Original Article

Population-based association between urinary excretion of sodium, potassium and its ratio with albuminuria in Chinese

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Background and Objectives: Albuminuria is a risk factor for cardiovascular and renal disease. However, little is known about the association of 24 h urinary sodium and potassium excretion with albuminuria in China. The aim of this study was to examine this association by analyzing the data from 1,975 Chinese adults living in north China. **Methods and Study Design:** Excretion of urinary sodium, potassium and albumin was assessed in a single 24-h urine sample for each participant. Height, weight, waist circumference and blood pressure were measured and body mass index was determined as weight divided by square height. Fasting blood sample was collected and fasting glucose was measured. **Results:** The average 24-h urinary sodium and potassium excretion were 232 mmol and 40.8 mmol, resulting a mean sodium to potassium ratio of 6.7. The median (Q1-Q3) 24-h urinary albuminuria excretion was 6.1 mg (4.5-8.7 mg). Overall, urinary sodium excretion was positively associated with albumin excretion (β=0.029, p<0.001). This association was independent of major cardiovascular risk factors including age, gender, systolic blood pressure, body mass index, fasting glucose, waist circumference, hypertensive drug treatment, and smoking. Moreover, the relation of sodium and albumin was similar in the subgroups stratified by gender, adiposity and diabetic status. No significant associations of potassium excretion or sodium to potassium ratio with urinary albumin excretion were observed. **Conclusions:** In cross-sectional analyses, high sodium intake was shown to be associated with increased urinary albuminuria in the general Chinese adult population, supporting salt restriction for renal and cardiovascular health benefit.

Key Words: albuminuria, China, potassium, sodium, 24-h urine

INTRODUCTION

Chronic Kidney Disease (CKD) is a worldwide public health problem. In China, 10.8% (95% CI: 10.2-11.3) adults are estimated to have CKD.[1] Albuminuria, an abnormal increase in urinary albumin excretion, is an early marker of kidney damage.[2] Evidence has been noted that albuminuria could predict end-stage renal disease risk and cardiovascular disease (CVD) events.[3-5]

Dietary sodium and potassium intakes are associated with blood pressure and cardiovascular events.[6,7] Population-wide moderate reduction of sodium intake and increase of potassium intake could prevent the onset of hypertension and consequently reduce cardiovascular events and stroke.[8,9] Sodium reduction is an advocated intervention strategy towards cardiovascular disease prevention and control in clinical practice.[10]

Sodium reduction is also a recommended modifiable life-style intervention for the patients with CKD.[11] The sodium effect on the course of kidney disease was not well-documented, might be mediated by its effect on blood pressure or having direct harmful effects on renal tissues through activated factors.[12] Recently, several studies have indicated that high sodium intake is positively related to albuminuria.[13-16] However, little is known about the association of 24 h urinary sodium and potassium excretion with albuminuria in China. Thus, we examined

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this association by using the data from a community-dwelling general Chinese population survey.

MATERIALS AND METHODS

Subjects who participated in the Shandong-Ministry of Health Action on Salt and Hypertension (SMASH) 2011 survey were analyzed. A detailed description of the SMASH 2011 survey has been previously reported.[17] Using a stratified multi-stage cluster sampling method, 2,112 adults aged 18-69 years were selected from 20 counties and districts across Shandong province, north of China. All the participants were asked to complete a face-to-face questionnaire survey, undergo an anthropometric and blood pressure examination, and provide fasting blood and timed 24-h urine samples. This study was conducted according to the guidelines of the Declaration of Helsinki, and all procedures involving human subjects were approved by the Ethics Committee of the Shandong Center for Disease Control and Prevention. Written informed consent was obtained from each participant and patient anonymity was preserved.

Anthropometric and blood pressure data

Physical examinations, including height, weight, waist circumference and blood pressure were performed by trained staff. Weight was measured barefoot and in light-clothing. Body mass index (BMI) was calculated as weight in kilograms divided by the square of height in meters. Normal weight, overweight-obesity were defined as BMI ≥18.5 but <24 kg/m^2, and BMI ≥24 kg/m^2 according to Chinese guidelines.[18]

Blood pressure was measured in a sitting position three times at 5 minute intervals on one occasion with an electronic sphygmomanometer (HEM-7071, Omron Corporation, Japan). The average of the three measures was used as individual blood pressure. Hypertension is defined as systolic blood pressure (SBP) ≥140 mmHg or diastolic blood pressure (DBP) ≥90 mmHg, or self-reported to take anti-hypertensive medications, according to JNC-7.[19]

Blood sample collection and biochemical assays

A morning sample of venous blood was drawn from each participant and centrifuged within 2 h of collection. Participants with fasting blood glucose (FBG) ≥6.1 mmol/L were invited to return for an oral glucose tolerance test (OGTT) on another day, at which time 2 h postload blood glucose (2hPBG) was tested. FBG concentration was measured by standard laboratory methods on an Olympus AU640. Diabetes was diagnosed according to the standard of the American Diabetes Association (2003).[20] Participants were defined as having type 2 diabetes if they had FBG ≥7.0 mmol/L, 2hPBG ≥11.1 mmol/L, or validated history of diabetes as diagnosed by a physician.

Serum samples were frozen at –80^{o}C and delivered to ADICON Clinical Laboratory Inc., Jinan, Shandong Province, China for assessment.

Twenty-four hour urine collection and measurements

Each participant was instructed on how to collect the 24-hour urine sample at each collection field site. The participant was given a standard plastic container with boric acid (around 1 g) as preservative, and was instructed to discard the first void and collect all the urine during the following 24 h in the container. The health professional recorded the beginning and ending time for each urine collection and the total hours between the first and last void collected. A standard questionnaire interview was conducted with each participant to assess urine collection completeness at the end. The urine volume was measured on a standard platform in the field site by a laboratory technician. All collected urine samples were kept in a freezer at –20^{o}C and were delivered to Jinan, Shandong for laboratory tests.

Urinary sodium and potassium were measured by the ion-selective electrode method on an Olympus AU680 Chemistry-Immuno Analyzer; the coefficient of variation (CV) was 1.5% for sodium and 2.5% for potassium. Urinary creatinine excretion was assessed using the picric acid method (CV=3.0%), and 24-h urinary albumin excretion (UAE) was assessed using an immuno nephelometric method (CV=7.8%), both on an Olympus AU640 Analyzer. UAE <30 mg/d, 30-299 mg/d and ≥300 mg/d were defined as normal-albuminuria, microalbuminuria and macroalbuminuria. Individual urinary excretion values were calculated as the product of concentrations in the urine and urinary volume and were corrected to 24 h.

An incompleteness of 24h urine collection was assessed by using urinary volume and gender specific urinary creatinine cut-off points. Incompleteness was defined as 24-h urinary volume <500 mL, and/or 24-h urinary creatinine <1.91 or >18.3 mmol in men, or <1.36 or >14.3 mmol in women, with these samples excluded from analysis.

Of the 2,112 participants, 88 provided incomplete 24-h urine collection and 47 had missing covariate information. Thus, the study involved 1,975 participants.

Statistical analysis

Continuous variables with a normal or approximately normal distribution are expressed as mean±standard deviation (SD). Categorical variables are shown as numbers and percentages. One-way ANOVA was used to assess the difference between groups for normally distributed data; otherwise, the Kruskal-Wallis test was used. Difference between proportions was assessed using Fisher's exact test or the Chi-square test. Spearman's correlation coefficients were calculated to evaluate correlations between continuous variables. Partial regression coefficients were estimated with adjustment for related covariates. Linear regression analysis was used to examine the association of UAE (dependent variable) with urinary sodium and potassium (independent variables), with adjustment for age, gender, BMI, waist circumference, FBG, SBP, hypertensive drug treatment, and smoking. We also repeated the linear regression analysis in subgroups, stratified by gender, adiposity, hypertensive and diabetic status.

Sensitivity analysis

We conducted several sensitivity analyses. First, we repeated our analysis by excluding the hypertensive participants who were taking drug treatments since there was reported interaction of salt intake on the protective effect of anti-hypertensive medication on renal health (i.e. rennin angiotensin blocker) (Supplemental table 1 to 2).[21]

Second, we excluded the participants with self-reported chronic disease including chronic kidney disease, cardiovascular disease and stroke, and repeated the analysis (Supplemental table 3 to 4). Awareness of the chronic disease status might have changed their intake of sodium and might reverse casualty. Third, to test the impact of incomplete 24-h urine collection, we used alternative measures of incompleteness of urine collection and repeated the multivariate analysis in the overall populations (Supplemental tables 5 to 6). We also repeated the analysis using sodium to creatinine ratio instead of urinary sodium excretion (Supplemental table 7).

Statistical analyses were performed with SAS 9.3 (SAS Institute Inc., Cary, North Carolina, USA). A p value <0.05 was considered as statistically significant.

RESULTS

Characteristics of the participants

Out of the 1,975 participants, 52.6% were male, and their average age was 41.4 yrs (SD=13.9 yrs). Approximately 23.7% of the participants were hypertensive and among the hypertensive participants, 26.3% was taking antihypertensive medication. About 51.6% of the participants were overweight or obese, and 6.2% were having diabetes.

Among all participants, the average 24-h urinary sodium and potassium excretion were 232 mmol (SD=87.4 mmol) and 40.8 mmol (SD=19.5 mmol), respectively. The sodium to potassium ratio was 6.7 (SD=3.6). The median (Q1-Q3) 24-h UAE was 6.1 mg (4.5-8.7), 4.2% and 0.1% of the participants were having microalbuminuria and macroalbuminuria, respectively.

The characteristics of the participants across quarters of urinary sodium excretion are shown in Table 1. Male participants were more likely to have higher urinary sodium excretion than females. SBP, DBP and BMI increased over the quarters of urinary sodium excretion. The prevalence of hypertension increased with increased urinary sodium excretion (Table 1). Participants with higher sodium excretion were more likely to have higher albuminuria excretion and having microalbuminuira (Figure 1, Figure 2).

Association of sodium, potassium intake and sodium-potassium ratio with UAE

The 24-h UAE was correlated with sodium excretion (r=0.107, p<0.001) (Table 2). In linear regression analysis, urinary sodium excretion was positively and significantly associated with 24-h UAE (β=0.029, p<0.001), with the multivariates adjusted (Table 3). The positive association between sodium and 24-h UAE did not differ in men and women, or by BMI and diabetic status (Table 3). Moreover, we didn't observe significant association between urinary potassium excretion, sodium-potassium ratio and 24-h UAE in overall population and by subgroup (Table 3 and Table 4).

The pattern of associations remained largely unchanged by excluding the participants currently using antihypertensive medications or with self-reported chronic disease (Supplemental table 1-4). In addition, we observed association of sodium, not potassium nor sodium-potassium ratio, with albuminuria in subsets of the study population using 5 different criteria to exclude participants with potentially incomplete urine collections (Supplemental table 5-6). When analyzing the sodium to creatinine ratio as independent variable, it was marginally associated with albuminuria among the overall population (p=0.09) (Supplement table 7).

DISCUSSION

In this cross-sectional study of general adults in Shandong province, we found that higher urinary sodium excretion, which reflects higher intake of salt, was associated with increased urinary albumin excretion, sign of early kidney damage. The above association existed after adjustment for important CVD risk factors including SBP and fasting glucose. However, we didn't observe an asso-

Table 1. Characteristics of study participants by quarters of 24-h Na, SMASH survey (n=1,975)

Characteristics	24 hour urinary Na excretion (mmol)				
	Q1	Q2	Q3	Q4	p-value
Median (min-max)	147 (22.1-180)	206 (180-230)	248 (230-258)	316 (258-751)	-
Age (years)	41.1±14.5	40.6±14.4	42.1±13.8	41.5±13.0	0.21
Men (n, %)	225 (45.0)	262 (52.6)	276 (55.8)	275 (57.1)	0.001
Smoking, %	26.4	25.9	26.3	26.1	0.99
BMI (kg/m^2)	23.6±3.7	24.3±3.9	24.7±3.5	25.5±4.1	<0.001
WC (cm)	80.3±10.5	83.3±11.0	84.2±10.1	86.7±12.2	<0.001
FBG (mmol)	5.5±1.2	5.5±1.0	5.5±1.2	5.6±1.2	0.11
SBP (mmHg)	119±17.3	122±19.3	122±18.0	124±20.5	<0.001
DBP (mmHg)	77.0±10.3	79.2±11.6	79.0±11.3	80.3±12.4	<0.001
Hypertension,%	19.8	24.7	23.3	27.0	0.04
Urinary excretion					
Volume (mL/24 h)	1,116±437	1,424±478	1,769±594	1,877±666	<0.001
Creatinine (mmol/24 h)	7.5±2.9	8.6±3.2	9.0±2.9	9.9±3.0	<0.001
Na (mmol/24 h)	138±32.1	206±15.2	247±8.1	344±86.1	<0.001
K (mmol/24 h)	32.6±18.7	39.3±17.9	42.3±17.7	49.5±20.1	<0.001
Na/K	5.4±3.5	6.5±3.8	7.0±3.5	7.9±3.3	<0.001
Na/Cr	21.5±10.9	28.1±13.7	30.9±12.5	38.0±14.9	<0.001

Q: quartile, BMI: body mass index; WC: waist circumference; FBG: fasting blood glucose; SBP: systolic blood pressure; DBP: diastolic blood pressure; Na: sodium; K: potassium; Na/K: sodium to potassium ratio; Na/Cr: sodium to creatinine ratio.
Values are expressed as mean±standard deviation unless otherwise specified.

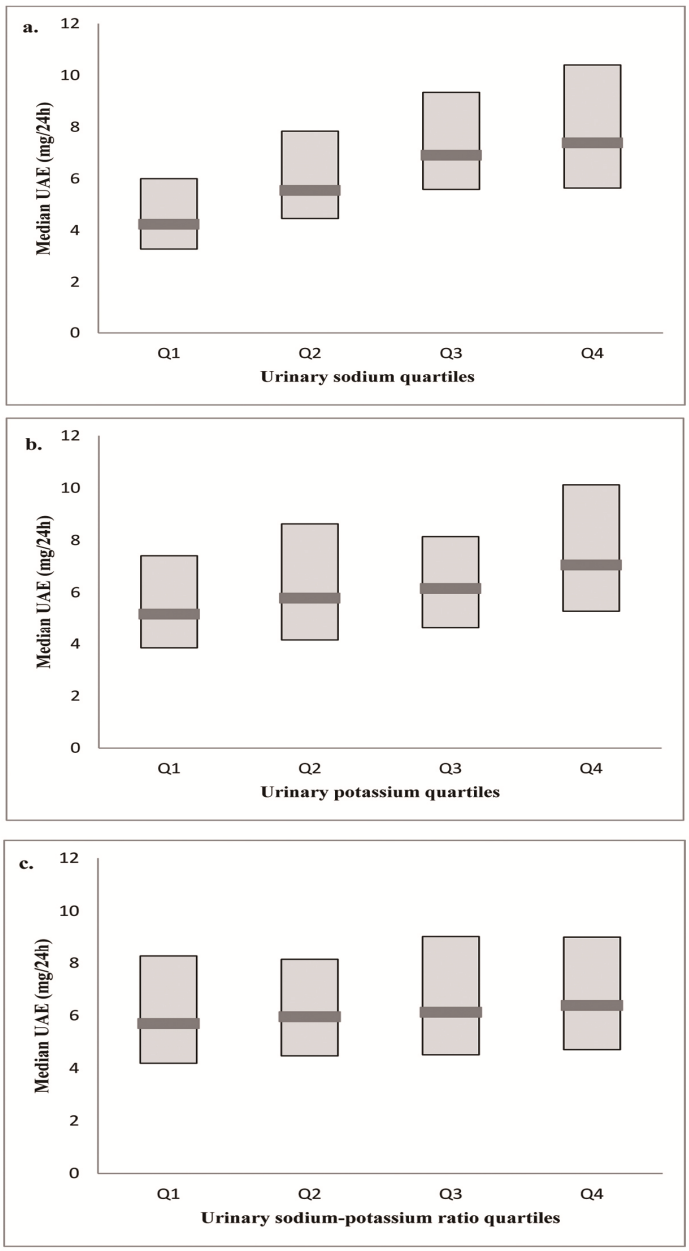

Figure 1. Median and interquartile ranges for albuminuria by quarters of urinary sodium, potassium excretion and sodium-potassium ratio, SMASH survey. Median and interquartile ranges for albuminuria by quartiles of urinary sodium, potassium and sodium-potassium ratio. The line indicates the median value and the box indicates the interquartile range. Cut points for sodium were 180, 230 and 258 mmol/24h, and cut points for potassium were 27, 37, 51 mmol/24h, and cut points for sodium-potassium ratio were 4.4, 5.8 and 8.3.

ciation of potassium excretion and sodium to potassium ratio with albumin excretion.

A link between dietary salt intake and renal target organ damage has been proposed in the experimental and human studies.[22-24] A high sodium intake might increase angiotensin-converting enzyme activity in renal and vascular tissues.[25] In addition, sodium intake might exert direct harmful effects on renal tissues through activation of transforming growth factor-β.[26] These deleterious effect on the renal vasculature by increased salt intake might result in arterial injury, consequently, albumin may leak through the blood vessel wall, and become detectable in the urine.[24] Prior studies support the positive association of salt intake and albumin, in patients or general population samples.[13-16,27,28] We extend these previous studies by examining the associations in a community dwelling general Chinese population who had high sodium intake, low potassium intake, and a high sodium-potassium ratio, and low prevalence of albuminuria.

Studies of the associations of sodium and potassium intake with albumin in Chinese residents are limited. The INTERMAP study included a Chinese sample and found an association of 24-h urinary sodium excretion with the prevalence of microalbuminuria in women, albeit not in men.[28] However, the association disappeared in the multivariate analysis with the major risk factors adjusted. The relative sample size of INTERMAP (410 men and 409 women) might limit the extension of the findings. By contrast, in our study, a significant correlation between sodium and albuminuria is consistently observed in men

and women, irrespective of the covariates adjustment. Nevertheless, the observational nature of both INTERMAP and our study could not get the causal relationship between sodium intake and albuminuria; cohort studies in Chinese population were demanded.

Several previous studies indicated that the association of sodium intake and urinary albumin excretion was modified by BMI status, such that the association was more pronounced in the overweight or obese subjects than the lean participants.[29-31] The findings were from the general population in the NHANES study and the REGARDS study or the hospital outpatient clinic in the PREVEND study. The interaction of BMI with albumin excretion was found in these studies. However, in our subgroup regression analysis by BMI status, we found that the association of sodium and albumin was similar in the normal weight participants and the overweight-obese participants. Our study had relative small sample size, compared with the previous mentioned studies. Further studies with large sample size in the Chinese population are needed to clarify whether there is effect modification by BMI on the sodium and albumin relationship.

Our study also shows that potassium intake and the ratio of sodium to potassium was not independently associated with albuminuria. These findings are conflicting with prior studies. The PREVEND study indicated that potas-

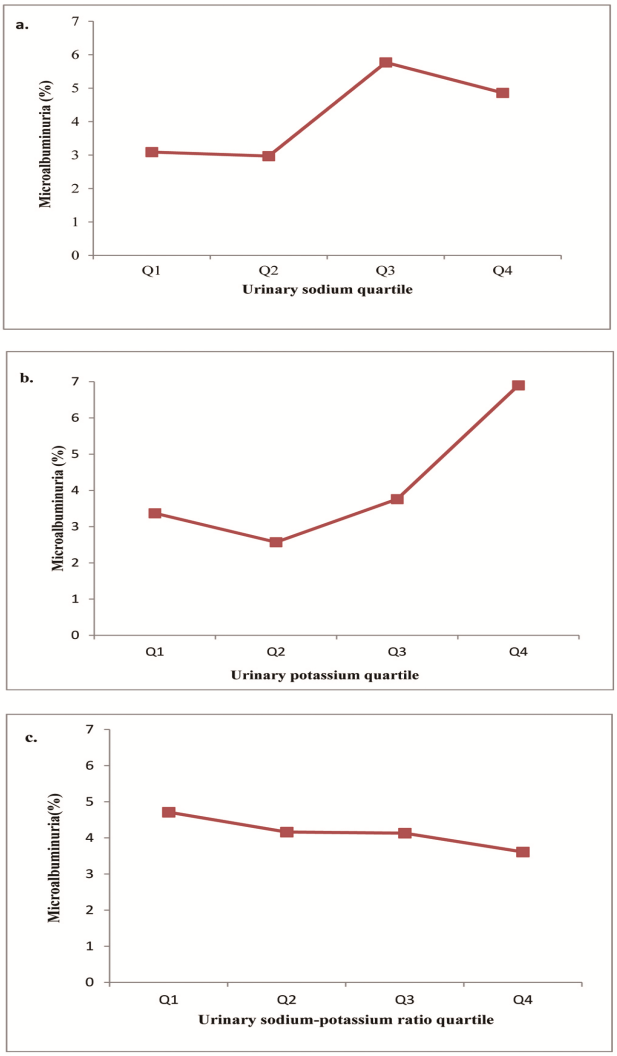

Figure 2. Prevalence of microalbuminuria by quarters of urinary sodium, potassium excretion and sodium-potassium ratio, SMASH survey. The prevalence of microalbuminuria by quarters of urinary sodium excretion were 3.1%, 3.0%, 5.8% and 4.9%, the corresponding prevalence by quarters of urinary potassium excretion were 3.4%, 2.6%, 3.8% and 6.9%, and the prevalence by quarters of sodium to potassium ratio were 4.7%, 4.2%, 4.2% and 3.6%.

Table 2. Correlation between Na, K, Na/K with albumin excretion

Variable	Urinary albumin excretion		
	Not adjusted	Adjust for age, sex†	Adjust for age, sex and SBP†
Na	0.107**	0.109**	0.101**
K	0.072*	0.069*	0.071*
Na/K	0.001	0.004	-0.006

Na: sodium; K: potassium; Na/K: sodium-potassium ratio; SBP: systolic blood pressure.
*p<0.05, **p<0.001
†Adjust potassium for the correlation of sodium with urinary albumin excretion, adjust sodium for the correlation of potassium with urinary albumin excretion.

Table 3. Linear regression of Na, K with albumin excretion in total and by subgroups†

Variable (mmol/24 h)	Beta-coefficient	p-value
All participants		
Na	0.029	<0.001
K	0.053	0.12
Gender		
Men		
Na	0.023	0.01
K	0.101	0.03
Women		
Na	0.033	0.01
K	0.014	0.78
BMI status‡		
Normal weight		
Na	0.030	0.004
K	0.037	0.40
Overweight-Obese		
Na	0.029	0.01
K	0.056	0.27
Hypertension		
Hypertensive		
Na	0.039	0.14
K	0.121	0.31
Non hypertensive		
Na	0.025	<0.0001
K	0.038	0.14
Diabetes		
Diabetic		
Na	0.094	0.02
K	0.201	0.29
Non diabetic		
Na	0.023	0.003
K	0.038	0.26

Na: sodium; K: potassium.
†Models adjusted for age, gender, BMI, waist circumference, glucose, SBP, hypertensive drug treatment, and smoking. All models contain both sodium excretion and potassium excretion.
‡The participants with BMI <18.5 were not included in the linear regression analysis by BMI status. Normal weight and overweight-obesity were defined as BMI ≥18.5 but <24 kg/m^2, and BMI ≥24 kg/m^2 according to Chinese guidelines.

Table 4. Linear regression of Na/K with albumin excretion in total and by subgroups[†]

Variable	Beta-coefficient	*p*-value
All participants	-0.043	0.80
Gender		
Women	0.073	0.79
Men	-0.079	0.70
BMI status[‡]		
Normal weight	0.187	0.43
Overweight-obese	-0.177	0.49
Hypertension		
Hypertensive	-0.298	0.56
Non-hypertensive	0.051	0.72
Diabetes		
Diabetic	-0.942	0.41
Non-diabetic	0.018	0.92

[†]Models adjusted for age, gender, BMI, Waist circumference, Glucose, SBP, hypertensive drug treatment, and smoking. All models contain both sodium excretion and potassium excretion.
[‡]The participants with BMI <18.5 were not included in the linear regression analysis by BMI status. Normal weight and overweight-obesity were defined as BMI ≥18.5 but <24 kg/m^2, and BMI ≥24 kg/m^2 according to Chinese guidelines.

sium was positively associated with urinary albumin excretion.[30] The NHANES (2001-2006) study found that individuals with the lowest potassium intake had increased odds of having chronic kidney disease compared with that of the highest potassium intake participants.[15] In the REGARDS study, no association was found between potassium intake and albuminuria.[31] It was unexpected that we didn't find an association of potassium or the sodium-potassium ratio with the albuminuria. Potassium intake was shown to decrease blood pressure and attenuate the effect of sodium, and therefore may play a protective role in the incidence of albuminuria.[7,32] The low potassium intake in Chinese population might be a partial reason that could explain this. In our study, the mean potassium intake was 1,587 mg/d and only 2.1% of the participants had met the WHO guideline of daily potassium intake to 3,510 mg/d. Yet, in US, the average potassium intake was 2,640 mg/d.[33]

A major strength of our study included use of the gold standard 24-h sodium and potassium excretion to estimate the sodium and potassium intake. Furthermore, this study included a representative sample of the general Chinese population, with rigorous data collection methods and strict quality control. Our study had several limitations worth noting. First, the cross-sectional nature of our study limited our ability to conclude any causal relationship between salt intake and albuminuria. Second, though the 24-h urinary sodium and potassium excretion was the gold standard way to measure dietary sodium and potassium intake, yet, one 24-h urine collection was not enough to cover the large intra-individual and inter-individual variation.[34] Third, the objective biomarker of completeness of urine collection was not available in our study. Using urinary volume and creatinine as alternative measurement might lead to the inclusion of some incomplete urine samples or to the exclusion of some complete urine samples and thus introduce an additional source of variability.[35] Fourth, diuretic medication was reported to have interaction on sodium and renal health, however, information of diuretic medication use was not collected, therefore we were not able to examine its effect in this study. Fifth, due to the lack of serum creatinine measurement, we were not able to examine the association of sodium and albuminuria by excluding the participants with CKD. The inclusion of participants with CKD might bias the these associations since CKD population were reported to have lower intake of sodium than the non CKD population.[15] However, a recent study reported high sodium intake is also associated with albuminuria in the CKD stage 3 patients.[36] Moreover, in our sensitive analyse by excluding the participants with self-reported chronic disease, the association of sodium, potassium and albuminuria remained unchanged. Nevertheless, the association of sodium and potassium intake and albuminura should be examined in the population by considering CKD status in the future study.

In conclusion, the main findings of the present study are that in Chinese adults, urinary sodium excretion is positively and significantly associated with urinary albumin excretion. Although further studies with longitudinal study deigns and clinical trials are needed to confirm these cross-sectional associations, findings of the present study would support recommendations for sodium reduction strategies in general population with benefits of lowering risk for kidney damage.

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AUTHOR DISCLOSURES

None of the authors had any conflicts of interest.

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Supplemental table 1. Linear regression analysis of urinary sodium and potassium, with urinary albumin excretion by excluding the participants taking antihypertensive medication (n=1,852), SMASH survey[†]

Variable (mmol/24 h)	Beta-coefficient	*p*-value
All participants		
Na	0.023	<0.0001
K	0.052	0.03
Gender		
Women		
Na	0.017	0.01
K	0.031	0.20
Men		
Na	0.025	0.004
K	0.079	0.07
BMI status[‡]		
Normal weight		
Na	0.027	0.005
K	0.056	0.18
Overweight-Obese		
Na	0.022	0.0002
K	0.034	0.20
Hypertension		
Hypertensive		
Na	0.013	0.29
K	0.141	0.01
Non hypertensive		
Na	0.025	<0.0001
K	0.039	0.15
Diabetes		
Diabetic		
Na	0.076	0.007
K	0.258	0.09
Non diabetic		
Na	0.019	<0.001
K	0.041	0.09

Na: sodium; K: potassium.
[†]Models adjusted for age, gender, BMI, waist circumference, glucose, SBP and smoking. All models contain both sodium excretion and potassium excretion.
[‡]The participants with BMI <18.5 were not included in the linear regression analysis by BMI status. Normal weight and overweight-obesity were defined as BMI ≥18.5 but <24 kg/m^2, and BMI ≥24 kg/m^2 according to Chinese guidelines.

Supplemental table 2. Linear regression analysis of sodium-potassium ratio with urinary albumin excretion by excluding the participants taking antihypertensive medication, SMASH survey[†]

Variable	Beta-coefficient	*p*-value
All participants	-0.067	0.59
Gender		
Men	-0.075	0.71
Women	-0.034	0.81
BMI status[‡]		
Normal weight	0.059	0.78
Overweight-obese	-0.107	0.44
Hypertension		
Hypertensive	-0.520	0.04
Non-hypertensive	0.051	0.72
Diabetes		
Diabetic	-0.764	0.39
Non-diabetic	-0.024	0.86

[†]Models adjusted for age, gender, BMI, Waist circumference, Glucose, SBP and smoking. All models contain both sodium excretion and potassium excretion.
[‡]The participants with BMI <18.5 were not included in the linear regression analysis by BMI status. Normal weight and overweight-obesity were defined as BMI ≥18.5 but <24 kg/m^2, and BMI ≥24 kg/m^2 according to Chinese guidelines.

Supplemental table 3. Linear regression analysis of urinary sodium and potassium excretion, with urinary albumin excretion by excluding the participants with reported chronic disease (n=1,938), SMASH survey[†]

Variable (mmol/24h)	Beta-coefficient	*p*-value
All participants		
Na	0.029	0.0002
K	0.050	0.14
Gender		
Women		
Na	0.030	0.004
K	0.037	0.40
Men		
Na	0.032	0.01
K	0.015	0.76
BMI status[‡]		
Normal weight		
Na	0.030	0.01
K	0.049	0.35
Overweight-Obese		
Na	0.041	0.13
K	0.104	0.40
Hypertension		
Hypertensive		
Na	0.041	0.13
K	0.104	0.40
Non hypertensive		
Na	0.025	<0.001
K	0.039	0.14
Diabetes		
Diabetic		
Na	0.101	0.01
K	0.171	0.40
Non diabetic		
Na	0.023	0.003
K	0.039	0.26

Na: sodium; K: potassium.
[†]Among 1,975 participants, 37 participants had self-reported chronic disease, 3 for chronic kidney disease, 14 for stroke and 25 for cardiovascular disease, leaving 1,938 participants for analysis. Models adjusted for age, gender, BMI, waist circumference, glucose, SBP, hypertensive drug treatment, and smoking. All models contain both sodium excretion and potassium excretion.
[‡]The participants with BMI <18.5 were not included in the linear regression analysis by BMI status. Normal weight and overweight-obesity were defined as BMI ≥18.5 but <24 kg/m^2, and BMI ≥24 kg/m^2 according to Chinese guidelines.

Supplemental table 4. Linear regression analysis of sodium-potassium ratio with urinary albumin excretion by excluding the participants with reported chronic disease, SMASH survey[†]

Variable[‡]	Beta-coefficient	*p*-value
All participants	-0.026	0.88
Gender		
Men	-0.051	0.80
Women	0.066	0.81
BMI status[§]		
Normal weight	0.184	0.43
Overweight-Obese	-0.131	0.61
Hypertension		
Hypertensive	-0.232	0.66
Non-hypertensive	0.050	0.72
Diabetes		
Diabetic	-0.764	0.39
Non-diabetic	-0.024	0.85

[†]Self reported chronic disease included chronic kidney disease, cardiovascular disease and stroke.
[‡]Models adjusted for age, gender, BMI, Waist circumference, Glucose, SBP, hypertensive drug treatment, and smoking. All models contain both sodium excretion and potassium excretion.
[§]The participants with BMI <18.5 were not included in the linear regression analysis by BMI status. Normal weight and overweight-obesity were defined as BMI ≥18.5 but <24 kg/m^2, and BMI ≥24kg/m^2 according to Chinese guidelines.

Supplemental table 5. Linear regression analysis of urinary sodium and potassium excretion, with urinary albumin excretion in the total population using the reported criterion, SMASH survey[†]

Criterion (mmol/24 h)[‡]	Beta-coefficient	*p*-value
Reinivuo (n=1,375)		
Na	0.024	0.01
K	0.042	0.32
WHO (n=1,554)		
Na	0.028	0.001
K	0.039	0.33
Malekshal (n=1,307)		
Na	0.023	0.01
K	0.030	0.46
Joossens and Geboers (n=1,282)		
Na	0.031	0.003
K	0.051	0.27
Knuiman (n=889)		
Na	0.031	0.002
K	0.034	0.47

Na: sodium; K: potassium.

[†]Models adjusted for age, gender, BMI, waist circumference, glucose, SBP hypertensive drug treatment, and smoking. All models contain both sodium excretion and potassium excretion.

[‡]There were 5 reported criteria for 24-h urine sample completeness, Reinivuo's, WHO's, Malekshal's, Joossens and Geboers's, Knuiman's. Reinivuo's criterion to classify incompleteness of 24 hour urine collection is urinary creatinine level <6 mmol/d plus a total urine volume <1000 ml/d. (Reinivuo H, Valsta LM, Laatikainen T et al. Sodium in the Finnish diet: II trends in dietary sodium intake and comparison between intake and 24-h excretion of sodium. Eur J Clin Nutr. 2006;60:1160-7). WHO's criterion to classify incompleteness of 24 hour urine collection is ratio of urinary creatinine (mg/d) to body weight (kg) <10.8 or >25.2. (WHO Regional Office for Europe. Estimation of sodium intake and output: review of methods and recommendations for epidemiological studies. Report on a WHO meeting by the WHO collaborating center for research and training in cardiovascular disease. Geneva: World Health Organization; 1984) Malekshal's criterion to classify incompleteness of 24 hour urine collection is ratio of urinary creatinine (mg/d)to body weight (kg) <11 or >20. (Malekshah AF, Kimiagar M, Saadatian-Elahi M et al. Validity and reliability of a new food frequency questionnaire compared to 24 h recalls and biochemical measurements: pilot phase of Golestan cohort study of esophageal cancer. Eur J Clin Nutr. 2006;60:971-7) Joossens and Geboers's criterion to classify incompleteness of 24 hour urine collection is gender specific ratio of urinary creatinine (mmol/d) to body weight (kg) <0.6. (Joossens JV, Geboers J. Monitoring salt intake of the population: methodological considerations.Wageningen: Department of Human Nutrition, Agricultural University; 1984.) Knuiman's criterion to classify incompleteness of 24hour urine collection is gender specific ratio of urinary creatinine (mmol/d) to body weight (kg) <0.7. (Knuiman JT, Hautvast JG, van der Heyden L et al. A multicentre study on completeness of urine collection in 11 European centres. I. Some problems with the use of creatinine and 4-aminobenzoic acid as markers of the completeness of collection. Hum Nutr Clin Nutr. 1986;40:229-37.)

Supplemental table 6. Linear regression analysis of urinary sodium to potassium ratio with urinary albumin excretion in the total population using the reported criterion, SMASH survey[†]

Criterion[‡]	Beta-coefficient	*p* -value
Reinivuo (n=1,375)	-0.052	0.84
WHO (n=1,554)	0.058	0.80
Malekshal (n=1,307)	0.010	0.97
Joossens and Geboers (n=1,282)	0.052	0.86
Knuiman (n=889)	0.195	0.49

[†]Models adjusted for age, gender, BMI, waist circumference, glucose, SBP hypertensive drug treatment, and smoking.

[‡]There were 5 reported criteria for 24-h urine sample completeness, Reinivuo's, WHO's, Malekshal's, Joossens and Geboers's, Knuiman's. Reinivuo's criterion to classify incompleteness of 24hour urine collection is urinary creatinine level<6mmol/d plus a total urine volume <1,000 ml/d. (Reinivuo H, Valsta LM, Laatikainen T et al. Sodium in the Finnish diet: II trends in dietary sodium intake and comparison between intake and 24-h excretion of sodium. Eur J Clin Nutr. 2006;60:1160-7). WHO's criterion to classify incompleteness of 24 hour urine collection is ratio of urinary creatinine (mg/d) to body weight (kg) <10.8 or >25.2. (WHO Regional Office for Europe. Estimation of sodium intake and output: review of methods and recommendations for epidemiological studies. Report on a WHO meeting by the WHO collaborating center for research and training in cardiovascular disease. Geneva: World Health Organization; 1984) Malekshal's criterion to classify incompleteness of 24hour urine collection is ratio of urinary creatinine (mg/d)to body weight (kg) <11 or >20. (Malekshah AF, Kimiagar M, Saadatian-Elahi M et al. Validity and reliability of a new food frequency questionnaire compared to 24 h recalls and biochemical measurements: pilot phase of Golestan cohort study of esophageal cancer. Eur J Clin Nutr. 2006;60:971-7) Joossens and Geboers's criterion to classify incompleteness of 24 hour urine collection is gender specific ratio of urinary creatinine (mmol/d) to body weight (kg) <0.6. (Joossens JV, Geboers J. Monitoring salt intake of the population: methodological considerations.Wageningen: Department of Human Nutrition, Agricultural University; 1984) Knuiman's criterion to classify incompleteness of 24 hour urine collection is gender specific ratio of urinary creatinine (mmol/d) to body weight (kg) <0.7. (Knuiman JT, Hautvast JG, van der Heyden L et al. A multicentre study on completeness of urine collection in 11 European centres. I. Some problems with the use of creatinine and 4-aminobenzoic acid as markers of the completeness of collection. Hum Nutr Clin Nutr. 1986;40:229-37).

Supplemental table 7. Linear regression analysis of sodium/creatinine and potassium with urinary albumin excretion in the total population (n=1,975), SMASH survey[†]

Variable	Beta-coefficient	*p*-value
All participants	0.074	0.09
Gender		
Men	0.040	0.46
Women	0.110	0.23
BMI status[‡]		
Normal weight	0.063	0.26
Overweight-Obese	0.087	0.21
Hypertension		
Hypertensive	0.074	0.59
Non-hypertensive	0.074	0.04
Diabetes		
Diabetic	0.004	0.99
Non-diabetic	0.081	0.06

[†]Models adjusted for age, gender, BMI, waist circumference, glucose, SBP, hypertensive drug treatment, smoking and urinary potassium excretion.
[‡]The participants with BMI <18.5 were not included in the linear regression analysis by BMI status. Normal weight and overweight-obesity were defined as BMI ≥18.5 but <24 kg/m^2, and BMI ≥24 kg/m^2 according to Chinese guidelines.

Original Article

Population-based association between urinary excretion of sodium, potassium and its ratio with albuminuria in Chinese

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中国人群尿钠、尿钾及其比值与蛋白尿的关系

背景与目的：研究表明蛋白尿是心脏病和肾病的一个危险因素。本研究的目的是探讨 24 小时尿钠、尿钾及其比值与蛋白尿的关系。**方法与研究设计：**本研究纳入了 1,975 名居住在中国北方人群，收集其完整的一次 24 小时尿样，测量尿钠、尿钾和尿白蛋白，并测量身高、体重、腰围、血压和空腹血糖等。**结果：**调查人群的 24 小时尿钠和尿钾均值为 232 mmol 和 40.8 mmol，尿钠钾比值为 6.7。24 小时尿白蛋白的中位数为 6.1 mg，25 分位数和 75 分位数为 4.5 mg 和 8.7 mg。尿钠与尿白蛋白排泄量呈显著正相关（β=0.029，p<0.001），独立于年龄、性别、血压、体重指数、血糖等主要的心血管病危险因素。未发现尿钾和尿钠钾比值与尿白蛋白的关联有统计学意义。**结论：**该横断面研究表明中国人群高钠盐摄入与高尿白蛋白排泄密切相关，减盐对心血管和肾的健康有益。

关键词：蛋白尿、中国、钠、钾、24小时尿