The USDA Automated Multiple-Pass Method accurately assesses population sodium intakes[1–3]

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ABSTRACT

Background: Given current sodium-reduction strategies, accurate and practical methods to monitor sodium intake in the US population are critical. Although the gold standard for estimating sodium intake is the 24-h urine collection, few studies have used this biomarker to evaluate the accuracy of a dietary instrument.

Objective: Our objective was to compare self-reported dietary intake of sodium with 24-h urinary excretion obtained in the USDA Automated Multiple-Pass Method (AMPM) Validation Study.

Design: Subjects were healthy, weight-stable volunteers aged 30–69 y recruited from the Washington, DC, area. Data from 465 subjects who completed at least one 24-h recall and collected a complete 24-h urine sample during the same period were used to assess the validity of sodium intake. Reporting accuracy was calculated as the ratio of reported sodium intake to that estimated from the urinary biomarker (24-h urinary sodium/0.86). Estimations of sodium intake included salt added in cooking but did not include salt added at the table.

Results: Overall, the mean (95% CI) reporting accuracy was 0.93 (0.89, 0.97) for men (n = 232) and 0.90 (0.87, 0.94) for women (n = 233). Reporting accuracy was highest for subjects classified as normal weight [body mass index (in kg/m^2) <25]: 1.06 (1.00, 1.12) for men (n = 84) and 0.99 (0.94, 1.04) for women (n = 115). For women only, reporting accuracy was higher in those aged 50–69 y than in those who were younger.

Conclusion: Findings from this study suggest that the USDA AMPM is a valid measure for estimating sodium intake in adults at the population or group level. *Am J Clin Nutr* 2013;97:958–64.

INTRODUCTION

The 2010 *Dietary Guidelines for Americans* recommend that we reduce daily sodium intake to <2300 mg and further reduce intake to 1500 mg among persons who are aged ≥51 y and those of any age who are African American or have hypertension, diabetes, or chronic kidney disease (1). However, consumption levels remain high; in 2007–2008 the mean daily sodium intake of the US population aged ≥2 y was 3330 mg (2).

The Institute of Medicine outlined strategies for reducing sodium intake with an innovative and unprecedented approach to gradually reduce sodium levels in foods (3). Accurate and practical methods to estimate the sodium intake of the US population are essential; therefore, supporting strategies related to monitoring and surveillance urged the inclusion of 24-h urine samples, in addition to the continuation of multiple 24-h recalls, during the NHANES.

Although the gold standard for estimating population sodium intake is the 24-h urine collection, it is a time consuming and inconvenient task. Intakes estimated from 24-h urinary sodium excretions are subject to error and bias because of individual sodium losses through sweat and feces, laboratory error, and incomplete collections; however, monitoring sodium via 24-h urine collections would capture intake from salt added at the table and during food preparation (4). Although used in observational studies and clinical trials in the United States (5), and to assess population sodium intake in nationally representative surveys in other countries (6–9), 24-h urine collections have yet to be used in a US nationally representative survey.

Multiple 24-h dietary recalls are the preferred method for population-level or group intake estimates (10). In addition, recalls provide data on food intake and can be used to determine changes in food-consumption patterns. Although improvements in methods have been made over the years and the validity of data from 24-h recalls has improved, there is still some degree of underreporting of energy intakes (11, 12). It is assumed that sodium intake is difficult to measure from food intake data, because the sodium content of otherwise similar foods vary greatly according to the amount of salt used in preparation and at the table (13). Data from both the Trials of Nonpharmacologic Intervention in the Elderly (4) and the International Study of Macro- and Micro-Nutrients and Blood Pressure (14) have shown that 24-h recalls underestimate sodium intake compared with urinary sodium excretion; however, a recent study (15) provides support for 24-h recalls as a useful method for estimating sodium intake.

The objective of this research was to compare the estimated sodium intake from foods from self-reported dietary recalls with 24-h urinary excretion in the USDA Automated Multiple-Pass Method (AMPM)[4] Validation Study (11). The AMPM, used to collect 24-h recalls in What We Eat in America, NHANES was

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[4] Abbreviations used: AMPM, Automated Multiple-Pass Method; DRNA, dietary sodium intake; FNDDS, Food and Nutrient Database for Dietary Studies; SR, Standard Reference; URNA, urinary sodium excretion.

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validated for energy intake in a large doubly labeled water study (11). Information on the magnitude of reporting error for sodium intake is critical to the interpretation of national survey data for monitoring sodium intake of the US population. Results from this study will now assess the validity of the dietary intake instrument used in our national survey to collect sodium intakes.

SUBJECTS AND METHODS

Subjects

Subjects in the current study included participants from the AMPM Validation Study ($n = 524$); the design and method were previously described (11). Basically, study participants were healthy, weight-stable volunteers aged 30–69 y, recruited from the greater Washington, DC, metropolitan area. Pregnant and lactating females, patients with diabetes, and individuals taking medications known to affect food intake or water balance were excluded. Sodium intake data were restricted to the 465 subjects (232 men and 233 women) who completed a least one 24-h dietary recall plus collected at least one 24-h urine sample; both measured the same 24-h period.

Body weight was measured to the nearest 0.01 kg with an electronic balance while the subject was wearing a hospital gown and no shoes. Height was measured to the nearest 0.1 cm with a wall-mounted stadiometer. BMI was defined as weight (kg)/height $(m)^2$. Data collection was conducted between July 2002 and June 2004. The Johns Hopkins University Bloomberg School of Public Health Committee on Human Research approved the study protocol; all procedures followed were in accordance with their ethical standards.

Dietary sodium intake

The 24-h dietary recalls were conducted by trained interviewers using USDA's AMPM—a 5-step, fully computerized recall method that uses multiple memory cues with standardized wording to elicit recall of all possible foods. The first 2 recalls (of the 3 recalls collected in the AMPM Validation Study) were scheduled to capture dietary intake during the same 24-h period as used for the 2 urine collections. The first dietary interview was in person, and the second interview, generally 4–6 d later, was by telephone. Portion sizes were estimated by using a variety of food models and other measurement aides. Quality control of the interviewing process was conducted over the course of the study.

Dietary recalls were processed by using USDA SURVEYNET software (version 3.15) (16). The USDA Food and Nutrient Database for Dietary Studies (FNDDS 1.0) (17) was used to convert food and beverages as consumed into gram amounts and to determine nutrient values. Nutrient values for each FNDDS 1.0 code were based on the National Nutrient Database for Standard Reference (SR), release 16.1 (18). Sodium values in SR include the inherent sodium in foods as well as sodium added during processing as sodium chloride or other sodium-containing additives. The SR, updated and released annually, contains values that may be based on the results of laboratory analyses or calculated by using appropriate algorithms, factors, or recipes. The documentation for each release of SR highlights major changes (18). Source codes in the SR identify each estimated value, and a date indicates when a value was either added to the database or last modified. The National Food and Nutrient Analysis Program was deigned to expand and improve data in the USDA food-composition databases through collection and analysis of nationally representative samples. From 1998 to 2006, >700 food items in SR have been updated or expanded by using National Food and Nutrient Analysis Program data (19).

Data for ~2600 items in SR16.1 were used to determine the nutrient values for the ~7000 commonly consumed foods in FNDDS 1.0. Estimations of sodium intake included salt added in cooking or food preparation as assumed from the nutrient profile for the foods in FNDDS 1.0. The salt content of homemade dishes as well as some commercial products (not linked to a single SR code) was calculated by using recipes based on popular cookbooks or product nutrient profiles. FNDDS is updated every 2 y and released in conjunction with What We Eat in America, NHANES. Sodium intake estimates did not include sodium from plain drinking water, dietary supplements, or medications.

Discretionary salt added at the table was not quantified. At the conclusion of the dietary interview, subjects were asked *1*) the type of salt used and *2*) how often they add salt to food at the table. Choices for the type of salt included the following: ordinary salt, lite salt, or salt substitute; subjects who replied "doesn't use or add salt products at the table" were classified as never adding salt at the table. Those who reported using salt products were classified as "rarely," "occasionally," or "very often" based on their reply to "how often they add ordinary salt to food at the table."

Urinary sodium excretion

During the 2-wk study period of the AMPM Validation Study, each subject collected two 24-h urine samples. Detailed instructions, both in writing and orally, on the method of urine collection and the necessity of obtaining a complete 24-h urine collection were provided. Subjects were instructed to discard their first urine void of the day and to collect all urine for the next 24 h, up to and including the first urine void of the next day. Subjects recorded the start and end times for their urine collection and reported any missed urine during the 24-h collection period. If any specimen was missed, subjects were asked to record the estimated volume of missing urine. In addition to the verbal and written instructions, subjects also received a reminder phone call on the evening before the urine collection was scheduled.

Urine was collected in weighted 4-L wide-mouth brown jugs that contained a small amount of the preservative boric acid. A cooler, ice packs, and a large beaker were provided to facilitate storage and collection. Each subject was also provided a travel bag that contained a small beaker and 1-L screw-cap container for collections made away from home. On the same day that the collection was completed, subjects returned their 24-h urine containers to the study center. The urine was weighed, and 24-h urine production was estimated as the difference between the full and empty weights. Samples were portioned as aliquots into 5-mL cryovials and stored at −20°C until the analysis was completed. The sodium concentration was measured by ion-selective electrode potentiometry (VITROS Na+ slide, VITROS Chemistry Products Calibrator Kit 2). Blinded aliquots from

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a pooled urine sample were sent to assess reproducibility; CVs were 6.6% (n = 11) and 3.1% (n = 8).

Total 24-h excretion was calculated by multiplying the measured concentration with the total calculated weight of urine collected. Sodium content in 24-h urine samples was divided by 0.86, assuming that 86% of sodium ingested is excreted through the urine (20) and used as a biological marker for sodium intake.

The completeness of the 24-h urine collection was assessed, and only data from 24-h collections determined as adequate were used for analysis. Criteria for adequacy were as follows: collection time, 22–26 h; urine volume, >500 mL; reported missing urine, <5% of total volume; and creatinine, >10 (women) or 15 (men) mg/kg body weight. Urinary creatinine was assayed by using the VITROS CREA slide, VITROS Chemistry Products Calibrator Kit 1. Reporting accuracy was calculated as the ratio of reported dietary sodium intake (24-h recall) to sodium estimated from a urinary biomarker (24-h urinary sodium/0.86).

Statistical analysis

Statistical analyses were performed with SAS/STAT software (version 9.2; SAS Institute Inc). Means and SDs were calculated to describe subject characteristics. Because dietary sodium intake (DRNA) and urinary sodium excretion (URNA) data were skewed to the right, all sodium measurements were log transformed to improve distribution toward normality. To account for serial correlations between individual subject dietary recalls and between individual urinary excretions, the sample within-subject variance and SD were estimated from a linear mixed model of dietary sodium intake and urinary sodium excretion with random intercepts and all fixed effects for up to 2 dietary recalls and urinary excretions by using PROC MIXED. Within sex and BMI, 24-h sodium subgroup means and 95% CIs were calculated directly from sample mean data by using the SAS LSMEANS statement of the PROC MIXED procedure and its 95% lower and upper CI limits. Missing values were assumed to be missing at random. Logarithmic means and 95% CIs were back transformed to geometric means and 95% CIs on the original scale.

When urinary sodium data were available, subgroup mean ratios of dietary sodium to excreted urinary sodium (DRNA: URNA) were calculated from subgroup geometric means. The 95% confidence limits of the ratio were calculated by adding

$$\pm 1.96\sqrt{\frac{\sigma^2_{wDRNA}}{d}+\frac{\sigma^2_{wURNA}}{d}-2r\frac{\sigma_{wDRNA}\sigma_{wURNA}}{d}} \qquad (1)$$

where σ_{wDRNA} is the within-subject SD for the log of 24-h dietary sodium intake, d is the number of days of dietary sodium intake, σ_{wURNA} is the within-subject SD for the log of urinary sodium, and r is the correlation between the log of dietary and urinary sodium.

Assuming independence for the two 24-h recalls and 2 urinary sodium measurements, σ_{wDRNA} and σ_{wURNA} can be estimated as one-half of the dietary sodium intake sample variance of ($\log_{DRNA1} - \log_{DRNA2}$) and half the urinary sodium excretion sample variance of ($\log_{URNA1} - \log_{URNA2}$), respectively, in a design with 2 dietary sodium intake DRNA (d = 2) and 2 urinary sodium excretion measurements per subject (21). On the original scale the 95% confidence limits are given by the exponential of the limits on the log scale. Pearson correlations between urinary sodium and 24-h dietary recalls were calculated; to estimate the correlation between urinary sodium and true usual sodium intake, the deatttenuated correlations correcting for within-person variation in the urinary biomarker were calculated (22).

RESULTS

Demographic characteristics of the analytic sample are presented in **Table 1**. Subjects, predominately non-Hispanic whites (79%), were distributed evenly by sex and approximately by age. Only 7% of subjects had not attended college; 40% had a postgraduate degree. More women (49%) than men (36%) were considered normal weight [BMI (in kg/m^2) <25.0].

Any differences in demographic characteristics between the analytic sample (n = 465) and the total AMPM Validation Study sample (n = 524) reflect the exclusion based on the inadequacy of urine collections. Of 1038 possible urinary specimens, 1 was not collected and 16 were not obtained during the same date as a dietary recall. Also excluded were urine specimens determined to be inadequate based on failure to meet the following criteria: collection time, 22–26 h (n = 178); urine volume, <500 mL (n = 8); reported missing urine, >5% of total volume (n = 64); and creatinine, >10 (women) or 15 (men) mg/kg body weight (n = 47). Because some urine specimens were in more than one exclusion criteria, the final analytic sample consisted of 787 useable 24-h urine collections. Overall, 24% of urine collections were excluded; 19% and 29% of first and second collections, respectively, were determined to be inadequate.

The only significant difference between the analytic sample and the samples for the 59 subjects excluded (because of inadequate urine collection) was BMI for women (P = 0.003). Of the 29 women excluded, 45% were classified as obese (BMI ≥30.0). For the 30 men excluded, 13% were obese.

The geometric means, medians, and 25th and 75th percentiles for sodium as measured by urinary biomarker and as self-reported from the AMPM are shown in **Table 2**. Of the 232 men and 233 women who had at least one valid urine collection and dietary recall, 147 men and 153 women had both a usable first and second collection. The number of subjects was greater for the first sodium measure than for the second measure: 216 compared with 179 for men and 205 compared with 187 for women.

TABLE 1
Demographic characteristics of the analytic sample[1]

	Men (n = 232)	Women (n = 233)
	%	%
Age		
30–39 y	21	23
40–49 y	29	27
50–59 y	26	29
60–69 y	24	21
Education		
High school diploma or less	4	9
Some college to bachelor's degree	48	59
Graduate degree	48	32
BMI		
<25.0 kg/m^2, normal weight	36	49
25.0–29.9 kg/m^2, overweight	42	32
≥30.0 kg/m^2, obese	21	19

[1] Some percentages do not total 100 because of rounding.

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TABLE 2
Daily sodium measured in male and female subjects

	Men						Women					
	No. of subjects	Geometric mean[1]	95% CI	25th	Median	75th	No. of subjects	Geometric mean[1]	95% CI	25th	Median	75th
Recall no. 1 (mg/d)[2]	216	4136	(3912, 4373)	3127	4190	5445	205	3175	(2999, 3362)	2498	3146	4073
Recall no. 2 (mg/d)	179	4308	(4055, 4577)	3400	4564	5689	187	3184	(3000, 3379)	2393	3174	4255
Mean recall (mg/d)	232	4221	(4030, 4422)	3383	4252	5506	233	3180	(3035, 3332)	2550	3181	4073
Biomarker no. 1 (mg/d)[3]	216	4619	(4377, 4874)	3677	4740	6354	205	3527	(3338, 3726)	2721	3579	4550
Biomarker no. 2 (mg/d)	179	4464	(4213, 4731)	3600	4584	5980	187	3524	(3329, 3732)	2682	3543	4657
Mean biomarker (mg/d)	232	4541	(4333, 4758)	3571	4675	5920	233	3526	(3363, 3696)	2727	3621	4544
Reporting accuracy[4]		0.93	(0.89, 0.97)	0.69	0.92	1.21		0.90	(0.87, 0.94)	0.69	0.90	1.17

[1] Geometric means (and 95% CIs) based on sex-specific 24-h dietary recall or biomarker least-squares means and CI lower and upper limits generated by a linear mixed model for repeated measures.
[2] Collected by using the Automated Multiple-Pass Method.
[3] Calculated as 24-h urinary sodium divided by 0.86, with the assumption that 86% of sodium consumed is excreted in the urine.
[4] Ratio of sodium intake estimated from dietary recall to that estimated from biomarker.

The 85 men and 80 women with only one valid collection were included in the sample. Mean dietary sodium, calculated by using individual subject means for the 2 recalls, represented 93% and 90% of the mean sodium biomarker for men and women, respectively.

The measurements of sodium biomarker increased as BMI increased; however, reported sodium intake remained stable, as shown in **Table 3**. Within a BMI class, reporting accuracy was similar for men and women. Among normal-weight subjects (BMI <25.0), dietary sodium intake, compared with the biomarker, was accurately reported. Overall, reporting accuracy was 88% and 78% for overweight (BMI 25.0–29.9) and obese (BMI ≥30.0) subjects, respectively. Raw correlations and deattenuated correlations (adjusted for the within-person variation in the biomarker) are reported in Table 3 by sex and BMI class. For all men, the raw and deattenuated correlations were 0.32 and 0.46, respectively; for all women, the raw and deattenuated correlations were 0.30 and 0.42, respectively.

The male and female subjects were separated into 2 age categories: 30–49 and 50–69 y; sodium measurements and reporting accuracy are shown in **Table 4**. For women, reporting accuracy was greater for those aged 50–69 y than for those who were younger. For men, reporting accuracy was similar between the 2 age categories.

In **Table 5** the data are presented according to the frequency of salt added at the table. For men, reporting accuracy was similar in all groups. For women, the geometric mean reporting accuracy was 1.00 (95% CI: 0.92, 1.08) for those who said they never added salt to food at the table. For those women who said they very often add salt to food at the table, the geometric mean reporting accuracy was 0.89 (95% CI: 0.80, 0.99). In this study, 68% of men and 55% of women reported that they never or

TABLE 3
Anthropometric and sodium measures and correlation coefficients of the subjects by BMI (in kg/m^2) category

	Men			Women		
	BMI <25.0 (n = 84)	BMI 25.0–29.9 (n = 98)	BMI ≥30.0 (n = 50)	BMI <25.0 (n = 115)	BMI 25.0–29.9 (n = 75)	BMI ≥30.0 (n = 43)
Anthropometric measure						
Age (y)	49 ± 11[1]	49 ± 11	52 ± 11	48 ± 11	51 ± 11	48 ± 10
Weight (kg)	72.9 ± 6.81	84.7 ± 8.39	103.3 ± 11.87	60.2 ± 5.98	71.8 ± 6.86	90.1 ± 10.20
Height (cm)	177.6 ± 6.65	176.1 ± 7.01	176.8 ± 6.25	163.6 ± 6.36	162.7 ± 6.67	163.0 ± 6.97
BMI (kg/m^2)	23.1 ± 1.55	27.3 ± 1.49	33.0 ± 3.34	22.5 ± 1.77	27.1 ± 1.34	34.0 ± 3.51
Sodium						
Intake (mg/d)[2]	4117 (3800, 4460)[3]	4305 (3998, 4636)	4211 (3797, 4671)	3237 (3036, 3451)	3104 (2861, 3368)	3151 (2835, 3502)
Biomarker (mg/d)[4]	3896 (3611, 4204)	4769 (4445, 5116)	5330 (4831, 5880)	3277 (3077, 3490)	3621 (3344, 3920)	4109 (3704, 4557)
Reporting accuracy[5]	1.06 (1.00, 1.12)	0.90 (0.85, 0.96)	0.79 (0.73, 0.86)	0.99 (0.94, 1.04)	0.86 (0.80, 0.92)	0.77 (0.71, 0.83)
Correlation coefficients						
Pearson	0.43	0.28	0.32	0.37	0.18	0.38
Pearson, deattenuated[6]	0.59	0.50	0.47	0.58	0.23	0.57

[1] Mean ± SD (all such values).
[2] Calculated from up to 2 dietary recalls collected by using the Automated Multiple-Pass Method.
[3] Geometric mean (and 95% CI) based on sex- and BMI-specific 24-h dietary recall or biomarker least-squares mean and CI lower and upper limits generated by a linear mixed model for repeated measures (all such values).
[4] Calculated from up to 2 urine collections as 24-h urinary sodium divided by 0.86, with the assumption that 86% of sodium consumed is excreted in the urine.
[5] Ratio of sodium intake estimated from dietary recall to that estimated from biomarker.
[6] Adjusted for the within-person variation in the biomarker.

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TABLE 4
Anthropometric and sodium measures of the subjects by age category

	Men		Women	
	30–49 y (n = 116)	50–69 y (n = 116)	30–49 y (n = 116)	50–69 y (n = 117)
Anthropometric measure				
Age (y)	40 ± 6[1]	59 ± 6	40 ± 6	58 ± 6
Weight (kg)	84.3 ± 14.38	84.5 ±14.0 8	69.0 ± 13.50	69.9 ± 13.02
Height (cm)	177.4 ± 7.37	176.2 ± 5.98	163.4 ± 6.76	163.0 ± 6.39
BMI (kg/m^2)	26.8 ± 4.23	27.2 ± 4.17	25.8 ± 4.80	26.3 ± 4.73
Sodium				
Intake (mg/d)[2]	4397 (4107, 4707)[3]	4055 (3791, 4336)	3153 (2956, 3364)	3201 (3002, 3413)
Biomarker (mg/d)[4]	4672 (4361, 5005)	4425 (4135, 4735)	3707 (3476, 3953)	3354 (3147, 3576)
Reporting accuracy[5]	0.94 (0.89, 1.00)	0.92 (0.87, 0.97)	0.85 (0.81, 0.90)	0.95 (0.90, 1.01)

[1] Mean ± SD (all such values).
[2] Calculated from up to 2 dietary recalls collected by using the Automated Multiple-Pass Method.
[3] Geometric mean (and 95% CI) based on sex- and age-specific 24-h dietary recall or biomarker least-squares mean and CI lower and upper limits generated by a linear mixed model for repeated measures (all such values).
[4] Calculated from up to 2 urine collections as 24-h urinary sodium divided by 0.86, with the assumption that 86% of sodium consumed is excreted in the urine.
[5] Ratio of sodium intake estimated from dietary recall to that estimated from biomarker.

rarely add salt at the table. Only 3% of subjects reported the use of either "lite" salt or salt substitute compared with ordinary salt.

Intrasubject variability, expressed as the CV, for the 300 subjects with 2 d of measurements are reported in **Table 6**. Overall, the within-subject CV was 23.0% for urinary sodium biomarker and 27.2% for dietary sodium intake. The CV% reported for energy was lower than the within-subject variability of 22.6% reported in the AMPM Study (11), which included three 24-h dietary recalls over a 2-wk period. Raw correlations between sodium biomarker and sodium self-reported from the AMPM were 0.32 for men and 0.30 for women.

DISCUSSION

The limited number of clinical studies comparing sodium intakes from dietary intake with those from urinary assessments have used different methods and produced mixed results (4, 9, 14, 15, 23–27). Because 24-h urine samples were collected in the AMPM Validation Study (11), the data offer a unique opportunity to evaluate dietary sodium intakes collected via the methodology used in the US national survey—What We Eat in America, NHANES. In this large sample of normal-weight, overweight, and obese adults, the mean reported energy intake was underestimated by 11% compared with mean total energy expenditure measured with the doubly labeled water technique (11). In the current analysis, the mean reported sodium intake was underestimated by <9% compared with the sodium biomarker. Studies that have compared the reported intakes of energy and sodium with their respective biomarkers have shown both lower (25) and higher (27) reporting accuracy for sodium compared with energy.

Sodium intake is highly correlated with energy intake; however, because discretionary salt added at the table is not included in the dietary measurement, a lower reporting accuracy for sodium might be expected. For the AMPM Validation Study, methodologic differences between energy and sodium measurements must be clarified. For energy, dietary intake estimated from three 24-h recalls was compared with daily energy expenditure estimated over a 2-wk period. For sodium, dietary intake estimated from two 24-h recalls was compared with a biomarker calculated from two 24-h urine samples collected during the same time period. Both the dietary sodium and energy measurements would be affected by underreporting; however, only the energy measurement would be affected by undereating on the day of the recall. Just as for energy, we found a greater underestimation of sodium with higher BMI classification. In a study of 353 female Japanese dietetic students, underreporting of energy and overreporting of sodium decreased with increasing BMI (27).

TABLE 5
Age, BMI, and sodium-reporting accuracy of the subjects by frequency of salt added at the table

	Men (n = 232)				Women (n = 233)			
Add salt to food at table	No. of subjects	Age	BMI	Reporting accuracy[1]	No. of subjects	Age	BMI	Reporting accuracy[1]
		y	kg/m^2			y	kg/m^2	
Never	83	50.1 ± 11.2[2]	27.1 ± 3.7	0.88 (0.81, 0.96)[3]	57	48.8 ± 9.7	26.3 ± 5.0	1.00 (0.92, 1.08)
Rarely	75	48.3 ± 11.1	26.4 ± 4.3	0.91 (0.83, 0.98)	70	48.9 ± 11.5	26.8 ± 5.2	0.85 (0.78, 0.93)
Occasionally	43	49.7 ± 10.7	27.8 ± 5.2	0.90 (0.81, 0.99)	59	49.9 ± 11.9	26.0 ± 4.7	0.88 (0.79, 0.98)
Very often	31	52.7 ± 10.1	27.0 ± 3.6	0.90 (0.82, 1.00)	47	48.4 ± 9.5	24.9 ± 3.7	0.89 (0.80, 0.99)

[1] Ratio of sodium intake estimated from dietary recall to that estimated from biomarker.
[2] Mean ± SD (all such values).
[3] Geometric mean (and 95% CI) based on sex- and frequency of salt added–specific 24-h dietary recall or biomarker least-squares mean and CI lower and upper limits generated by a linear mixed model for repeated measures (all such values).

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TABLE 6
CV for the subjects who had 2 urine collections and 2 dietary recalls

	CV[1]	
	Men (n = 147)	Women (n = 153)
	%	%
Urine weight	17.7	18.5
Urinary creatinine	11.3	11.7
Sodium biomarker[2]	23.4	22.6
Sodium intake[3]	25.3	29.0
Energy intake[3]	19.2	19.3

[1] CV calculated from sex-specific least-squares means and SEs generated by a linear mixed model for repeated measures.
[2] Calculated from 2 urine collections as 24-h urinary sodium divided by 0.86, with the assumption that 86% of sodium consumed is excreted in the urine.
[3] Calculated from 2 dietary recalls collected by using the Automated Multiple-Pass Method.

Urinary sodium

Although sodium intake estimates based on urinary measures are inherently more objective than measures based on self-reported dietary intake, Dennis et al (14) recognized that 24-h urine samples are not gold standards for validity because there was no procedure to estimate with certainty the accuracy (ie, completeness) of each 24-h urine collection. In this study, considerable resources were dedicated to ensure that the highly motivated and well-educated volunteers collected complete 24-h urine collections. Assessment of the completeness of 24-h urine collections is difficult, and self-reporting of collection and missed urine samples may not be reliable; however, it allows the exclusion of samples admitted to being incomplete. Although the *p*-amino-benzoic acid check method (28) is undoubtedly a suitable strategy to verify completeness; the 26% of urine samples that were considered incomplete in this study is similar to that reported in a comparable study using a *p*-amino-benzoic acid check (12). Given the subject burden involved in urine collections, it is not surprising that individuals do not always comply with instructions. In Finland, participation in surveys, and especially in 24-h urine collections, has declined during 20 y of cross-sectional population surveys. In 2002 only 60% of participants who received urine collection bottles returned them and adequately complied with the instructions (8).

Further research is needed to determine what effect BMI classification has on the collection of valid 24-h urine. In our study, 45% of the women, excluded because of inadequate urine collections, had a BMI ≥30; obese females are the subgroup with the highest percentage of energy underreporters (11, 12). Another area of limited research involves the effect that collection of 24-h urine samples has on dietary behavior. By design, our dietary recalls and subsequent urine collections were distributed fairly equally across all 7 d of the week; subjects were provided a travel bag to lessen the inconvenience of collecting urine while away from home.

An additional limitation that needs to be considered is the precision of the correction factor used in estimating sodium intake from 24-h urine samples. In this study, urine samples were collected during all 4 seasons of the year. During four 7-d balance studies, one in each season of the year, Holbrook et al (20) observed that average sodium urinary excretions were 86% of total intake. The amount of dietary sodium excreted in the urine tended to be lowest in the summer balance period (82.6%) and highest in the winter balance period (89.5%). The use of other correction factors, or no correction factor, would influence the magnitude of misreporting.

Dietary sodium

Dietary intakes may underestimate sodium intake because databases used to assign nutrient values do not account for discretionary salt added at the table or sodium obtained from sources other than food. Salt added at the table actually accounts for only a small amount of daily sodium intake. In a study published in 1991 on 62 adults, Mattes and Donnelly (29) estimated that 77% of average daily sodium intake came from processed foods and another 12% occurred naturally in foods; salt added during cooking (6%) or at the table (5%) made up the remainder. Anderson et al (26), using a lithium-marker technique, assessed the intake of household salt in a cross-section of healthy Danish adults; median contribution of household salt was 8–10% of the total salt intake. In our study, 61% of the subjects reported that they rarely or never add salt at the table compared with 17% who reported that they very often add salt at the table.

Sources other than food also contribute minimally to total sodium intake. On average, the intake of sodium due to use of dietary supplements is very low. On the basis of NHANES 2007–2008 data, mean (±SE) daily sodium intake from dietary supplements was 3 ± 0.6 mg for all adults (≥20 y) and 52 ± 8.8 mg for the estimated 7% of adults taking a supplement containing sodium (30). Tap water and plain bottled water were not collected with the AMPM version used for our study (31). Daily sodium intake from tap and bottled water in What We Eat in America, NHANES 2007–2008 accounted for <1% of total sodium intake for adults (JC Clemens, unpublished observations, May 2012).

Unlike urinary collections, dietary recalls allow one to assess simultaneously intakes of many nutrients and to provide data that are directly relevant to food intake behaviors. Forty-four percent of sodium consumed by Americans came from 10 food categories; bread and rolls (7.4%) and cold cuts/cured meats (5.1%) were the top contributors (32).

Webster et al (33) identified 32 salt-reduction initiatives globally. Many initiatives have industry reformulation of processed and catered foods at the core of their salt-reduction efforts. The sodium content of raw foods and manufactured foods and the salt used in average recipes has regularly been updated in the food-composition databases in Finland since the early 1980s. Using a stratified random sample of Finnish adults, Reinivuo et al (9) concluded that sodium intake estimation based on 48-h recalls is a valid method.

In the United States, major food makers and restaurant chains have taken steps or announced plans to reduce sodium in their products (34). The constant changes in the food marketplace present issues and challenges for maintaining food-composition databases; Pennington et al (35) acknowledged that these databases are never complete because of the dynamic nature of the food supply. Adequate funding for NHANES, including related and supporting databases, is a supporting strategy recommended by the Institute of Medicine in "Strategies to Reduce Sodium Intake in the United States" (3).

The findings from this study indicate that the USDA AMPM is a valid measure for estimating sodium intakes at the population or group level. An important limitation is the generalizability of the findings to the US population. Demographic characteristics (eg, age, education, and race) may be associated with accurate reporting and completeness of urine collection and would require additional validation with an appropriate sample.

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