Original Article

Urinary Excretion of Sodium and Potassium in a Screened Cohort in Okinawa, Japan

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Information regarding daily intake of sodium (Na) is useful for both normotensive and hypertensive subjects. We measured urinary excretion of sodium (U-Na) and urinary excretion of potassium (U-K) to estimate daily salt intake in a cohort of health screening subjects in Okinawa, Japan. Urine samples were obtained from 2,411 subjects (1,554 men and 857 women) who were examined on a half-day dry-doc at the Okinawa General Health Maintenance Association (OGHMA). Four hundred and one subjects were examined twice, once between September and November in 1997, and once between September and November in 1998. The mean U-Na was 182 mEq/day for men and 176 mEq/day for women. The mean U-K was 54 mEq/day for men and 50 mEq/day for women. U-Na was higher in young men, and U-K was lower in young women. In both men and women, smokers had a significantly lower Na excretion compared to nonsmokers. Subjects treated for hypertension had a significantly lower Na excretion (173 mEq/day) compared to subjects not treated for hypertension (192 mEq/day). Our findings suggest that Na excretion in screened subjects in Okinawa is lower than the national average. Sodium excretion, however, was higher in young men than in elderly subjects, and K excretion was lower in young women than in elderly subjects. Both trends are disadvantageous for controlling hypertension. (*Hypertens Res* 2002; 25: 731–736)

Key Words: sodium, potassium, urine, screening, hypertension

Introduction

Dietary intake of sodium (Na) and potassium (K) has a significant impact on blood pressure (1, 2). Restricting Na intake and increasing K intake are effective treatments used to lower blood pressure in patients with essential hypertension (3–5). For patients with hypertension and on Na restriction, the target Na intake recommended by the Japanese Society of Hypertension Guidelines is 7 g/day (6). Twenty-four-hour urine collection, if it is complete, would be better than spot-urine when estimating a subject's daily intake of Na and K. Twenty-four-hour collection, however, is not always feasible

for mass screening. Kawasaki *et al.* derived a convenient method for estimating daily intake of Na and K that is based on the second morning voided urine sample (7–9). The method's utility has been confirmed in populations of Japan and Nepal (10).

In general, people in Okinawa live longer than people in other parts of Japan. Although the reasons for this are not clear, the phenomenon is often attributed to differences in dietary habits, such as low salt intake. The incidences of stroke, acute myocardial infarction, and end-stage renal disease (ESRD) have been studied in Okinawa. The incidence of ESRD in Okinawa is high compared to other parts of Japan. However, the incidences of stroke and acute myocar-

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dial infarction in Okinawa are similar to those in other parts of Japan (11). Recently, we showed that survivors of stroke and acute myocardial infarction had an incidence of ESRD higher than that of the general population (12). Low salt intake may help to prolong life, and thus survivors of cardiovascular events would have sufficient time to develop ESRD. Against this background, we estimated the dietary intake of Na and K in Okinawa by measuring urinary excretion of Na (U-Na) and urinary excretion of K (U-K) in a screened cohort.

Methods

Subjects

In this study, we measured the concentrations of U-Na and U-K and estimated the daily dietary Na and K of screened subjects in Okinawa, Japan. The ethical committee of the Okinawa General Health Maintenance Association (OGHMA) approved the study design. Only a field data set, which excluded information such as names and addresses, was used for this study. We obtained urine samples from subjects who visited the OGHMA for a 1-day health check (13, 14). The OGHMA has been providing data from community-based mass screenings of Okinawa residents since 1973 (15). The clinical and laboratory data have been stored in a computer registry since 1983. Individuals who visited the OGHMA clinic completed a questionnaire that covered smoking habits, alcohol consumption, exercise habits, medical history, and current medications (16). Each participant was given a physical examination, during which the responses to the questionnaire were discussed, and the physician conducted a further interview. Participants were each classified into five categories related to smoking: ex-smoker, never-smoked, and current smoker at 1–10 cigarettes per day, 11–20 cigarettes per day, or more than 20 cigarettes per day. With respect to alcohol consumption, the categories were: ex-drinker, never-drunk, and current drinker at less than 1.5 cups, 1.5–3.0 cups, and more than 3.0 cups of alcohol per day. One cup of sake contains 15% alcohol (180 ml). We also calculated and accounted for the alcohol contents of other beverages, such as whisky, wine, and beer. For exercise habits, three categories based on the frequency of exercise were used: none, 1 or 2 times per week, 3 or 4 times per week, and more than 5 times per week. Hypertension was defined as systolic blood pressure ≥ 140 mmHg, diastolic blood pressure ≥ 90 mmHg, or use of antihypertensive drugs. Diabetes mellitus (DM) was diagnosed as fasting blood glucose levels ≥ 126 mg/dl, hemoglobin A1c $\geq 7.0\%$, or use of medications for DM. Body mass index (BMI) was calculated by body weight in kg divided by height squared in m and expressed as kg/m². The collection of samples was performed twice, once between September and November 1997 and once between September and November 1998. The number of screenees was 1,511 (945 men and 566 women) in 1997

and 1,301 (885 men and 416 women) in 1998.

Estimation of Na and K Intake

Na intake was estimated by using the original method (7–9). Urinary concentrations of Na and K were measured by flame photometry with lithium used as the internal standard (Hitachi 205D; Hitachi, Tokyo, Japan) and urinary concentration of creatinine was measured by kinetic assay with Jaffe reaction. All computations were performed on a FACOM 320-E computer at the Computer Center, Nakamura Gakuen University, Fukuoka (9). The estimated 24-h urinary creatinine excretion (24 Ucr) was calculated according to the following formula:

For men

$$24\text{Ucr} = 15.1 \times \text{weight (kg)} + 7.4 \times \text{height (cm)} - 12.6 \times \text{age (year)} - 80$$

For women

$$24\text{Ucr} = 8.6 \times \text{weight (kg)} + 5.1 \times \text{height (cm)} - 4.7 \times \text{age (year)} - 75$$

The estimated 24-h U-Na and U-K were calculated according to the following formula:

For U-Na (mEq/day)

$$\text{U-Na} = 16.3 \times \sqrt{(\text{urinary Na/urinary Cr}) \times 24\text{Ucr}}$$

For U-K (mEq/day)

$$\text{U-K} = 7.2 \times \sqrt{(\text{urinary K/urinary Cr}) \times 24\text{Ucr}}$$

Statistical Analysis

Data are shown as the mean ($\pm$ SD). Student's *t*-test, both paired and unpaired, and the χ^2 test were used for comparisons of discrete variables. We used multivariate logistic regression analysis to estimate the odds ratio (95% confidence interval) of the determinants of urinary excretion of Na and K by using the SAS model (SAS Institute, Cary, USA). We used one-factor analysis of variance (ANOVA) to examine differences in mean urinary excretion of Na and K according to age groups. *P* values of less than 0.05 were taken to indicate statistical significance.

Results

Baseline clinical demographics for the screened subjects are summarized for both 1997 and 1998 in Table 1. U-Na and U-K were lower in women than in men in 1997 and 1998. U-Na in 1997 (*y*₁) was significantly correlated with U-Na in 1998 (*y*₂) for subjects who were screened both years (Fig. 1). This was also true for U-K (Fig. 2). The mean ($\pm$ SD) U-Na in 1997, 184 ($\pm$ 50) mEq/day, was significantly larger than that in 1998, 175 ($\pm$ 47) mEq/day, but the mean U-K in 1997, 54 ($\pm$ 15) mEq/day, was similar to that in 1998, 52 ($\pm$ 11) mEq/day.

The relation between U-Na and age is shown in Fig. 3, and the relation between U-K and age is shown in Fig. 4. In men, U-Na decreased with age from 201 ($\pm$ 63) mEq/day in

Table 1. Baseline Clinical Data of Screened Men and Women

	1997	1998
Men		
N	945	885
Age (years)	48.2 (10.5)	48.1 (10.1)
Range	20–79	21–74
Height (cm)	166 (6)	166 (6)
Weight (kg)	67.7 (10.2)	68.2 (10.0)
Body mass index (kg/m ²)	24.7 (3.2)	24.8 (3.1)
Systolic blood pressure (mmHg)	124 (16)	123 (18)
Diastolic blood pressure (mmHg)	77 (11)	76 (11)
Serum cholesterol (mg/dl)	207 (35)	205 (34)
Serum creatinine (mg/dl)	1.1 (0.2)	1.1 (0.2)
Urinary sodium excretion (mEq/day)	187 (51)	179 (46)
Urinary potassium excretion (mEq/day)	54 (14)	54 (11)
Women		
N	566	416
Age (years)	50.6 (10.4)	51.6 (10.9)
Range	21–80	20–81
Height (cm)	152 (5)	153 (5)
Weight (kg)	53.4 (7.0)	54.3 (8.0)
Body mass index (kg/m ²)	23.3 (2.9)	23.3 (3.3)
Systolic blood pressure (mmHg)	121 (19)	120 (18)
Diastolic blood pressure (mmHg)	73 (11)	72 (11)
Serum cholesterol (mg/dl)	210 (36)	207 (36)
Serum creatinine (mg/dl)	0.9 (0.1)	0.9 (0.2)
Urinary sodium excretion (mEq/day)	177 (48)**	172 (47)*
Urinary potassium excretion (mEq/day)	52 (17)**	49 (10)**

Data are expressed as the mean (SD). * $p < 0.05$, ** $p < 0.01$ (vs. men).

Fig. 1. Urinary sodium excretion (U-Na, mEq/day) in the 401 (276 men and 125 women) subjects screened in 1997 and 1998.

Table 2. Factors Associated with High Urinary Excretion of Sodium and Potassium in Men and Women According to a Multivariate Logistic Regression Model

Variables	Odds ratio	95% CI	p value
High urinary Na excretion			
Men (vs. women)	1.59	1.17–2.15	0.003
Age (years)	0.99	0.98–1.01	NS
BMI (kg/m ²)	1.09	1.05–1.13	< 0.0001
Hypertension (vs. NT)	1.06	0.81–1.39	NS
DM (vs. non DM)	0.58	0.36–0.93	0.02
Smoker (vs. nonsmoker)	0.57	0.43–0.74	< 0.0001
Drinker (vs. nondrinker)	0.80	0.59–1.08	NS
Exercise (vs. no exercise)	0.91	0.73–1.14	NS
High urinary K excretion			
Men (vs. women)	1.89	1.39–2.56	< 0.0001
Age (years)	1.00	0.99–1.01	NS
BMI (kg/m ²)	1.07	1.03–1.11	0.0003
Hypertension (vs. NT)	0.96	0.73–1.25	NS
DM (vs. non DM)	0.95	0.61–1.50	NS
Smoker (vs. nonsmoker)	0.69	0.53–0.89	0.005
Drinker (vs. nondrinker)	0.83	0.62–1.12	NS
Exercise (vs. no exercise)	1.09	0.87–1.37	NS

CI, confidence interval; BMI, body mass index; NT, normotension; DM, diabetes mellitus; NS, not significant. High urinary excretion of Na was ≥ 184 mEq/day and high urinary excretion of K was ≥ 54 mEq/day.

Fig. 2. Urinary potassium excretion (U-K, mEq/day) in the 401 (276 men and 125 women) subjects screened in 1997 and 1998.

subjects aged 20–29 years to $167 (\pm 36)$ mEq/day in those aged 70–79 years ($p = 0.003$), but U-K did not change with age. In women, U-Na increased with age ($p < 0.0001$) and U-K increased from $42 (\pm 10)$ mEq/day in subjects aged 20–29 years to $53 (\pm 12)$ mEq/day in those aged 70–79

Fig. 3. Urinary excretion of sodium (U-Na) according to age at screening for men and women. The number of subjects was 2,411 (1,554 men and 857 women). * $p < 0.01$ (vs. women).

Table 3. Urinary Excretion of Sodium and Potassium in Men and Women by Body Mass Index

	Body mass index (kg/m ²)		<i>p</i> value
	< 24.0	≥24.0	
Men			
<i>N</i>	667	887	
BMI	22.0 (1.5)	26.7 (2.4)	
Age (years)	47.8 (10.8)	47.8 (10.0)	NS
SBP (mmHg)	120 (16)	126 (17)	< 0.0001
DBP (mmHg)	74 (10)	78 (11)	< 0.0001
TC (mg/dl)	202 (33)	209 (35)	< 0.0001
SCr (mg/dl)	1.1 (0.2)	1.0 (0.2)	NS
U-Na (mEq/day)	176 (47)	186 (50)	< 0.0001
U-K (mEq/day)	53 (12)	56 (12)	< 0.0001
U-Na/U-K	3.5 (0.9)	3.4 (0.9)	NS
Women			
<i>N</i>	547	310	
BMI	21.4 (1.7)	26.5 (2.3)	
Age (years)	48.6 (10.7)	53.5 (2.3)	< 0.0001
SBP (mmHg)	116 (17)	128 (18)	< 0.0001
DBP (mmHg)	70 (10)	77 (10)	< 0.0001
TC (mg/dl)	204 (35)	217 (36)	< 0.0001
SCr (mg/dl)	0.9 (0.1)	0.9 (0.2)	NS
U-Na (mEq/day)	171 (46)	184 (49)	0.0006
U-K (mEq/day)	49 (15)	52 (14)	0.008
U-Na/U-K	3.6 (0.9)	3.6 (0.9)	NS

Data are expressed as the mean (SD). BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; SCr, serum creatinine; NS, not significant.

years ($p < 0.0001$). The ratio of urinary Na/K was $4.4 (\pm 1.2)$ in male subjects aged 20–29 years and $3.6 (\pm 0.7)$ in male subjects aged 70–79 years ($p = 0.006$), and $3.8 (\pm 0.9)$ in female subjects aged 20–29 years and $3.3 (\pm 0.9)$ in female subjects aged 70–79 years ($p = 0.03$).

U-Na was significantly larger in men and in subjects with

Fig. 4. Urinary excretion of potassium (U-K) according to age at screening for men and women. The number of subjects was 2,411 (1,554 men and 857 women). * $p < 0.01$ (vs. women).

Table 4. Factors Associated with the Presence ($N = 333$) and Absence ($N = 1,076$) of Hypertension

Variables	Odds ratio	95% CI	<i>p</i> value
Men (vs. women)	1.03	0.71–1.51	NS
Age (years)	1.07	1.06–1.09	< 0.0001
BMI (kg/m ²)	1.18	1.12–1.23	< 0.0001
DM (vs. non DM)	1.56	0.95–2.55	NS
Smoker (vs. nonsmoker)	0.60	0.42–0.84	0.003
Drinker (vs. nondrinker)	1.54	1.06–2.23	0.02
Exercise (vs. no exercise)	0.91	0.69–1.20	NS
Urinary Na excretion	1.08	0.80–1.45	NS
Urinary K excretion	0.94	0.70–1.26	NS

CI, confidence interval; BMI, body mass index. Urinary excretion of Na (K) was grouped into low as ≤ 183 (53) mEq/day and high as ≥ 184 (54) mEq/day.

higher BMI, and it was significantly lower in subjects with DM and smokers (Table 2). U-K was significantly larger in men and in subjects with higher BMI, and it was significantly lower in smokers (Table 2). Large BMI (≥ 24.0 kg/m²) was associated with higher systolic and diastolic blood pressure, higher total serum cholesterol, and larger U-Na and U-K in both sexes (Table 3). Presence of hypertension was associated with aging, obesity, and a drinking habit (Table 4). Smokers had less prevalence of hypertension. Neither U-Na nor U-K differed between hypertensive and normotensive subjects (Table 4). Antihypertensive medication was more prevalent in aged or obese screenees (Table 5). However, use of antihypertensive medicine did not affect the urinary excretion of Na or K (Table 5).

Discussion

Dietary salt intake is most precisely estimated using 24-h urine collection, and indeed, several clinical studies have used 24-h urine collections to measure this parameter (2–4).

Table 5. Factors Associated with Presence (N = 120) and Absence (N = 198) of Antihypertensive Medication Use

Variables	Odds ratio	95% CI	p value
Men (vs. women)	0.60	0.30–1.19	NS
Age (years)	1.05	1.02–1.08	0.003
BMI (kg/m ²)	1.13	1.05–1.22	0.002
DM (vs. non DM)	1.89	0.85–4.21	NS
Smoker (vs. nonsmoker)	1.23	0.63–2.40	NS
Drinker (vs. nondrinker)	0.86	0.43–1.74	NS
Exercise (vs. no exercise)	0.65	0.30–1.08	NS
SBP (mmHg)	0.99	0.97–1.01	NS
DBP (mmHg)	0.97	0.94–1.01	NS
Urinary Na excretion	0.99	0.56–1.74	NS
Urinary K excretion	0.79	0.45–1.40	NS

CI, confidence interval; BMI, body mass index; DM, diabetes mellitus; SBP, systolic blood pressure; DBP, diastolic blood pressure. Urinary excretion of Na (K) was grouped into low as ≤ 183 (53) mEq/day and high as ≥ 184 (54) mEq/day.

It is not practical, however, to collect 1-day urine within the setting of a community-based mass screening (17). On the other hand, the problem with the spot urine sample method is that, even among healthy individuals, Na intake varies widely (17), and it is often difficult to know whether the urine collection is precise. Kawasaki *et al.* derived a simple and convenient method for estimating U-Na by using the second morning voided urine sample and other clinical data obtained at the time of screening (8, 9). In a field study (10), this method was shown to be more accurate in estimating U-Na than the spot urine sample method. More recently, other investigators have developed an alternative method known as casual urine collection for estimating U-Na and U-K in field studies (18), although the efficacy of this method remains uncertain.

Why Na intake is lower in Okinawa than in other parts of Japan remains uncertain. Okinawa was occupied by the United States after the Second World War. Public health policy and dietary patterns changed during that period. People in Okinawa ate less salt and fewer pickles and other preserved foods than people in other parts of Japan. Fresh fruits and vegetables are available year-round in Okinawa. The average temperature is about 22.4°C, and the intradiurnal temperature difference is about 5°C throughout the year (19).

Hypertension is a significant predictor of stroke, acute myocardial infarction, and ESRD in Okinawa (11, 20). The incidences of stroke and acute myocardial infarction in Okinawa are similar to those in other parts of Japan. The incidence of ESRD, however, is above the national average in Okinawa (21, 22). However, since dialysis patients were counted as ESRD patients in calculating these averages, the incidence of ESRD may have been underestimated (23). In addition, the indications for dialysis therapy may differ among districts. We recently showed that the survivors of

stroke and acute myocardial infarction had an incidence of ESRD higher than that of the general population (12). However, data concerning the incidence of hypertension and the compliance with hypertension treatment are not available yet. We speculate that the incidence of hypertension in Okinawa is high despite the low Na intake or low compliance with treatment for hypertension. In the present cohort, only 30.7% of hypertensive men had been prescribed antihypertensive drugs.

There are several limitations in this study. First, the screened subjects may not have been representative of the general population, since they were generally concerned about their health and were in relatively good condition. Most of the subjects had jobs and even the elderly subjects were socially active. Because we collected urine samples on only one occasion, it is possible that the samples did not accurately reflect the daily variation in Na excretion (17). In addition, we did not examine for the use of diuretics or other types of medications in this study. U-Na was lower in men being treated for hypertension than in men not being treated. However, the U-Na value in men was still higher than the target amount of salt intake recommended by the Japanese Society of Hypertension Guidelines for the Management of Hypertension, which is 7 g/day (119 mEq/day of Na) (6). In this study, the Na intake was about 10.7 g/day for men and 10.3 g/day for women; these values are lower than those reported by Jumabay *et al.* (24), but higher than the United States national average (25).

In conclusion, our study suggests that the Na excretion in screened subjects in Okinawa was lower than the national average (26). Na excretion, however, was higher in young men than in elderly subjects.

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