Sodium and potassium intake measurements: dietary methodology problems[1-5]

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ABSTRACT This study compared methods that measured dietary intake of sodium and potassium by chemical analysis, by calculation from a table, and by measurement of these elements in 24-h urine. Total sodium included analyzed plus discretionary sodium. Analyzed elements were measured values in diets and urine performed by atomic absorption spectrophotometry. Calculated elements were estimated values from a food composition table. Food samples were collected by duplicate analysis. Total, analyzed, calculated, and discretionary sodium intake for 7 days by adolescent females averaged 2.890, 2.518, 1.852, and 0.372 g/day, respectively. Analyzed and calculated potassium intake by subjects averaged 1.447 and 1.667 g/day, respectively. Urinary sodium and potassium averaged 2.389 and 1.118 g/day, respectively. Subjects differed significantly in the amount of sodium ingested, partly due to discretionary sodium use. Total sodium and analyzed potassium were the accurate methods of determining sodium and potassium intake. Element intakes can be estimated from regression equations. *Am J Clin Nutr* 1986;43:470–476.

KEY WORDS Sodium, potassium, intake, excretion, duplicate analysis, female, adolescents

Introduction

High sodium intake may be involved with high blood pressure and development of hypertension (1–5). Liu et al (6) stated that this relationship in children may be important since a positive result would lend support to using nutritional intervention for the early prevention of hypertension. Potassium may also be involved with blood pressure regulation. Tannen (7) has recently reviewed the effects of potassium on blood pressure control. Potassium depletion can lower blood pressure in hypertensive humans and animals. A high potassium intake does not alter blood pressure in normotensive animals and humans, but can lower blood pressure in subjects with hypertension. Recently, it has been reported that dietary potassium intake was significantly and negatively correlated with age-adjusted blood pressure in men (8). Because of the aforementioned relationships, it is of primary importance to have accurate information about sodium and potassium intakes. Once this information is available, then causal relationships between sodium and potassium consumption and health problems may be identified.

Several methods, eg, dietary history, 24-h recalls, 7-day food records, have been used to estimate nutrient intake of population groups (9–13), but the accuracy of these methods is

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doubtful since each method is subject to errors. The purpose of this study was to evaluate sodium and potassium intakes more accurately and to report on a comparison of methods used to determine sodium and potassium intakes and amounts of discretionary (consumer controlled) and nondiscretionary (commercially controlled and naturally occurring) sources of sodium intake of adolescent females. The analyses of the daily variations in sodium and potassium intakes and excretions were performed for 7 days.

Materials and methods

Subjects

Eight healthy white females, 13–15 yr of age and having a mean body wt of 47.0 kg, participated in this study. All girls lived with their parents in air-conditioned homes located in residential areas of Auburn/Opelika, AL. Subjects were not ingesting any drugs containing sodium during data collection. Subjects were not monitored nor restricted in their physical activities before and during data collection, although the majority of subjects participated in light to moderate physical activity (14) during data collection. Most subjects were more active during the mornings when temperature and humidity were lower than in the afternoon. One subject was physically active during some days in the afternoon. The study was approved by the university's human subjects committee and informed consent was obtained from both the subject and a parent.

Diets

In this study, food and drink including water were obtained by the method of duplicate analysis (15). Drinking water was not softened in any residences of the subjects. Subjects were asked to prepare or purchase a duplicate of each food or drink consumed during mealtime and all other times during the day. Subjects were paid a monetary award at termination of food collections. In this study, five subjects consumed all meals and snacks at home. Subjects 1, 6, and 8 each consumed 2, 4, and 2 meals away from home, respectively. Subject 8 purchased 3 snacks away from home. Each day of the wk was represented for sample collections. All subjects performed food collections on successive 4-day intervals during a wk. The following week, subjects collected food for the remaining 3-day interval. Because of one subject's activities, a 2-day collection during a week was made and during the following week a 1-day collection was conducted. All samples were collected during the months of July and August, 1982.

Amounts consumed were measured to the nearest g by weighing the food or liquids before ingestion with a small dietary balance with taring capability. Subjects and mothers were instructed on use of the balance and demonstrated competence with weighing procedures and collection of foods before food samples and liquids to be analyzed were collected. Food that was not eaten was weighed back and an appropriate duplicate portion that was ingested was taken for analysis. Frequency of weighing back uneaten food occurred rarely because subjects were instructed to eat all foods and liquids on the plate. Subjects were asked to use a small piece of bread to wipe their plate to ensure that salt used from the shaker was ingested. On the day of sampling, subjects prepared a written record containing the date and columns for inserting the wt of foods, liquids including water, description of food consumed, and method of preparation. Records were collected daily and scrutinized for clarity and errors. Mothers supervised subjects during weighings and recordings for each meal. After weighing, food and liquids were transferred to a preweighed plastic container (6 l capacity) with a double lip lid for a tape seal. A plastic wash bottle containing deionized water was used to facilitate transfer of liquids and some types of food. Food samples were stored in a refrigerator and picked-up the next day following the subjects' preparation of the composite sample. The composite sample was weighed and homogenized for 5 min in a large capacity stainless steel blender. In some instances, measured volumes of deionized water were added to allow formation of a thick, creamy homogenate. Approximately 250 g of the homogenate were removed and stored in nalgene bottles at −20°C. Subjects used a preweighed salt shaker so that daily salt consumption or discretionary sodium use was measured by weighing. Subjects were not involved in the weighing or determination of sodium used from the shaker. Duplicate food samples and, if necessary, fluids taken for analysis were not salted by the subjects.

The procedures used in this study allowed determinations of total sodium, analyzed sodium and potassium, and calculated sodium and potassium intake from food and liquids consumed. Total sodium included analyzed sodium plus sodium used from a salt shaker; analyzed sodium and potassium were values determined from the composite food sample. The kcal intake and calculated amount of sodium and potassium in food consumed were estimated from a table of food composition (16). These different methods also estimated the amounts of daily sodium coming from discretionary and nondiscretionary sources (17).

Urine

Twenty-four-hour urine collections were obtained in 2 l nalgene widemouth bottles which contained a lentil-sized crystal of thymol. Food and corresponding 24-h urine samples were collected on the same days; all subjects were not experiencing menstruation during data collection. Total urine volume was measured and an aliquot removed and transferred to a screw cap nalgene bottle. Urine was stored at −20°C. For screening purpose, subjects were asked to precollect two urine samples before actual collections were made. After this precollection period, some subjects refused further participation.

Analyses

Urine samples were thawed and an aliquot was removed and diluted appropriately with deionized water similar to procedures described by Grunbaum and Pace (18). Food samples were thawed and three weighed aliquots from each sample were transferred into Vycor crucibles. After drying, the samples were prepared for dry ashing as previously described (19). The ashed residues were dissolved in 6 N HCl (Ultrex, JT Baker, Phillipsburg, NJ) after heating in a steam bath and then diluted appropriately with deionized water. Analyses of sodium and potassium in all samples were accomplished by flame atomic absorption spectrophotometry.

Statistical analysis of data

Analysis of variance, regression analysis, correlation coefficients, and *t* test were the methods used for statistical analysis (20). Repeated values were obtained on the same individuals for 7 days to measure the pattern and variation of sodium and potassium intake. In some instances, doubtful values for sodium intake and corresponding values for urinary sodium were obtained for some subjects on certain days. No values were excluded from the statistical analyses.

Results

Sodium intake, excretion, and kilocalorie intake

For each method, means of measured total, analyzed, and calculated sodium from food and liquids ingested and 24-h urinary sodium for each subject are presented in **Table 1.** Subjects differed significantly in mean sodium intake as measured by total and analyzed sodium, but not for calculated sodium intake. Subjects differed significantly in the amount of sodium excreted in the urine. For each subject, mean total sodium intake was greater than or equal to analyzed sodium which was greater than calculated sodium. For each subject, mean urinary sodium was greater than calculated sodium and in most instances it was less than total sodium intake. There were no significant differences of any means calculated for sodium by day of the wk. The mean total sodium intake by day of the wk ranged from 2.627 to 3.078 g/day. The mean kcal intake was not high for each subject.

Discretionary and nondiscretionary sodium intake

The subjects differed markedly in their discretionary use of salt (Table 1). The two subjects with the high discretionary use of salt had 30% of their total sodium intake from the salt shaker during eating. The remaining subjects had 5% or less of total sodium intake represented from discretionary sodium intake. The measured discretionary sodium intake represents only part of the total discretionary sodium intake during meal ingestion. The mean difference between the analyzed and calculated sodium methods was 0.666 g sodium/day; and in all cases, the analyzed values were higher than the calculated values with the differences ranging from 0.3 to 1.1 g/day. This difference represents an estimate of part of the discretionary and nondiscretionary sodium intake from food preparation and drinking water/

TABLE 1
Daily mean sodium intake and excretion and kcal intake by adolescent females

		Sodium					
Subject	n*	Total†	Discretionary‡	Analyzed§	Calculated	Urine‖	Energy intake
				g/day ± SEM			kcal/day¶
1	7	1.911 ± 0.199[ac]	0.001 ± 0.001	1.910 ± 0.200[ac]	1.619 ± 0.395	1.701 ± 0.125[ad]	1462 ± 169
2	7	2.530 ± 0.292[a]	0.093 ± 0.056	2.437 ± 0.282	1.910 ± 0.357	1.974 ± 0.387[ad]	1568 ± 214
3	7	4.726 ± 0.173[b]	1.661 ± 0.366	3.065 ± 0.318[b]	2.162 ± 0.169	3.290 ± 0.151[c]	1735 ± 128
4	7	2.600 ± 0.307[a]	0.0	2.600 ± 0.307	1.780 ± 0.338	2.407 ± 0.414[a]	1588 ± 231
5	7	4.173 ± 0.366[b]	1.011 ± 0.478	3.162 ± 0.279[be]	2.457 ± 0.294	3.563 ± 0.305[b]	1571 ± 191
6	7	2.260 ± 0.300[a]	0.001 ± 0.001	2.259 ± 0.301[f]	1.622 ± 0.317	2.359 ± 0.328[ad]	1327 ± 120
7	7	2.081 ± 0.338[a]	0.106 ± 0.059	1.975 ± 0.369[a]	1.634 ± 0.305	2.087 ± 0.230[ad]	1086 ± 235
8	7	2.840 ± 0.262[ad]	0.103 ± 0.054	2.737 ± 0.297[d]	1.647 ± 0.284	1.670 ± 0.220[ad]	1602 ± 79
Group mean		2.890 ± 0.159	0.372 ± 0.117	2.518 ± 0.114	1.852 ± 0.110	2.389 ± 0.130	1489 ± 64

* n equals number of daily determinations.

† Means within column with superscript a are significantly different ($p < 0.03$) from those with b; mean with superscript c is significantly different ($p < 0.03$) from mean with d.

‡ Sodium intake as measured from saltshaker use.

§ Means within column with superscript a are significantly different ($p < 0.01$) from those with b; means with superscript c and e are significantly different ($p < 0.05$) from means with d and f, respectively.

‖ Mean within column with superscript b is significantly different ($p \leq 0.05$) from those with a; mean within column with superscript c is significantly different from those with d.

¶ Mean ± SEM.

other beverages that were consumed, respectively. The mean difference between total and calculated sodium was 1.038 g sodium/day, which represents an estimate of sodium intake from the two sources described above. The mean calculated sodium intake represents the major contribution from nondiscretionary sodium sources.

Potassium intake and excretion

Means of analyzed and calculated potassium from food and liquids ingested and 24-h urinary potassium values for each subject are shown in **Table 2.** For most subjects, calculated potassium intake was larger than analyzed potassium. Daily potassium intake of subject 8 as measured by analysis was significantly greater than that of the other subjects. For each subject, urinary potassium was less than analyzed and calculated potassium intake. There were no significant differences for potassium calculated by day of the wk. The mean total potassium intake by day of the wk ranged from 1.335 to 1.582 g/day.

Correlation and regression of sodium and potassium intake with excretion

Pearson correlation coefficients were calculated from combined data for each method (**Table 3**) to determine which dietary method was the most accurate in predicting urinary sodium and potassium excretion. The r for each method was positive and highly significant. Total sodium and analyzed potassium had the highest correlation with urinary sodium and potassium, respectively. When the amount of discretionary sodium intake was added to calculated sodium, the correlation with urinary sodium excretion was improved but did not equal the correlation with total sodium. The analyzed potassium method was more effective in predicting potassium excretion than the calculated potassium procedure. Regression equations predicting urine sodium and potassium values from sodium and potassium intakes, respectively, for the different methods are shown in **Table 4.**

Discussion

The present study provides an assessment of the accuracy of different procedures used in determining sodium intake of adolescent females. Total sodium was the most accurate method used because it included and measured all sources of sodium intake by the subjects. The analyzed sodium intake was a less accurate method than total sodium because it did not account for discretionary sodium intake at the table, which is its major disadvantage. Fregly (17) recently reviewed estimates of total sodium intake of adult males based upon urinary excretion and survey data and reported a range of 3.9 to 5.7 g/day. The range of total sodium of our adolescents was 1.911

TABLE 2
Daily mean potassium intake and excretion by adolescent females

Subject	n*	Potassium		
		Analyzed†	Calculated‡	Urine§
			g/day ± SEM	
1	7	1.362 ± 0.162[a]	2.015 ± 0.325	1.181 ± 0.092[bd]
2	7	1.310 ± 0.139[a]	1.902 ± 0.266	1.062 ± 0.137
3	7	1.621 ± 0.128[a]	1.621 ± 0.199	1.241 ± 0.097[bd]
4	7	1.405 ± 0.124[a]	1.446 ± 0.244	1.188 ± 0.135[b]
5	7	1.495 ± 0.160[a]	1.533 ± 0.312	1.330 ± 0.152[bd]
6	7	1.202 ± 0.144[a]	1.741 ± 0.132	0.871 ± 0.083[c]
7	7	1.108 ± 0.186[a]	1.113 ± 0.313[a]	0.807 ± 0.061[a]
8	7	2.074 ± 0.237[b]	2.036 ± 0.237[b]	1.258 ± 0.166[b]
Group mean		1.447 ± 0.061	1.667 ± 0.095	1.118 ± 0.046

* n equals number of daily determinations.
† Means within column not sharing common superscript are significantly different at $p < 0.025$.
‡ Mean within column with superscript a is significantly different ($p < 0.05$) from mean with superscript b.
§ Mean within column with superscript a is significantly different ($p < 0.04$) from those with superscript b; mean within column with superscript c is significantly different ($p < 0.05$) from those with superscript d.

TABLE 3
Pearson correlation coefficients between sodium and potassium intakes and excretion*

Methods	Analzyed sodium	Calculated sodium	Calculated sodium and discretionary sodium	Urine sodium	Calculated potassium	Urine potassium
Total sodium	0.769	0.540	0.824	0.814		
Analyzed sodium		0.642	0.488	0.601		
Calculated sodium			0.761	0.421		
Calculated sodium and discretionary sodium†				0.678		
Analyzed potassium					0.613	0.487
Calculated potassium						0.227

* $p < 0.0002$ for all coefficients.
† Sodium determined from saltshaker use was added to calculated sodium intake.

to 4.726 g/day, somewhat lower than the above range but supported by their kcal intake. Data from HANES I (21) have indicated an effect of age and sex on sodium intake. Average sodium intake of females aged 1 to 74 yr in HANES I was 1.8 g/day.

Calculated sodium was the least accurate method in estimating sodium intake because all sodium sources were not represented and values obtained by this method were less than sodium values excreted in 24-h urine. As a consequence, the r between the two methods was low. Calculated sodium intake represents nondiscretionary sodium intake from weighed food and some liquids but not from drinking water. This method did not include discretionary sodium intake from eating while at the table or during meal preparation. This value averaged 1.852 g/day in the present study which is similar to that observed for females in HANES I (21) using the 24-h recall method. Fregly (17) recently reviewed data on sources of nondiscretionary sodium and concluded that this sodium intake ranges from 1.8 to 3.3 g/day. Our calculated sodium and the 24-h recall used in HANES I were estimating the same sources of nondiscretionary sodium but by different procedures. McCarron et al (22) have stated that sodium intake was subject to the greatest underestimation of all nutrients measured in HANES I. Our results support this conclusion based upon actual determinations of sodium intake obtained from total, analyzed, and 24-h urine methods as compared to calculated sodium values.

TABLE 4
Regression equations predicting urinary sodium and potassium from sodium and potassium intakes

Methods	Regression equation*
Total sodium	US = 0.504 + 0.651X†
Analyzed sodium	US = 0.704 + 0.669X‡
Calculated sodium	US = 1.496 + 0.493X§
Analyzed potassium	UP = 0.594 + 0.363X‖
Calculated potassium	UP = 0.942 + 0.112X¶

* Equations are for all days of wk and subjects combined; values for urinary sodium (US) and urinary potassium (UP) are in g/day.
† X equals g of total sodium ingested.
‡ X equals g of analyzed sodium in food.
§ X equals g of calculated sodium in food.
‖ X equals g of analyzed potassium in food.
¶ X equals g of calculated potassium in food.

Recently, Engstrom and Tobelmann (23) reported that females aged 11–18 yr consumed 2.450 g sodium/day based on 14-day food records. This estimate of sodium intake is higher than the 1.852 g sodium/day obtained by the calculated sodium method used in the present study. Again, both methods were measuring the same sodium sources but by different approaches. Calculating sodium intake from weighed food and liquids over 7 days should be more accurate than estimating serving sizes from 14-day food records.

When the amount of sodium consumed from daily salt shaker use was added to calculated sodium, the correlation with total and urinary sodium was improved. This study clearly indicates that measuring salt use during eating is important in estimating sodium intake and calculated values are useful only if discretionary sodium intake is measured.

The 24-h urinary sodium was an effective method of estimating sodium intake because this method had a higher correlation with total ingested sodium than did the other methods. Unfortunately, urinary sodium significantly ($p < 0.02$) underestimated total sodium intake by 17.3%. Since the majority of sodium lost from the body is via urine, the amount of sodium excreted should accurately reflect the amount ingested of this ion (24); our urinary sodium and total sodium intake data support this conclusion. In this study, a major problem concerning the methodology of measuring sodium excretion was compliance involving collection of the urine sample. Pietinen et al (25) have discussed the problem of compliance in collecting urine samples from free-living subjects. In the present study, urinary sodium was used to verify the amount of sodium ingested. The magnitude and algebraic difference between total sodium and urinary sodium of each subject for each day usually indicated whether a subject had complied with a complete urine collection. Improper urine collection by some subjects was probably the major factor for explaining the 17.3% difference between total sodium intake and urinary sodium. Body weights of the subjects did not change which eliminates the possibility of sodium retention. The amount of sodium loss from stool represents only 75–145 mg/day (26) and some sodium loss occurs by sweating. The amount of sodium loss in perspiration would be influenced by physical activity and data were collected during months when temperature and humidity were high which would further influence perspiration losses. The majority of subjects were not very active and air conditioning was available for all subjects; however, some sodium loss occurred by sweating which contributed to the above 17.3% difference. Two major advantages of using the urine method are that *1*) collection of urine by subjects is much easier than obtaining duplicate samples of food for analysis and *2*) discretionary and nondiscretionary sodium intakes are accountable.

The analyzed potassium method was the most accurate determination of potassium intake because it quantitatively measured all sources of potassium intake by the subjects. The calculated potassium method significantly ($p < 0.001$) overestimated analyzed potassium intake by 15.2%. The correlations of analyzed and calculated potassium with urinary potassium were low, indicating that urinary potassium was not very reliable in estimating potassium intake; however, compliance of collecting the urine and perspiration losses are reasons for this low correlation. Fregly (17) has recently reviewed studies on nondiscretionary potassium intake and reported a range of potassium intake from 2.1 to 5.8 g/person/day. In the present study, the range was 0.807 to 1.330 g/subject/day. Mickelson et al (26) reported that young men ingested an average daily potassium intake of 4.141 g from diets containing 2500 kcal. This value is much higher than the 1.447 g of potassium ingested by our adolescent females, but their kcal intake was also much lower.

In the present study, the mean intake of sodium and potassium did not differ during days of the wk. Other reports indicate that subjects eat differently on weekdays than on weekends (27, 28). It would appear that all days of the wk should be included in estimating sodium intake for an adolescent population group.

In this study, a problem concerning the methodology of measuring sodium and potassium intake was compliance involving collection of the duplicate food sample. The individual instances where urinary sodium or potassium were greater than total sodium or analyzed potassium, respectively, indicated that improper weighing or omission of a duplicate food sample had occurred. Compliance and subject knowledge concerning weighing procedures are essential for the success of the duplicate analysis method. Regardless of the problems involved, duplicate analysis provides a reliable quantitative procedure in determining sodium and potassium intake.

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