Association between 24 h urinary sodium and potassium excretion and the metabolic syndrome in Chinese adults: the Shandong and Ministry of Health Action on Salt and Hypertension (SMASH) study

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Abstract
The association of 24 h urinary Na and potassium excretion with the risk of the metabolic syndrome (MetS) has not been studied in China. The aim of the present study was to examine this association by analysing the data from 1906 study participants living in north China. To this end, 24 h urine samples were collected. Of the 1906 participants, 471 (24·7 %) had the MetS. The mean urinary Na and K excretion was 228·7 and 40·8 mmol/d, respectively. After multivariate adjustment, the odds of the MetS significantly increased across the increasing tertiles of urinary Na excretion (1·00, 1·40 and 1·54, respectively). For the components of the MetS, the odds of central obesity, elevated blood pressure and elevated TAG, but not the odds of low HDL-cholesterol and elevated fasting glucose, significantly increased with the successive tertiles of urinary Na excretion. Furthermore, for every 100 mmol/d increase in urinary Na excretion, the odds of the MetS, central obesity, elevated blood pressure and elevated TAG was significantly increased by 29, 63, 22 and 21%, respectively. However, urinary K excretion was not significantly associated with the risk of the MetS. These findings suggest that high Na intake might be an important risk factor for the MetS in Chinese adults.

Key words: Urinary sodium excretion: 24 h Urinary potassium excretion: Metabolic syndrome: Cross-sectional studies: China

High Na intake is a serious public health challenge in China and worldwide because of its contribution to the high prevalence and concomitant risks of elevated blood pressure and CVD(1,2). Na intake has been reported to be higher in the Asian than in the Western population, with the intake being highest in the Chinese population(3). According to the 2010 Report on Chronic Disease Risk Factor Surveillance in China, the average salt intake per family member is estimated to be about 10·6 g/d. More worryingly, approximately 81 and 73% of individuals have been reported to consume over 5 and 6 g/d, respectively(4).

Previous studies have demonstrated that high Na intake was positively associated with blood pressure, and the risk of stroke and CVD(1,2,5–8). Although several studies, attempting to examine the relationship between Na intake and the risk of the metabolic syndrome (MetS), have been conducted globally(9–15), detailed analyses evaluating the association between the risk of high Na intake estimated by 24 h urinary Na excretion and the MetS have been limited(13–15). Meanwhile, none of the population-based studies has specifically examined the association of 24 h urinary Na excretion with the risk of the MetS among Chinese adults.

Therefore, in the present study, we analysed the data from 1906 Chinese adults to examine the association between 24 h urinary Na and K excretion and the risk of the MetS among Chinese adults.

Methods

Participants

In 2011, the Shandong and Ministry of Health Action on Salt and Hypertension (SMASH) Project was conducted initially. Details of the study design and preliminary results have been published previously(16). Briefly, the study used a four-stage stratified sampling method to select a provincially representative sample of the general adult population aged...
Data collection

Information on variables, including demographic characteristics, smoking habit, alcohol consumption, leisure-time physical activity, as well as previous diagnosis and treatment of hypertension and diabetes, was collected at local health stations, in community clinics, or during home visits by specially trained research staff using a standard questionnaire. High school education was defined as having ≥ 9 years of schooling. Alcohol consumption was defined as drinking alcohol at least twelve times during the past year. Smoking was defined as having smoked at least 100 cigarettes across lifetime.

Overall, three blood pressure measurements were obtained in the sitting position after at least 5 min of rest by trained investigators. Waist circumference was measured at 1 cm above the navel at minimal respiration. Body weight and height were measured with participants wearing light indoor clothing without shoes during clinical examination. BMI was calculated as weight (in kg) divided by height (in m²).

Overnight fasting blood specimens (≥ 10 h) were obtained at the examination centres and shipped to Jinan ADICON Clinical Laboratories where the measurements of fasting plasma glucose, TAG, as well as HDL-cholesterol concentrations were made. Plasma glucose concentration was measured using a modified hexokinase enzymatic method. Serum cholesterol and TAG levels were analysed enzymatically using commercially available reagents.

Additionally, a single 24 h urine sample was collected from each participant. All participants were instructed orally on the collection of 24 h urine samples. Each participant was provided with two urine collection plastic containers, with boric acid (about 1 g) being used as a preservative in each container. Participants were asked to discard the first specimen ($b → 10 h$) were obtained and measured by urine volume and urinary creatinine excretion. Urinary salt excretion and metabolic syndrome

The MetS was defined according to the harmonised criteria as the presence of three or more of the following risk factors: (1) central obesity – waist circumference ≥ 90 cm for Chinese men and ≥ 80 cm for Chinese women; (2) elevated blood pressure – systolic blood pressure ≥ 130 mmHg and/or diastolic blood pressure ≥ 85 mmHg, or antihypertensive drug treatment for patient with hypertension; (3) elevated TAG – fasting plasma TAG level ≥ 1.7 mmol/l or drug treatment for elevated TAG level; (4) reduced HDL-cholesterol – fasting HDL-cholesterol < 1.0 mmol/l in men and < 1.3 mmol/l in women, or drug treatment for reduced HDL-cholesterol level; (5) elevated fasting glucose – fasting glucose level ≥ 5.6 mmol/l or drug treatment for elevated glucose level.

Statistical analysis

Data are expressed as either means and standard deviations for continuous variables or percentages for categorical variables. Study participants were classified into three categories according to their 24 h urinary Na excretion (< 195.4 mmol, 195.4–252.0 mmol and ≥ 252.0 mmol) and 24 h urinary K excretion (< 30.7 mmol/l, 30.7–45.5 mmol/l and ≥ 45.5 mmol/l), separately.

Logistic regression models were applied to estimate OR and 95% CI for the odds of the MetS according to 24 h urinary Na or K excretion, adjusted for age, sex, education level (less than high school or high school graduate), smoking habit, leisure-time physical activity, alcohol consumption, hypertension, as well as urbanisation (urban vs. rural). Participants with 24 h urinary excretion of Na < 195.4 mmol or K < 30.7 mmol/l were used as reference groups for those analyses estimating OR and 95% CI. The presence of a linear trend was tested by using the medians of the average 24 h urinary Na excretion in each group treated as a continuous variable in the logistic regression models.

All statistical analyses were conducted using SAS software version 9.3 (SAS Institute, Inc.). All tests were two-sided, and a $P$ value of $< 0.05$ was considered statistically significant.

Results

On average, 1003 (52.6%) of the study participants were men and 903 (47.4%) were women. Table 1 shows the characteristics of the study participants by MetS status. Of the 1906 participants, 471 (24.7%) had the MetS. Participants with the MetS were older and more likely to have higher mean systolic and diastolic blood pressure, waist circumference, BMI, fasting glucose, TAG and 24 h Na excretion compared with their counterparts without the MetS. However, high school education and HDL-cholesterol were more prevalent in participants without the MetS (Table 1).

For all participants, the respective mean 24 h urinary Na and K excretion was 228.7 and 40.8 mmol/l. The 24 h urinary Na excretion was significantly higher among participants with central obesity, elevated blood pressure or elevated TAG than among those without these risk factors. Similarly, 24 h...
urinary K excretion was statistically significantly associated with central obesity (Table 2). In addition, mean 24 h urinary Na excretion for participants with none (n 498), one (n 511), two (n 426), three (n 302), and four or five (n 169) of the metabolic risk factors was 214·9, 227·2, 233·5, 241·3 and 238·7 mmol, respectively. The corresponding 24 h urinary K excretion was 39·0, 40·7, 41·7, 42·3 and 41·2 mmol, respectively. In aggregate, mean 24 h urinary Na but not K excretion significantly increased with the number of metabolic risk factors (P for linear trend <0·001 and P for linear trend =0·12, respectively; Fig. 1).

As expected, 24 h urinary Na excretion was a strong independent predictor of the risk of the MetS. The respective multivariate-adjusted OR for the MetS compared with participants with 24 h urinary Na excretion 195·4–252·0 and ≥252·0 mmol was 1·40 (95 % CI 1·05, 1·87) and 1·54 (95 % CI 1·16, 2·06) for participants with 24 h urinary Na excretion 195·4–252·0 and ≥252·0 mmol. A statistically significant dose–response relationship between 24 h Na excretion and the odds of the MetS was documented (P for linear trend <0·05; Table 3). Increases in 24 h urinary Na excretion were associated with significantly increased odds of the MetS. In general, an increase in 24 h urinary Na of 100 mmol was significantly associated with a 29 % increased odds of the MetS (OR 1·29, 95 % CI 1·12, 1·48; Table 4). However, no significantly positive association was observed between 24 h urinary K excretion and the risk of the MetS (Table 3).

As for the components of the MetS, the odds of central obesity, elevated blood pressure and elevated TAG significantly increased across the increasing tertiles of 24 h urinary Na excretion (1·00, 1·45 and 2·32, respectively, for central obesity; 1·00, 1·38 and 1·54, respectively, for elevated blood pressure; 1·00, 1·68 and 1·66, respectively, for elevated TAG; Table 2).

<table>
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<tr>
<th>Participant (n)</th>
<th>24 h Na excretion</th>
<th>24 h K excretion</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 h Urinary Na</td>
<td>24 h Urinary K</td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td></td>
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<tr>
<td>Central obesity</td>
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<td>No</td>
</tr>
<tr>
<td>Yes</td>
<td>834</td>
<td>1072</td>
</tr>
<tr>
<td>243·3 (87·8)</td>
<td>217·2 (76·3)</td>
<td></td>
</tr>
<tr>
<td>&lt;0·001</td>
<td>&lt;0·001</td>
<td></td>
</tr>
<tr>
<td>Elevated blood pressure</td>
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<td>No</td>
</tr>
<tr>
<td>Yes</td>
<td>679</td>
<td>1227</td>
</tr>
<tr>
<td>237·8 (83·2)</td>
<td>223·6 (81·7)</td>
<td></td>
</tr>
<tr>
<td>&lt;0·001</td>
<td>0·87</td>
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<td>Elevated TAG</td>
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<td>1499</td>
</tr>
<tr>
<td>241·2 (83·8)</td>
<td>225·3 (81·9)</td>
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</tr>
<tr>
<td>&lt;0·001</td>
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<td></td>
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<td>No</td>
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<tr>
<td>Yes</td>
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<td>1496</td>
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<td>223·8 (79·8)</td>
<td>230·0 (83·2)</td>
<td></td>
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<td>0·18</td>
<td>0·55</td>
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<td>1255</td>
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<td>227·7 (86·5)</td>
<td>229·2 (80·4)</td>
<td></td>
</tr>
<tr>
<td>0·72</td>
<td>0·16</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Mean 24 h urinary excretion of sodium and potassium among the participants with and without each component of the metabolic syndrome (Mean values and standard deviations)
Na excretion
example, compared with participants with 24 h urinary were similar to those reported in the main analysis. For
of 1371 participants were retained for this analysis. All results
the participants with incomplete 24 h urine samples, a total
found online at http://www.journals.cambridge.org/bjn

Fig. 1. Mean 24 h urinary (a) sodium and (b) potassium excretion according
to the number of metabolic risk factors. A colour version of this figure can be
found online at http://www.journals.cambridge.org/bjn

P (for linear trend <0·05 for all). Overall, for each increment of
100 mmol 24 h urinary Na excretion, the odds of central obesity,
elevated blood pressure and elevated TAG was 63, 22 and
21 % higher, respectively (Table 4). Nevertheless, 24 h urinary
K excretion was not significantly associated with the com-
ponents of the MetS apart from central obesity (Table 3).

Sensitivity analysis
We conducted a sensitivity analysis by applying creatinine
coefficients, calculated as urinary creatinine excretion
(in mg/d) divided by weight (in kg), to assess the complete-
ness of 24 h urine collections. Creatinine coefficients of
14·4–33·6 in men and 10·8–25·2 in women were categorised
as an acceptable 24 h urine collection(19). After exclusion of
the participants with incomplete 24 h urine samples, a total
of 1371 participants were retained for this analysis. All results
were similar to those reported in the main analysis. For example, compared with participants with 24 h urinary
Na excretion <195·4 mmol, the multiple-adjusted OR for
those with 24 h urinary Na excretion 195·4–252·0 and
≥252·0 mmol were 1·77 (95 % CI 1·26, 2·49) and 1·77 (95 %
CI 1·26, 2·49) for the MetS, respectively.

Discussion
Data from the present study identified that 24 h urinary Na
but not K excretion significantly increased with number of
metabolic risk factors. As expected, we found a signifi-
cant dose–response relationship between 24 h urinary Na
excretion and the risk of the MetS, even after adjustment for
multiple risk factors. It indicates that high Na intake is a
stronger independent predictor of the risk of the MetS.
Moreover, high Na intake was significantly associated
with the risk of MetS components, including central obesity,
elevated blood pressure and elevated TAG. However, there
was no significant association between K intake and the risk
of the MetS. Our findings clearly illustrate the public health
importance of the reduction of Na intake for preventing
the MetS.

To our knowledge, this was the first study to report the
association of Na and K intake assessed by 24 h urine
sample with the risk of the MetS in China. It has important
clinical and public health implications because high Na
intake and the risk of the MetS are becoming common in
the Chinese adult population(6,20). Accordingly, these findings
contribute to the existing literature and provide new and
important information in relation to the relationship between
Na intake and the risk of the MetS in the Chinese general
adult population, and suggest that the reduction of Na
intake should be an important priority for reducing the preva-
ience of the MetS in China.

We observed that Na intake significantly increased with
the number of metabolic risk factors, which is in line with
previous studies(11,14,15), but inconsistent with the finding
of a cross-sectional study conducted in 781 normotensive
Brazilian adults aged 25–64 years(12). This inconsistency
could be, in part, due to the estimation of Na intake in 12 h
nocturnal urine samples in the Brazilian study.

In most but not all studies, high Na intake has been
identified as a risk factor of the MetS(10–15). To date, only
two previous studies have attempted to quantify the associ-
ation between Na intake and the risk of the MetS(11,13).
Baudrand et al(13) reported that compared with participants
having urinary Na excretion ≤150 mEq/24 h, those with
urinary Na excretion >150 mEq/24 h were significantly
associated with the elevated risk of the MetS (OR 3·98, 95 % CI 2·15,
7·36) among 370 participants aged 18–85 years(12). This inconsistency
could be, in part, due to the estimation of Na intake in 12 h
to nocturnal urine samples in the Brazilian study.

Urinary salt excretion and metabolic syndrome
Table 3. Adjusted OR of the metabolic syndrome and its components according to tertiles of 24 h urinary sodium and potassium excretion
(Odds ratios and 95 % confidence intervals)

<table>
<thead>
<tr>
<th></th>
<th>24 h Urinary Na excretion (mmol)</th>
<th>24 h Urinary K excretion (mmol)</th>
<th></th>
<th></th>
<th></th>
<th></th>
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<th>P for linear trend</th>
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<tr>
<td></td>
<td>&lt; 195·4</td>
<td>195·4–252·0</td>
<td>≥ 252·0</td>
<td>&lt; 30·7</td>
<td>30·7–45·5</td>
<td>≥ 45·5</td>
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</tr>
<tr>
<td></td>
<td>OR</td>
<td>OR</td>
<td>95 % CI</td>
<td>OR</td>
<td>OR</td>
<td>95 % CI</td>
<td>P</td>
<td></td>
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<td>Metabolic syndrome</td>
<td>1·00</td>
<td>1·40</td>
<td>1·07, 1·83</td>
<td>1·52</td>
<td>1·17, 1·98</td>
<td>0·002</td>
<td>1·00</td>
<td>1·29</td>
</tr>
<tr>
<td></td>
<td>Model*</td>
<td>1·00</td>
<td>1·40</td>
<td>1·05, 1·87</td>
<td>1·54</td>
<td>1·16, 2·06</td>
<td>0·004</td>
<td>1·00</td>
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<td></td>
<td>Model†</td>
<td>1·00</td>
<td>1·40</td>
<td>1·45</td>
<td>1·14, 1·85</td>
<td>2·32</td>
<td>1·82, 2·96</td>
<td>&lt;0·001</td>
</tr>
<tr>
<td>Central obesity</td>
<td>1·00</td>
<td>1·34</td>
<td>1·07, 1·69</td>
<td>2·01</td>
<td>1·60, 2·52</td>
<td>&lt;0·001</td>
<td>1·00</td>
<td>1·23</td>
</tr>
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<td>Model*</td>
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<td>1·45</td>
<td>1·45</td>
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<td>2·32</td>
<td>1·82, 2·96</td>
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</tr>
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<td>Model†</td>
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<td>1·45</td>
<td>1·45</td>
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<td>2·32</td>
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<td>1·57</td>
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<td>1·00</td>
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<td>1·10, 2·16</td>
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<tr>
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<td>1·00</td>
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<td>0·89</td>
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<td>0·84</td>
<td>0·66, 1·07</td>
<td>0·92</td>
<td>0·72, 1·16</td>
<td>0·50</td>
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</tr>
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Model* Adjusted for age.
Model† Adjusted for age, sex, high school education, urbanisation, leisure-time physical activity, alcohol consumption, smoking habit and hypertension.
A recent multi-ethnic cohort study has found that urinary Na excretion is associated with the risk of the MetS. However, these estimates were based on a small sample of 52 centres from 32 countries. The INTERSALT study, conducted in 1975–80, and the INTERMAP study, conducted in 2000–2003, have documented that urinary Na excretion is an independent predictor of the risk of CVD mortality. It has been documented that waist circumference significantly increased with Na intake. Additionally, in a prospective cohort study of 1935 Finnish aged 35–64 years, high Na intake has been significantly associated with the increased risk of central obesity. The INTERSALT study (an international study of electrolyte excretion and blood pressure) conducted in 52 centres from 32 countries has suggested that a 100 mmol increase in 24 h urinary Na excretion was associated with at least 2.2 mmHg increase in systolic blood pressure. Consistently, in the present study, the odds of elevated blood pressure increased across the tertiles of 24 h urinary Na excretion. However, Stolarz-Skrzypek et al. (23) found that there was no significant relationship between 24 h urinary Na excretion and the risk of incident hypertension. In summary, the present study reported an independent and dose–response association between 24 h urinary Na excretion and the odds of the MetS. However, no significant association was observed between 24 h urinary K excretion and the odds of the MetS. These findings suggest that the reduction of Na intake should be a potential approach for reducing the risk of the MetS and its societal burden in China.

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The authors declare that there are no conflicts of interest.

References


