vv} were the within-person variances in 24-h sodium excretion and timed-void sodium excretion, respectively, and σ_{uv} was the covariance between the errors in the observed 24-h and timed-void sodium excretions. Using the EEM approach, we modeled these 2 correlated error terms and expressed the association of person i's usual 24-h sodium excretion (y_i) with the person's observed sodium excretion from a urine void specimen on the jth day (X_{ij}) in conjunction with the person's timed-void urine creatinine value (C_{ij}) and other covariates ($\mathbf{Z}_i$) as the following:

$$y_i = \theta_0 + \theta_1 X_{ij} + \theta_2 C_{ij} + \theta_3 \mathbf{Z}_i + e_i \quad (4)$$

In this model, θ_0 was the intercept, θ_1 and θ_2 were the regression slopes of expected usual 24-h sodium excretion on timed-void sodium and

creatinine excretions, respectively, θ_3 was the 3-dimensional coefficient vector associated with the 3 covariates (i.e., race, age, and BMI) in the model, and e_i was the equation error. For detailed methods used in estimating the slope and variance components of the model, see the **Supplemental Methods**.

With the above model, we calibrated each participant's sodium excretion from each of the 4 one-void urines (i.e., morning, afternoon, evening, and overnight) and 6 combined two-void urines (i.e., morning + afternoon, morning + evening, morning + overnight, afternoon + evening, afternoon + overnight, and evening + overnight) to the expected usual 24-h sodium excretion. We used these calibrated sodium excretion values from each individual to estimate the population distribution of usual sodium excretion with use of software for intake distribution estimation (PC-SIDE) (version 1.0; Iowa State University). The software was used to estimate the population percentiles of usual 24-h sodium excretion by gender and the timing of urine void collection, accounting for between- and within-person variation and the day of the week of the urine collection (16).

The question of interest is whether the distribution of usual 24-h sodium excretion can be adequately approximated when using calibrated urine measurements from timed voids in place of observed 24-h urine. To evaluate this, we further examined the concordance between observed and estimated distributions of usual 24-h sodium excretion for selected percentiles: the 5th, 25th, 50th, 75th, and 95th percentiles. We first computed the sodium excretion values corresponding to the selected percentiles in the observed usual distributions for males and females separately. We then calculated these values' corresponding percentile estimates in the estimated usual sodium distributions from timed urine voids.

To test the validity of our approach, we randomly (stratified by gender and availability of the second 24-h urine collection) assigned participants to a modeling (n = 160) or a validation (n = 247) group (**Supplemental Figure 1**). We repeated this protocol to yield 100 different pairs of modeling-validation groups through bootstrapping. For each pair, we used data from the modeling group to develop the calibration equations with the EEM approach described above. The resulting coefficients were applied to the individuals in the corresponding validation group to estimate their 24-h sodium values. The validation group's calibrated 24-h sodium excretion values obtained from timed urine voids were then used to estimate the population percentiles of usual sodium excretion. We compared the estimated population percentiles to the observed population distribution. The observed population distribution in the validation analyses was derived from the validation group's 24-h urine collections with use of PC-SIDE. This comparison process was repeated 100 times, once for each of the bootstrapping modeling-validation pairs. We calculated the bias of the percentiles estimates as the difference between the estimated and observed percentiles of usual 24-h sodium excretion by gender and the timing of spot urine collections. To express the bias within the context of the magnitude of usual excretion, we also calculated the relative bias as the bias divided by the observed percentile.

In addition to using PC-SIDE to estimate the population distribution, we used R statistical software, version 2.12.1 (R Foundation for Statistical Computing), to fit the EEM models. Other statistical analyses in this report were conducted with use of SAS, version 9.2 (SAS Institute). P values < 0.05 were considered statistically significant.

Results

Regression coefficients from EEM models calibrating sodium excretion from timed urine voids to the expected 24-h sodium excretion for individuals based on all 407 participants (133 of whom had two 24-h urine collections) are presented in **Table 1** by gender and the timing of urine void collections. For both men and women, timed-void sodium excretion and BMI were significantly and positively associated with the expected individual 24-h sodium excretion across the different times and combinations of single-void urine specimens. Creatinine excretions from urine voids were consistently negatively associated with the expected 24-h sodium excretion, although the association was not always statistically significant. Neither race nor age (except age in females, overnight void, P = 0.03) was significantly associated with the expected 24-h sodium excretion.

The EEM-calibrated sodium excretion from 4 one-void and 6 two-void combined urines were used to estimate the population distribution of usual sodium excretion. The observed and estimated population means and medians are presented in **Supplemental Table 1** by gender, race, and the timing of urine void collection. The percentile distributions of observed and estimated usual 24-h sodium excretion are illustrated for selected urine voids and combinations in **Figure 1** and **Supplemental Figures 2–6** for males and females. Across the timing of urine void collections and the distribution of usual 24-h sodium excretion, two-void combinations consistently presented closer estimates with the percentiles estimated from observed 24-h urines than one-void urines.

To further examine the concordance between observed and estimated distributions, we produced percentile estimates for selected sodium values based on observed usual 24-h sodium excretion and usual distributions estimated from calibrated urine voids by gender (**Table 2**). For males, the 25th percentile of the usual sodium excretion based on observed 24-h urine (3070 mg) corresponded to the 14th–31st percentile of the distributions estimated using the calibrated one-void urines and the 22nd–31st percentile using combined two-void urines. At the other end of the distribution, the 75th percentile of the observed usual 24-h sodium excretion (3950 mg) corresponded to the 78th–85th percentile of the distributions estimated using one-void urines and the 74th–83rd using two-void urines. For females, the 25th percentile of usual sodium excretion based on the observed 24-h urines (2560 mg) corresponded to the 7th–25th percentile estimated using one-void urines and the 18th–29th using two-void urines. The 75th percentile of observed usual sodium excretion (3520 mg) corresponded to the 81st–88th percentile estimated using one-void urines and the 75th–78th using two-void urines.

Validation analyses. To evaluate the validity of our approach, we split study participants into modeling or validation subgroups: the performance of calibration equations developed from modeling groups was tested with use of data from validation groups. Participant characteristics such as age, race, BMI, and sodium and creatinine excretions were similar between the modeling and validation groups across the 100 bootstrapping pairs (**Supplemental Table 2**). Among the 100 validation groups, median bias in predicting selected population percentiles of usual 24-h sodium excretions ranged from −367 to 284 mg for males and −604 to 486 mg for females with use of calibrated one-void urines, which was ∼−7.7 to 12.2% and −14.6 to 23.7% of the observed percentiles of usual excretions, respectively (**Figure 2**). Using calibrated two-void urines, the median bias between estimated and observed percentiles ranged from −338 to 263 mg for males and −166 to 153 mg for females, which was equivalent to the median relative bias of −6.9 to 10.4% and −4.1 to 8.1%, respectively (**Figure 3**).

With one-void urines, most percentile estimates (18 out of 20 for males, 16 out of 20 for females) produced median relative bias <10% of the observed usual excretions in these validation analyses (Figure 2). Across different spots, the relative biases showed larger variation for estimates at the tails of the distribution (i.e., 5th, 95th percentiles). For males, IQR of all but 2 median relative biases included zero (no bias). For females, only half of the percentile estimates produced by one-void urines had median relative bias with IQRs including zero. The overnight specimen produced unbiased estimates (relative biases with IQRs

TABLE 1 EEM model parameters for calibrating individual sodium excretion from timed urine voids to expected usual 24-h sodium excretion by gender and the timing of urine void collection: overall study sample[1]

	Male						Female					
	β_0	Timed-void sodium, mg	Race	Age, y	Timed-void creatinine, mg	BMI, kg/m^2	β_0	Timed-void sodium, mg	Race	Age, y	Timed-void creatinine, mg	BMI, kg/m^2
Morning												
β	1150	2.69	35	1.0	−3.4	69.0	1570	2.23	106	−10.4	−2.27	41.2
SE	—	0.41	179	15.7	0.82	14.9	—	0.68	181	13.6	2.14	12.0
P	—	<0.01	0.85	0.95	<0.01	<0.01	—	<0.01	0.56	0.45	0.29	<0.01
Afternoon												
β	1130	1.25	180	−19.8	−0.52	83.7	1500	2.99	−113	−2.4	−2.63	24.8
SE	—	0.47	181	16.1	1.19	16.6	—	0.29	137	10.9	0.78	9.6
P	—	<0.01	0.32	0.22	0.66	<0.01	—	<0.01	0.41	0.83	<0.01	0.01
Evening												
β	580	3.02	76	−5.3	−3.08	82.4	1610	2.83	−99	−5.8	−2.77	30.6
SE	—	0.76	164	14.5	1.37	14.5	—	0.29	136	11.0	0.75	10.4
P	—	<0.01	0.64	0.71	0.03	<0.01	—	<0.01	0.46	0.6	<0.01	<0.01
Overnight												
β	1190	1.77	97	−13.0	−0.65	60.3	2470	2.41	−71	−23.0	−2.93	24.6
SE	—	0.43	151	13.8	0.81	14.0	—	0.27	129	10.5	0.77	9.3
P	—	<0.01	0.52	0.35	0.42	<0.01	—	<0.01	0.58	0.03	<0.01	<0.01
Morning + afternoon												
β	820	1.63	60	−6.9	−1.66	76.2	990	2.21	95	−2.5	−1.97	29.8
SE	—	0.24	169	14.8	0.52	14.2	—	0.24	152	11.9	0.57	10.6
P	—	<0.01	0.72	0.64	<0.01	<0.01	—	<0.01	0.53	0.83	<0.01	<0.01
Morning + evening												
β	850	2.37	−22	1.6	−2.67	61.7	1100	2.42	2	−0.6	−3.05	35.2
SE	—	0.29	162	14.1	0.59	13.7	—	0.26	147	11.6	0.71	10.8
P	—	<0.01	0.89	0.91	<0.01	<0.01	—	<0.01	0.99	0.96	<0.01	<0.01
Morning + overnight												
β	880	1.95	67	2.8	−1.59	50.2	2440	1.97	−33	−20.8	−3.33	30.5
SE	—	0.23	154	13.6	0.48	13.6	—	0.21	139	11.1	0.71	9.7
P	—	<0.01	0.67	0.84	<0.01	<0.01	—	<0.01	0.81	0.06	<0.01	<0.01
Afternoon + evening												
β	860	1.54	79	−16.0	−1.71	85.7	1050	2.36	−135	5.9	−2.32	19.7
SE	—	0.26	157	14.0	0.59	14.6	—	0.19	125	10.0	0.49	9.1
P	—	<0.01	0.62	0.25	<0.01	<0.01	—	<0.01	0.28	0.56	<0.01	0.03
Afternoon + overnight												
β	970	1.57	78	−14.5	−1.00	60.6	1940	2.02	−134	−11.0	−2.43	17.6
SE	—	0.26	142	12.9	0.53	13.7	—	0.13	110	8.8	0.40	7.8
P	—	<0.01	0.58	0.26	0.06	<0.01	—	<0.01	0.22	0.21	<0.01	0.03
Evening + overnight												
β	680	1.14	128	−6.8	−0.27	61.6	2040	2.01	−132	−14.8	−2.68	25.1
SE	—	0.33	148	13.4	0.74	14.2	—	0.15	113	9.2	0.41	8.3
P	—	<0.01	0.39	0.61	0.72	<0.01	—	<0.01	0.25	0.11	<0.01	<0.01

[1] Based on overall study sample, combining modeling and validation groups. The race variable was coded as "0" (black) and "1" (other races). All other variables in the models were fit as continuous variables. EEM, error-in-the-equation measurement error model.

including 0%) across all selected population percentiles for males and in 4 out of 5 selected population percentiles for females.

Using two-void urine combinations, 88% (53 out of 60) of the percentile estimates produced median relative bias <5% of the observed usual excretions (Figure 3). The morning + afternoon, morning + evening, morning + overnight, and evening + overnight combinations all produced unbiased estimates across all selected percentiles for both males and females (Figure 3).

Discussion

In this study, we developed a new approach to estimate the usual distribution of 24-h sodium excretion at the population level, using calibrated sodium excretion from timed urine voids while accounting for day-to-day variation and covariance between measurement errors in timed-void and 24-h urine collections. The estimated sodium excretion distributions are fairly consistent with the observed usual distribution of 24-h sodium excretion across urine voids collected at different times of the day for both men and women. In general, the estimated usual distribution curves from a two-void urine combination (e.g., evening + overnight) were more consistent with the observed usual sodium excretion distribution, compared to curves estimated from the one-void urines (e.g., evening), especially for the tails of the distributions and among women (Figure 1, Supplemental Figures 2–6). Using a morning + afternoon, morning + evening, morning + overnight, or evening +

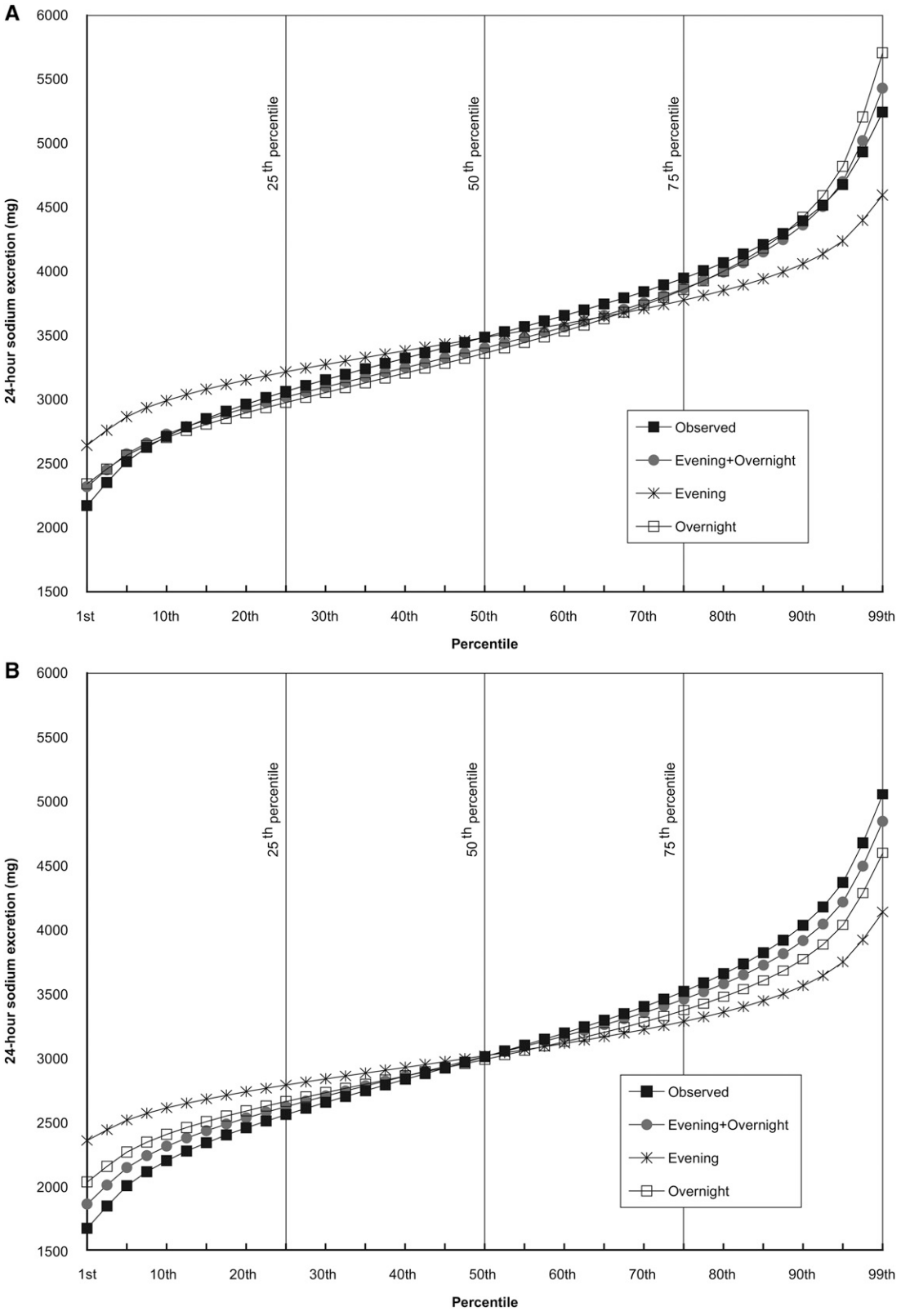

FIGURE 1 Population distributions of usual 24-h sodium excretion: observed vs. estimated from evening, overnight, or evening-overnight combination specimens for males (A) and females (B) aged 18–39 y. The observed population usual distribution of 24-h sodium excretion was derived with use of 24-h urine collections from the overall study sample (i.e., all 407 participants; 274 with one and 133 with two 24-h urine collections). The estimated usual 24-h sodium excretions were derived with use of calibrated sodium excretions from urine voids collected in the evening, overnight, or the combination of evening and overnight specimens. All observed and estimated population usual sodium excretion distributions were adjusted for day-to-day variation in excretion and day of the week.

TABLE 2 Concordance between observed and estimated percentiles of usual 24-h sodium excretion by gender and the timing of urine void collection: overall study sample

	Male						Female					
		Percentile estimates for the specified sodium excretion,[1] mg						Percentile estimates for the specified sodium excretion,[2] mg				
	n	2520	3070	3490	3950	4680	*n*	2000	2560	3010	3520	4370
Observed percentile	186	5	25	50	75	95	221	5	25	50	75	95
Estimated percentile[3]												
Morning	155	3.5 ± 4.1	22.9 ± 7.4	52.3 ± 4.8	78.6 ± 7.5	95.2 ± 4.9	195	0	11.2 ± 5.7	50.4 ± 4.0	84.5 ± 6.1	98.8 ± 1.7
Afternoon	179	0.7 ± 0.8	21.4 ± 4.6	57.3 ± 3.7	82.7 ± 4.5	96.3 ± 2.4	215	1.2 ± 1.3	24.8 ± 4.8	56.8 ± 3.7	81.3 ± 5.0	96.4 ± 2.7
Evening	182	0.3 ± 2.4	13.9 ± 22.4	50.2 ± 7.4	85.3 ± 22.5	99.3 ± 4.2	221	0	7.0 ± 11.9	49.2 ± 5.8	88.3 ± 14.1	99.6 ± 1.8
Overnight	186	3.7 ± 2.9	30.6 ± 4.8	57.4 ± 4.0	78.2 ± 5.2	93.6 ± 3.8	221	0.8 ± 1.3	18.2 ± 6.6	51.6 ± 4.1	81.8 ± 6.6	98.0 ± 2.5
Morning + afternoon	150	2.5 ± 4.3	23.7 ± 9.1	53.1 ± 5.4	79.4 ± 9.4	96.5 ± 5.2	188	3.6 ± 3.3	25.5 ± 5.7	52.7 ± 4.0	77.1 ± 5.9	95.1 ± 3.9
Morning + evening	153	7.6 ± 7.6	29.4 ± 8.1	52.2 ± 5.3	73.8 ± 8.6	92.7 ± 7.4	195	3.8 ± 3.9	23.0 ± 6.7	48.7 ± 4.2	74.5 ± 6.5	94.9 ± 4.6
Morning + overnight	155	6.7 ± 5.8	30.8 ± 6.6	54.9 ± 4.9	75.8 ± 7.3	92.9 ± 5.9	194	1.9 ± 2.6	18.0 ± 7.0	47.1 ± 4.3	77.9 ± 6.8	97.4 ± 3.2
Afternoon + evening	176	1.4 ± 3.4	21.8 ± 10.6	54.7 ± 5.7	83.1 ± 10.9	98.1 ± 4.2	215	4.6 ± 4.5	26.8 ± 6.5	53.3 ± 4.3	77.4 ± 6.9	95.3 ± 4.6
Afternoon + overnight	179	4.2 ± 5.0	30.0 ± 7.1	58.0 ± 5.2	80.4 ± 8.2	95.6 ± 5.2	215	5.8 ± 2.9	29.4 ± 4.0	54.7 ± 3.4	76.8 ± 4.2	94.1 ± 3.0
Evening + overnight	183	3.6 ± 3.5	27.8 ± 5.8	55.3 ± 4.3	78.3 ± 6.2	94.8 ± 4.2	221	2.4 ± 3.2	21.4 ± 7.0	49.9 ± 4.2	77.7 ± 7.0	96.6 ± 3.9

[1] Sodium values used (i.e., 2520, 3070, 3490, 3950, and 4680 mg) correspond to the 5th, 25th, 50th, 75th, and 95th percentile, respectively, of observed usual 24-h sodium excretion, derived from PC-SIDE, among male participants in the overall study sample, combining modeling and validation groups. PC-SIDE, software for intake distribution estimation.

[2] Sodium values used (i.e., 2000, 2560, 3010, 3520, and 4370 mg) correspond to the 5th, 25th, 50th, 75th, and 95th percentile, respectively, of observed usual 24-h sodium excretion, derived from PC-SIDE, among female participants in the overall study sample, combining modeling and validation groups.

[3] Values are percentile estimates ± SEs.

overnight two-void combination, the current approach produced the 5th, 25th, 50th, 75th, and 95th percentile estimates of the population distribution of usual 24-h sodium excretion for both men and women aged 18–39 y with no significant bias. Therefore, these two-void combination specimens may be optimal urine void choices in monitoring population sodium distributions, at least among healthy young adults.

Previous studies have developed predictive equations to estimate population mean and individual 24-h sodium excretion from spot urine specimens (7, 17–28), however, we found no study that produced population percentile estimates adjusting for measurement error. In our study, we used a second-day collection of 24-h urine and timed urine voids from a subset of participants to account for within-person day-to-day variation and to model correlated measurement errors between usual 24-h and usual timed-void sodium excretions. This approach allowed us to produce population percentile estimates throughout the distribution with consistently low bias. The ability to produce low biased estimates for the tail of the population distribution is important in monitoring the population sodium intake, given that ~90% of the US population consumes sodium in excess of recommendations (29).

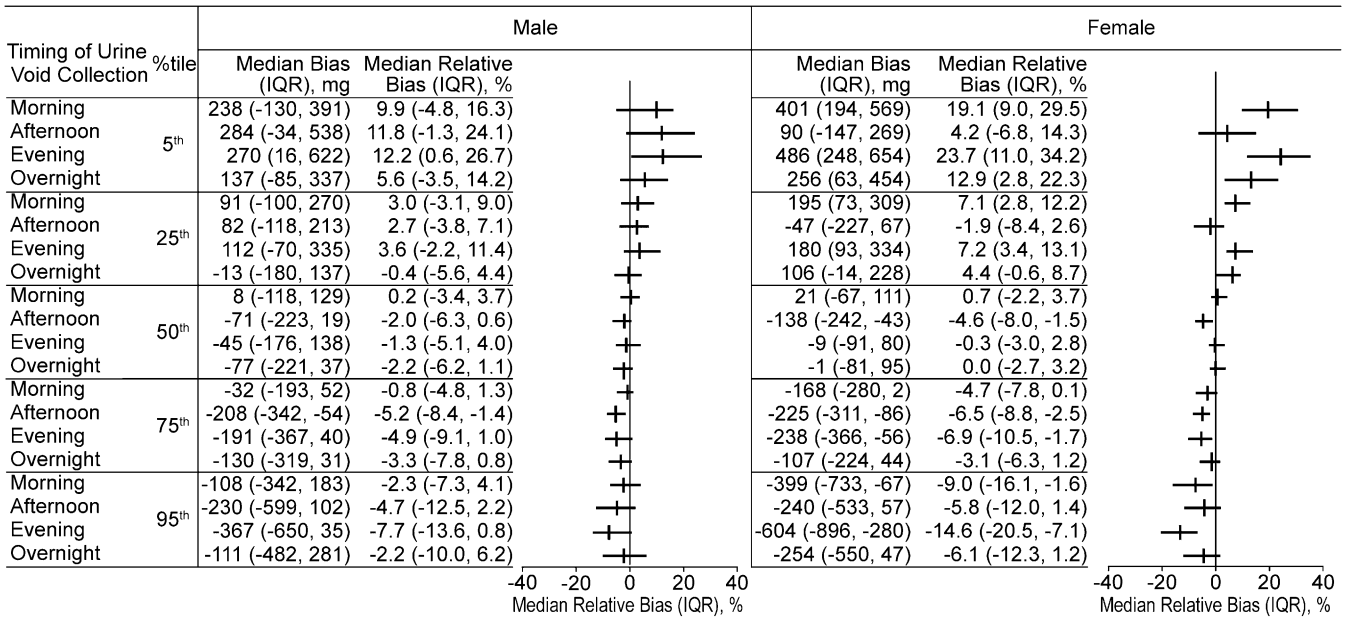

FIGURE 2 Median bias and median relative bias of selected percentiles of usual 24-h sodium excretion estimated from one-void specimens by gender and the timing of urine void collection among 100 validation groups.

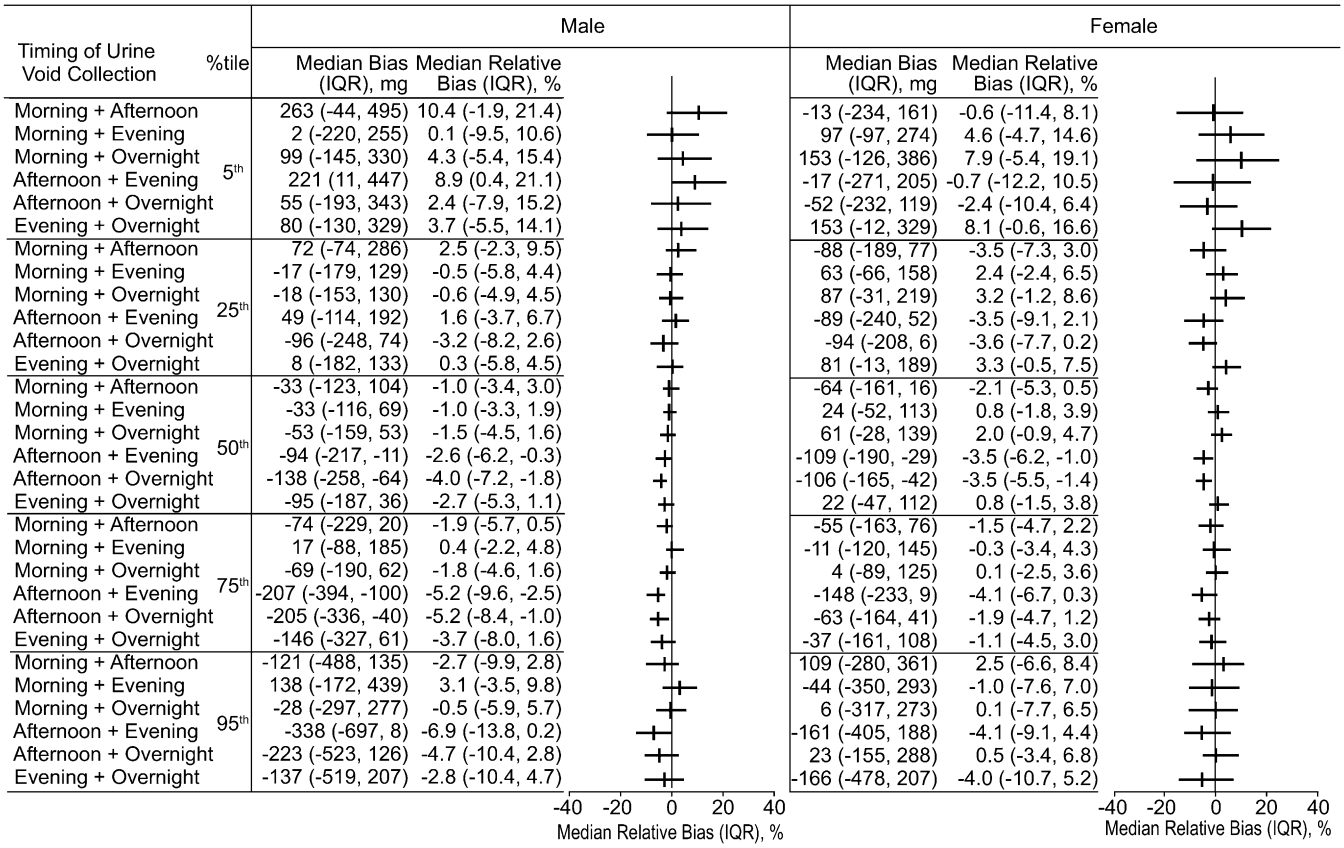

FIGURE 3 Median bias and median relative bias of selected percentiles of usual 24-h sodium excretion estimated from two-void urine combinations by gender and the timing of urine void collection among 100 validation groups.

Unlike previous studies using sodium concentration as the predictor (7, 17–28), we used the total sodium excreted in the urine voids to predict the 24-h sodium excretion. This calibration approach accounted for spot urine volumes and provided a viable option in combining measurements from 2 urine voids.

Our study sample was comprised of adults aged 18–39 y. Less than 1% took antihypertensive medication (11). Our approach requires further verification in older adults with higher rates of chronic disease. This study was designed to develop calibration equations accounting for potential racial differences in urine excretion between blacks and other persons, previously shown to be related to the racial differences in hypertension (8, 9). Although we observed lower urine volumes and higher urine sodium concentrations in all urine specimens from blacks compared to those from participants of other races (11), our data indicated that among young healthy adults, race was not associated with expected usual 24-h sodium excretion. The urine void specimens in our study were part of the 24-h collection and thus were not independent. This may also partially explain the better performance of two-void specimens because two-void combined urines often represented a greater proportion of sodium excreted in the same day than one-void urines.

Our approach to estimate the distribution of usual 24-h urine excretion, which uses 1 or 2 timed-void urine specimens and accounts for day-to-day variation and covariance between measurement errors, may provide a low-burden, low-cost alternative to 24-h collections in monitoring population sodium intake among healthy young adults. It produced population percentile estimates with relatively low biases and might be used to estimate the proportion of the population with excess dietary sodium intakes with reasonable precision using a two-void combination specimen. This approach is designed to produce population estimates and is not intended for use in assessing sodium intake at an individual level. Although regression coefficients from the EEM calibration equations in this study may need to be adjusted for other populations, such as older adults or populations with higher rates of chronic disease, the estimation approach should be broadly applicable and merits further investigation.

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