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Are 24 h urinary sodium excretion and sodium:potassium independently associated with obesity in Chinese adults?

Zeng Ge[1], Jiyu Zhang[2], Xiaorong Chen[1], Liuxia Yan[1], Xiaolei Guo[2], Zilong Lu[2], Aiqiang Xu[2] and Jixiang Ma[1,*]

[1]National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, No. 27 Nanwei Road, Xicheng District, Beijing 100050, People's Republic of China: [2]Department of Chronic and Noncommunicable Disease Control and Prevention, Shandong Center for Disease Control and Prevention, Jinan, People's Republic of China

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Abstract

Objective: To examine the association of 24 h urinary Na excretion and Na:K with obesity in Chinese adults.

Design: Population-based cross-sectional study using a four-stage stratified sampling strategy.

Setting: Shandong Province, China.

Subjects: Chinese adults (*n* 1906) aged 18–69 years who provided complete 24 h urine samples.

Results: Odds of obesity increased significantly across increasing quartiles of urinary Na excretion (1·00, 1·54, 1·69 and 2·52, respectively, for overweight; 1·00, 1·20, 1·50, and 2·03, respectively, for obesity; 1·00, 1·44, 1·85 and 2·53, respectively, for abdominal obesity (assessed by waist circumference); and 1·00, 1·28, 1·44 and 1·75, respectively, for abdominal obesity (assessed by waist-to-height ratio); *P* for linear trend <0·001 for all). In addition, odds of abdominal obesity, but not odds of overweight and obesity, increased significantly with successive Na:K quartiles. Additionally, for each increment in urinary Na excretion of 100 mmol, odds of overweight, obesity, abdominal obesity (by waist circumference) and abdominal obesity (by waist-to-height ratio) increased significantly by 46 %, 39 %, 55 % and 33 %, respectively. Similarly, with a 1 SD increase in Na:K, odds of abdominal obesity (by waist circumference) and abdominal obesity (by waist-to-height ratio) increased significantly by 12 % and 15 %, respectively.

Conclusions: These findings suggest that 24 h urinary Na excretion and Na:K might be important risk factors for obesity in Chinese adults.

Keywords
24 h urinary Na excretion
Na:K
Obesity
Cross-sectional studies
China

Obesity is a serious public health challenge in China and worldwide because of its high prevalence and concomitant risks of CVD and all-cause mortality[1,2]. According to the 2002 China Health and Nutrition Survey and the 2010 Report on Chronic Disease Risk Factor Surveillance in China, obesity has become more common and its prevalence increased from 7·1 % in 2002 to 12·0 % in 2010[3,4]. The 2004, 2007 and 2010 Report on Chronic Disease Risk Factor Surveillance in China also demonstrated this trend[4]. In addition, Na intake is higher in Asian than in Western populations, and is highest in Chinese[5]. Currently, the average salt intake of the Chinese adult population is estimated at about 10·6 g/d, more than double the intake of <5 g/d recommended by the WHO[4]. Accordingly, identifying the association between Na intake and obesity has important public health implications for preventing obesity.

Na intake can be estimated by timed or spot urine Na measurements, duplicate diets and dietary surveys, with 24 h urine collection regarded as the gold standard method. Previous studies have identified that high Na intake is a risk factor for CVD incidence and mortality[6,7]. Although several studies, attempting to examine the relationship between high Na intake and risk of obesity, have been conducted globally[8–12], detailed analyses evaluating the risk of high Na intake estimated by 24 h urinary Na excretion on obesity have been limited[8,12]. Additionally, only one previous study explored the association between Na:K estimated by early-morning first-void urine samples and total-body percentage fat measured by dual-energy X-ray absorptiometry[13]. In the meantime, no population-based study has specifically examined the effect of 24 h urinary Na excretion as well as Na:K on the risk of obesity among Chinese adults.

*Corresponding author: Email majix@163.com

Therefore, in the present study, we analysed group data from a cross-sectional study of Chinese adults to examine the link between 24 h urinary Na excretion and Na:K and risk of obesity among Chinese adults.

Methods

Participants

In 2011, the Shandong and Ministry of Health Action on Salt and Hypertension (SMASH) project was conducted. Details of the study design and preliminary results have been published previously[14]. Briefly, the study used a four-stage stratified sampling method to select a provincially representative sample of the general adult population aged 18–69 years in China. Two thousand one hundred and twelve participants were randomly selected and invited to provide 24 h urine samples. Finally, 1906 participants were identified and retained for the current analysis, after we excluded eighty-eight participants with incomplete 24 h urine collections and 118 missing other variables of interest. The study was approved by the Shandong Center for Disease Control and Prevention Ethics Committee. All study participants gave written informed consent.

Data collection

Information on variables, including demographic characteristics, smoking, 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 by 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[2]. Smoking was defined as having smoked at least 100 cigarettes across one's lifetime[15].

Body weight and height were measured with participants wearing light indoor clothing without shoes during clinical examination, and BMI was calculated as weight in kilograms divided by the square of height in metres. Waist and hip circumferences were measured by using a flexible plastic tape while the participant was in standing position. Overweight was defined as BMI ≥25·0 kg/m^2 and obesity was defined as BMI ≥30·0 kg/m^2[16]. Waist-to-hip ratio (WHR) was calculated as waist circumference (WC) in metres divided by hip circumference in metres. Abdominal obesity was defined as WC ≥85 cm for men and ≥80 cm for women[17] or WHR >0·90 for men and >0·85 for women[18].

Overnight fasting blood specimens (≥10 h) were obtained at the examination centres and shipped to Jinan ADICON Clinical Laboratory where the measurements of fasting plasma glucose, TAG and HDL cholesterol were performed. Plasma glucose 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 and also shipped to Jinan ADICON Clinical Laboratory to be analysed for Na and K concentration using an ion-selective electrodes method with an Olympus AU680 autoanalyser (CV was 1·5 % for Na and 2·5 % for K). Creatinine was determined using the picric acid method with an Olympus AU640 analyser (CV was 3·0 %). The completeness of urine collections was validated by urine volume and urinary creatinine. Collections with urine volume ≥500 ml and urinary creatinine within the gender-specific mean ± 2 SD (1·91–18·27 mmol for men; 1·36–14·28 mmol for women) were considered complete. Na:K was calculated as Na excretion in mmol divided by K excretion in mmol.

Statistical analysis

Data are expressed either as mean and SD for continuous variables or as percentages for categorical variables. Study participants were classified into four categories according to their 24 h urinary Na excretion (<178·0, 178·0–227·5, 227·6–257·0 and ≥257·0 mmol) and 24 h urinary Na:K (<4·3, 4·3–5·6, 5·7–8·1 and ≥8·1), separately.

Logistic regression models were applied to estimate OR and 95 % CI for odds of obesity according to 24 h urinary Na excretion or Na:K, adjusted for age, sex, high-school education, urbanization, leisure-time physical activity, alcohol consumption, smoking, hypertension, antihypertensive treatment in past two weeks, fasting plasma glucose and TAG. Participants with 24 h urinary Na excretion <178·0 mmol or Na:K <4·3 were used as the 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 or Na:K in each group treated as a continuous variable in the logistic regression models[19].

All statistical analyses were conducted using the statistical software package SAS version 9·3. All tests were two-sided and a P value of <0·05 was considered to indicate statistical significance.

Results

The baseline characteristics of study participants according to quartiles of 24 h urinary Na excretion are presented in Table 1. In total, 1003 (52·6 %) of the study participants were men and 903 (47·4 %) were women. Participants with higher 24 h urinary Na excretion levels were more likely to have higher mean systolic and diastolic blood pressure, WC, BMI, WHR, TAG, 24 h urinary K excretion, as well as Na:K.

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Table 1 Baseline characteristics of participants according to quartiles of 24 h urinary sodium excretion; Chinese adults aged 18–69 years, Shandong Province, 2011

	24 h urinary Na excretion (mmol)								
	<178·0		178·0–227·5		227·6–257·0		≥ 257·0		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* for trend
No. of participants	476		478		470		482		
Age (years)	41·13	14·43	40·68	14·40	42·26	13·88	41·20	13·06	0·53
SBP (mmHg)	118·60	17·11	122·03	19·56	121·62	17·13	122·68	19·63	0·002
DBP (mmHg)	76·96	10·32	78·98	11·52	79·15	10·97	79·83	12·43	<0·001
WC (cm)	80·14	10·44	83·22	10·95	84·25	10·40	86·66	11·85	<0·001
BMI (kg/cm^2)	23·60	3·67	24·28	3·87	24·66	3·66	25·47	3·98	<0·001
WHR	0·85	0·07	0·86	0·07	0·87	0·07	0·88	0·09	<0·001
Hypertension (%)	17·65		24·27		21·49		23·24		0·10
High-school graduate (%)	25·84		26·15		27·02		21·16		0·13
Smoking (%)	30·25		30·96		32·98		31·33		0·58
Alcohol consumption (%)	30·04		34·31		41·28		41·49		<0·001
Leisure-time physical activity (%)	18·91		21·34		22·13		17·01		0·54
Urban (%)	35·92		28·45		37·23		28·63		0·16
Fasting plasma glucose (mmol/l)	5·52	1·21	5·45	1·04	5·49	1·11	5·54	1·28	0·70
TAG (mmol/l)	1·21	1·09	1·46	1·41	1·48	1·81	1·53	1·99	0·003
HDL cholesterol (mmol/l)	1·43	0·34	1·41	0·37	1·41	0·35	1·40	0·34	0·15
24 h urinary Na excretion (mmol)	136·84	31·72	203·28	14·90	244·66	8·60	328·88	79·87	<0·001
24 h urinary K excretion (mmol)	32·56	18·51	39·00	17·54	42·20	18·29	49·39	20·26	<0·001
24 h urinary Na:K	5·36	3·53	6·49	3·74	7·09	3·76	7·63	3·26	<0·001

Data are presented as mean and SD unless indicated otherwise.

For all participants, the respective mean 24 h urinary Na excretion and Na:K was 228·7 mmol and 6·64, respectively. The prevalence of overweight, obesity abdominal obesity (WC) and abdominal obesity (WHR) was 41·6 %, 8·0 %, 52·0 % and 41·3 %, respectively. The 24 h urinary Na excretion was significantly higher among participants with overweight, obesity and abdominal obesity compared with those without. For example, overweight participants had higher 24 h urinary Na excretion than non-overweight participants (242·04 *v.* 219·14 mmol, $P < 0·001$). Similarly, obese participants had higher 24 h urinary Na:K than non-obese participants. Yet no significantly positive association was observed between 24 h urinary Na:K and overweight and abdominal obesity (Table 2).

Age- and multivariate-adjusted odds of overweight, obesity and abdominal obesity according to quartiles of 24 h urinary Na excretion and Na:K are shown in Table 3. As expected, 24 h urinary Na excretion was a strong independent predictor of the risk of obesity. Odds of overweight, obesity and abdominal obesity increased significantly across increasing quartiles of 24 h urinary Na excretion (1·00, 1·54, 1·69 and 2·52, respectively, for overweight; 1·00, 1·20, 1·50 and 2·03, respectively, for obesity; 1·00, 1·44, 1·85 and 2·53, respectively, for abdominal obesity (WC); and 1·00, 1·28, 1·44 and 1·75, respectively, for abdominal obesity (WHR); *P* for linear trend <0·001 for all). Similarly, a significant upward trend was observed with increases in 24 h urinary Na:K for odds of abdominal obesity. The multivariate-adjusted OR (95 % CI) for abdominal obesity (WC) and abdominal obesity (WHR) with the highest quartile of Na:K compared with the lowest quartile was 1·35 (1·02, 1·79) and 1·57 (1·18, 2·10), respectively. This positive dose–response association was consistent between 24 h urinary Na:K and overweight in the age-adjusted model. However, it was not statistically significant after multivariate adjustment. Additionally, no significant dose–response relationship between 24 h urinary Na:K and obesity was found.

Adjusted odds of obesity associated with a 100 mmol increase in 24 h urinary Na excretion and a 1 SD (3·67) increase in 24 h urinary Na:K are presented in Table 4. Twenty-four-hour urinary Na excretion was significantly and positively associated with increased odds of overweight, obesity, abdominal obesity (WC) and abdominal obesity (WHR) in both age- and multivariate-adjusted models. For each increment of 100 mmol in 24 h urinary Na excretion, the odds of overweight, obesity, abdominal obesity (WC) and abdominal obesity (WHR) was 46 %, 39 %, 55 % and 33 % higher, respectively. Similarly, 24 h urinary Na:K was significantly and positively associated with increased odds of abdominal obesity (WC) and abdominal obesity (WHR). With a 1 SD increase in 24 h urinary Na:K, the odds of abdominal obesity (WC) and abdominal obesity (WHR) was 12 % and 15 % higher, respectively.

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Table 2 Mean 24 h urinary sodium excretion and sodium:potassium among participants with and without obesity; Chinese adults aged 18–69 years, Shandong Province, 2011

	No. of participants	24 h urinary Na excretion			24 h urinary Na:K		
		Mean	SD	*P* value	Mean	SD	*P* value
Overweight							
Yes	792	242·04	87·59	<0·001	6·77	3·77	0·15
No	1114	219·14	77·34		6·56	3·60	
Obesity							
Yes	153	258·4	96·26	0·002	7·41	4·24	0·005
No	1753	226·06	80·72		6·58	3·61	
Abdominal obesity (WC)							
Yes	992	241·83	85·99	<0·001	6·84	3·77	0·06
No	914	214·35	76·06		6·44	3·55	
Abdominal obesity (WHR)							
Yes	787	239·86	88·00	<0·001	6·91	3·74	0·27
No	1119	220·78	77·49		6·46	3·61	

WC, waist circumference; WHR, waist-to-hip ratio.

Discussion

These data identify that 24 h urinary Na excretion was significantly higher among participants with overweight, obesity and abdominal obesity than those without. As expected, we found a significant dose–response relationship between 24 h urinary Na excretion and risk of overweight, obesity and abdominal obesity. This association is independent of other important risk factors for obesity, including age, sex, high-school education, urbanization, leisure-time physical activity, alcohol consumption, smoking, hypertension, antihypertensive treatment in past two weeks, fasting plasma glucose and TAG. It indicates that Na intake is an independent predictor of the risk of overweight, obesity and abdominal obesity. In addition, the odds of abdominal obesity, but not the odds of overweight and obesity, increased significantly with successive Na:K quartiles. This finding suggests that Na:K is an independent predictor of the risk of abdominal obesity. Our findings clearly illustrate the public health importance of the reduction of Na intake and the increase of Na:K for preventing obesity.

To our knowledge, the present study is the first to report the association of Na intake and Na:K assessed by 24 h urine collection with the risk of obesity in China. It has important clinical and public health implications because high Na intake and obesity are becoming common in the Chinese adult population[4]. Accordingly, these findings contribute to the existing literature and provide new and important information in relation to the relationship between Na intake and Na:K and obesity in a representative sample of the Chinese general adult population and suggest that the reduction of Na intake and increase of K intake should be an important priority for reducing the prevalence of obesity in China.

Similar to previous studies[9,10,12,20–23], in the present study, with increase of 24 h urinary Na excretion, WC and BMI increased significantly. However, Baudrand *et al.*[24] reported that there is no statistical difference in BMI between participants with high Na intake and adequate Na intake (29·4 *v.* 29·0 kg/m^2). In addition, the current study observed that participants with obesity had higher Na excretion than those without. This finding is in line with previous studies[8], but inconsistent with the finding of a cross-sectional study of 1008 students in grade 7 in Canada[11]. The inconsistency could be in part due to Na intake estimated by 24 h diet recall.

To date, only two cross-sectional studies have attempted to quantify the association between Na intake and risk of obesity. Woodruff and colleagues reported that the odds of overweight increased with successive quartiles of Na intake in grade 7 students (*n* 1008). Compared with participants in the first quartile of Na intake, the OR (95 % CI) of overweight was 1·26 (0·86, 1·83), 1·72 (1·14, 2·59) and 2·88 (1·76, 4·73) for participants in the second, third and fourth quartile of Na intake, respectively[11]. Similarly, Yoon and Oh's study suggested that the odds of obesity (BMI ≥25·0 kg/m^2) increased significantly across increasing quintiles of Na density, defined as the ratio of daily dietary Na intake to daily food weight consumed, in both adults and children (1·00, 1·05, 1·08, 1·12 and 1·24, respectively, in adults; 1·00, 1·29, 1·28, 1·95 and 2·00, respectively, in children). Their study also examined the association between Na density and abdominal obesity. A similar positive association was found in both adults and children in the unadjusted model. However, for adults, the association was not statistically significant after multivariate adjustment[9]. Additionally, one prospective cohort study examined the relationship between WC and 24 h urinary Na excretion, documenting a non-significant change in WC of 0·34 cm (95 % CI −0·32, 1·01 cm) per 100 mmol increase in 24 h urinary Na excretion. However, these estimates were based on 215 participants[10]. The present study, as the first study to examine the association between Na intake based on 24 h urine samples and risk of obesity in China, documented a positive–dose response

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Table 3 Adjusted OR of obesity according to quartiles of 24 h urinary sodium excretion and sodium:potassium; Chinese adults aged 18–69 years, Shandong Province, 2011

	24 h urinary Na excretion (mmol)								24 h urinary Na:K							
	Q1	Q2		Q3		Q4			Q1	Q2		Q3		Q4		
	OR	OR	95 % CI	OR	95 % CI	OR	95 % CI	*P* value*	OR	OR	95 % CI	OR	95 % CI	OR	95 % CI	*P* value*
Overweight																
Model 1†	1·00	1·68	0·97, 2·90	1·76	1·02, 3·04	2·82	1·70, 4·69	<0·001	1·00	1·14	0·69, 1·87	1·11	0·67, 1·84	1·69	1·06, 2·69	0·016
Model 2‡	1·00	1·54	0·87, 2·72	1·69	0·96, 2·98	2·52	1·47, 4·30	<0·001	1·00	1·04	0·62, 1··74	0·99	0·59, 1·68	1·44	0·88, 2·36	0·097
Obesity																
Model 1†	1·00	1·34	1·03, 1·75	1·58	1·21, 2·07	2·15	1·66, 2·80	<0·001	1·00	1·02	0·78, 1·31	1·09	0·84, 1·42	1·19	0·92, 1·54	0·15
Model 2‡	1·00	1·20	0·90, 1·60	1·50	1·13, 2·00	2·03	1·53, 2·69	<0·001	1·00	0·96	0·73, 1·26	1·03	0·78, 1·36	1·07	0·80, 1·41	0·53
Abdominal obesity (WC)																
Model 1†	1·00	1·59	1·22, 2·06	1·89	1·46, 2·46	2·61	2·01, 3·40	<0·001	1·00	1·09	0·85, 1·41	1·22	0·94, 1·58	1·43	1·10, 1·85	0·005
Model 2‡	1·00	1·44	1·08, 1·90	1·85	1·40, 2·45	2·53	1·91, 3·36	<0·001	1·00	1·06	0·80, 1·39	1·18	0·90, 1·57	1·35	1·02, 1·79	0·024
Abdominal obesity (WHR)																
Model 1†	1·00	1·42	1·08, 1·86	1·49	1·14, 1··96	1·88	1·44, 2·46	<0·001	1·00	1·24	0·95, 1·62	1·18	0·90, 1·54	1·63	1·25, 2·13	<0·001
Model 2‡	1·00	1·28	0·96, 1·71	1·44	1·08, 1·92	1·75	1·31, 2·32	<0·001	1·00	1·23	0·92, 1·63	1·15	0·86, 1·54	1·57	1·18, 2·10	0·003

WC, waist circumference; WHR, waist-to-hip ratio.
**P* values for linear trends.
†Adjusted for age.
‡Adjusted for age, sex, high-school education, urbanization, leisure-time physical activity, alcohol consumption, smoking, hypertension, antihypertensive treatment in past two weeks, fasting plasma glucose and TAG.

Table 4 Adjusted OR of obesity associated with a 100 mmol increase in 24 h urinary sodium excretion and a 1 SD (3·67) increase in 24 h urinary sodium:potassium; Chinese adults aged 18–69 years, Shandong Province, 2011

	24 h urinary Na excretion				24 h urinary Na:K			
	Model 1*		Model 2†		Model 1*		Model 2†	
	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI
Overweight	1·50	1·26, 1·79	1·46	1·21, 1·77	1·21	1·05, 1·39	1·14	0·98, 1·33
Obesity	1·41	1·26, 1·58	1·39	1·23, 1·57	1·07	0·98, 1·18	1·03	0·94, 1·14
Abdominal obesity (WC)	1·55	1·38, 1·75	1·55	1·36, 1·76	1·14	1·04, 1·25	1·12	1·01, 1·24
Abdominal obesity (WHR)	1·35	1·21, 1·52	1·33	1·18, 1·51	1·17	1·07, 1·29	1·15	1·04, 1·27

WC, waist circumference; WHR, waist-to-hip ratio.
*Adjusted for age.
†Adjusted for age, sex, high-school education, urbanization, leisure-tine physical activity, alcohol consumption, smoking, hypertension, antihypertensive treatment in past two weeks, fasting plasma glucose and TAG.

relationship between Na intake and risk of overweight, obesity and abdominal obesity. This might be in part due to participants with high Na intake consuming more energy, sugar-sweetened beverages, as well as unhealthy foods[12,25].

A recent multi-ethnic cohort study, as the only study investigating the association between urinary Na:K estimated by early-morning first-void urine samples and obesity assessed by total-body percentage fat measured by dual-energy X-ray absorptiometry, identified Na:K as an independent predictor of risk of obesity. With a 3-unit change in urinary Na:K, a statistically significant change of 0·75 (95 % CI 0·25, 11·25) in total-body percentage fat was documented[13]. Interestingly, we observed that Na:K was significantly associated with increased risk of abdominal obesity but not overweight and obesity defined by BMI.

Some potential limitations of our study should be noted. The cross-sectional study design makes it hard to draw inferences regarding the causal relationship between Na intake and Na:K and odds of overweight, obesity and abdominal obesity. In addition, the Na and K intakes estimated by a single 24 h urine collection might have overestimated or underestimated the actual Na intake in the Chinese adult population. This random measurement error, owing to day-to-day variation in Na intake in individuals, is possible to bias the association toward zero. Furthermore, the OR might be slightly overestimated owing to the lack of adjustment for antihypertensive drugs and dietary pattern[26–28]. Nevertheless, the strengths of our study include its stringent quality control procedures; large sample size; using 24 h urine collection considered the gold standard method for estimation of Na intake; using different indices of obesity including BMI, WC and WHR; and careful measures of outcome variables.

Conclusion

In conclusion, our study documented an independent and dose–response relationship between 24 h urinary Na excretion and odds of overweight, obesity and abdominal obesity, as well as a positive dose–response relationship between Na:K and odds of abdominal obesity. Moreover, 24 h urinary Na excretion was a stronger risk factor for overweight, obesity and abdominal obesity than Na:K. These findings suggest that the reduction of Na intake and increase of K intake should be a potential approach for reducing risk of obesity and its societal burden in China.

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