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Original Article

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Association between the metabolic syndrome and chronic kidney disease in Chinese adults

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Abstract

Background. The metabolic syndrome is a common risk factor for cardiovascular and chronic kidney disease (CKD) in Western populations. We examined the relationship between the metabolic syndrome and risk of CKD in Chinese adults.

Methods. A cross-sectional survey was conducted in a nationally representative sample of 15 160 Chinese adults aged 35–74 years. The metabolic syndrome was defined as the presence of three or more of the following risk factors: elevated blood pressure, low high density lipoprotein (HDL)-cholesterol, high triglycerides, elevated plasma glucose and abdominal obesity. CKD was defined as an estimated glomerular filtration rate <60 ml/min/1.73 m^2 and elevated serum creatinine was defined as $\geq$1.14 mg/dl in men and $\geq$0.97 mg/dl in women ($\geq$95th percentile of serum creatinine in Chinese men and women aged 35–44 years without hypertension or diabetes, respectively).

Results. The multivariate-adjusted odds ratios [95% confidence interval (CI)] of CKD and elevated serum creatinine in participants with compared to those without the metabolic syndrome were 1.64 (1.16, 2.32) and 1.36 (1.07, 1.73), respectively. Compared to participants without any components of the metabolic syndrome, the multivariate-adjusted odds ratios (95% CI) of CKD were 1.51 (1.02, 2.23), 1.50 (0.97, 2.32), 2.13 (1.30, 3.50) and 2.72 (1.50, 4.93) for those with 1, 2, 3, and 4 or 5 components, respectively. The corresponding multivariate-adjusted odds ratios (95% CI) of elevated serum creatinine were 1.11 (0.88, 1.40), 1.39 (1.07, 2.04), 1.47 (1.06, 2.04) and 2.00 (1.32, 3.03), respectively.

Conclusions. These findings suggest that the metabolic syndrome might be an important risk factor for CKD in Chinese adults.

Keywords: China; chronic kidney disease; cross-sectional studies; diabetes; metabolic syndrome; obesity

Introduction

Chronic kidney disease (CKD) has become a global public health challenge because of its high prevalence [1–3] and the concomitant increase in risk of end-stage renal disease (ESRD), cardiovascular disease (CVD) and premature death [4–6]. Patients with ESRD have a poorer quality of life and a shorter life expectancy compared with individuals of the same age in the general population [4]. A better understanding of the aetiology of CKD, leading to early detection and prevention and effective therapy might alleviate the future burden of ESRD, CVD, and its associated mortality.

The metabolic syndrome, characterized by a clustering of abdominal obesity, hypertriglyceridaemia, low high-density lipoprotein (HDL) cholesterol, elevated blood pressure (BP), and high fasting glucose, has been associated with an increased risk for the development of diabetes and CVD as well as an increased mortality from CVD and all-causes [7,8]. A few epidemiological studies in the US adult population have reported that the metabolic syndrome is associated with CKD and microalbuminuria [9,10]. However, the relationship between the metabolic syndrome and risk of CKD has not been studied in the Chinese population, a group that still has a low prevalence of CKD and obesity [3,11]. The objective of the present study was to examine the association between the metabolic syndrome and risk of CKD in a large representative

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sample of Chinese adults who participated in the International Collaborative Study of Cardiovascular Disease in ASIA (InterASIA) study.

Subjects and methods

Study population

InterASIA was a cross-sectional study of CVD risk factors conducted during 2000–2001 in China and Thailand. The InterASIA study used a four-stage stratified sampling method to select a nationally representative sample of the general population aged 35–74 years in China. The sampling process was stratified by rural *vs* urban areas and north *vs* south. A total of 19 012 persons were randomly selected from 20 primary sampling units (street districts in urban or townships in rural) and invited to participate. A total of 15 838 persons (7684 men and 8154 women) completed the survey and examination. The overall response rate was 83.3% (82.1% in men and 84.5% in women; and 82.2% in urban and 84.4% in rural areas). The analysis reported in this article was restricted to adults aged 35–74 years who had complete laboratory results ($n = 15\,160$).

The Institutional Review Board at the Tulane University Health Sciences Center and ethics committees and other relevant regulatory bodies in China approved the InterASIA study. Informed consent was obtained from each participant prior to data collection.

Data collection

Information on demographic characteristics, including age, sex, education, occupation and household income was collected during the clinic visits by trained research staff using a standard questionnaire. The interview included questions related to the diagnosis and treatment of hypercholesterolaemia, hypertension and diabetes.

During the clinical examination, BP and anthropometric measurements were collected by trained and certified observers using standard protocols and technique [12]. Three BP measurements were obtained with the participant in a seated position after 5 min of rest. Participants were advised to avoid cigarette smoking, alcohol, caffeinated beverages, and exercise for at least 30 min prior to their BP measurement. Body weight and height were measured twice during the examination. Weight and height were measured in light indoor clothing without shoes. Waist circumference was measured at 1 cm above the navel at minimal respiration.

Overnight fasting blood specimens were collected for measurement of serum lipids, plasma glucose and serum creatinine. Blood specimens were only collected from those who had fasted overnight for a minimum of 10 h. Blood specimens were processed at the examination centre and shipped to a central clinical laboratory in Beijing where they were stored at -70°C until laboratory assays could be performed. Plasma glucose was measured using a modified hexokinase enzymatic method. Serum cholesterol and triglyceride levels were analysed enzymatically using commercially available reagents. The study laboratory was standardized for lipid measurements according to the criteria of the US CDC-NHLBI Lipid Standardization Programs [13].

Serum creatinine was measured by the modified kinetic Jaffe reaction on a Hitachi 7060 Clinical Analyser (Hitachi High-Technologies Corporation, Japan) using commercial reagents. A random sample of 60 serum specimens was sent to the Cleveland Clinic Laboratory (Cleveland, OH) for measurement of serum creatinine. This was the laboratory where serum creatinine levels for the Modification of Diet in Renal Disease (MDRD) Study were measured [14]. On average, serum creatinine assays on the same samples were 2.99 μmol/l (0.0338 mg/dl) higher in the Cleveland Clinic Laboratory than in the InterASIA Study laboratory. Therefore, serum creatinine measurements among study participants were calibrated by adding this difference.

Study outcome and risk factors

Glomerular filtration rate (GFR) was estimated from the simplified equation developed using MDRD data [14]: Estimated $\mathrm{GFR} = 186.3 \times (\text{serum creatinine in mg/dl})^{-1.154} \times \text{age}^{-0.203} \times (0.742 \text{ for women}) \times (1.212 \text{ if African American})$. CKD was defined as a $\mathrm{GFR} < 60$ ml/min/1.73 m^2 according to the US National Kidney Foundation guidelines [4]. In addition, elevated serum creatinine was used as an outcome measurement because estimated GFR using the MDRD formula has not been validated in the Chinese population. Elevated serum creatinine was defined as ≥100.8 μmol/l (1.14 mg/dl) in men and ≥85.7 μmol/l (0.97 mg/dl) in women (≥95th percentile of serum creatinine in Chinese men and women aged 35–44 years without hypertension or diabetes, respectively).

The metabolic syndrome was defined according to the National Cholesterol Education Program Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (ATP III) criteria as the presence of three or more of the following risk factors: waist circumference >102 cm in men or >88 cm in women; serum triglyceride level ≥1.70 mmol/l (150 mg/dl); HDL-cholesterol level <1.04 mmol/l (40 mg/dl) in men or <1.30 mmol/l (50 mg/dl) in women; BP ≥ 130/85 mmHg and/or use of antihypertensive medications; or serum glucose level ≥6.11 mmol/l (110 mg/dl) and/or use of insulin or hypoglycaemic medication [15]. In a sensitivity analysis, the recent International Diabetes Federation (IDF) definition of metabolic syndrome was used: the presentation of central obesity (defined as waist circumference ≥90 cm in men and ≥80 cm in women for Asian populations) plus any two of the following risk factors: triglyceride concentration ≥1.70 mmol/l (150 mg/dl), or specific treatment for this lipid abnormality; HDL-cholesterol concentration <1.04 mmol/l (40 mg/dl) in men or <1.30 mmol/l (50 mg/dl) in women, or specific treatment for this lipid abnormality; BP ≥ 130/85 mmHg, or treatment of previously diagnosed hypertension; or fasting plasma glucose ≥5.55 mmol/l (100 mg/dl), or previously diagnosed type 2 diabetes [16].

Statistical methods

Age- and sex-adjusted mean values of continuous variables and percentages of categorical variables for exposures, covariates and outcomes were calculated by the metabolic syndrome status. The statistical significance of differences in these characteristics across the metabolic syndrome status was examined by means of the Z test (continuous variables)

and the Wald χ^2 test (categorical variables) in multivariate regression models after adjustment for age and sex. The prevalence of CKD or elevated serum creatinine was determined for participants with and without each of the five components of the metabolic syndrome. The prevalence of CKD or elevated serum creatinine was also calculated by the number of the metabolic syndrome components present.

The age and sex-adjusted, and multivariate-adjusted [adjustment for age, sex, non-steroidal anti-inflammatory drug (NSAID) use in the past month, a high school education, physical inactivity, alcohol drinking, current and former smoking and body mass index (BMI)] odds ratio of CKD or elevated serum creatinine associated with each component of the metabolic syndrome was calculated using logistic regression models. The adjusted odds ratios of CKD or elevated serum creatinine were also determined by clustering of the components of the metabolic syndrome. In these analyses, the odds ratios of CKD or elevated serum creatinine were calculated comparing participants with 1, 2, 3 and 4 or 5 components of the metabolic syndrome to persons without any component of the metabolic syndrome. Because only a few participants had all 5 components of the metabolic syndrome, participants with 4 or 5 components were considered together as a single group. Finally, the adjusted odds ratios of CKD and elevated serum creatinine were calculated for participants with the metabolic syndrome ($\geq$3 components) compared with their counterparts without the metabolic syndrome (<3 components).

Hypertension and diabetes are the most important established risk factors for CKD. We examined the association of CKD and elevated serum creatinine with the metabolic syndrome after excluding patients with hypertension and diabetes, separately. Hypertension was defined as systolic BP $\geq$ 140 mmHg and/or diastolic BP $\geq$ 90 mmHg and/or current use of antihypertensive medication. Diabetes was defined as a self-reported history of a prior diagnosis of diabetes or fasting plasma glucose $\geq$7.0 mmol/l (126 mg/dl). In addition, we examined the association of CKD and elevated serum creatinine with the metabolic syndrome defined by the IDF criteria. All data analyses were conducted using SUDAAN (Version 8.0; Research Triangle Institute, Research Triangle Park, NC).

Results

The general characteristics of study participants are presented by metabolic syndrome status in Table 1. Mean serum creatinine was similar, but estimated-GFR was lower among persons with the metabolic syndrome compared with those without. The percent of persons with CKD and elevated serum creatinine was statistically significantly higher among those with compared to their counterparts without the metabolic syndrome.

Table 2 compares the age and sex-adjusted proportion of participants with CKD and elevated serum creatinine, separately, among those with and without each component of the metabolic syndrome. Low HDL-cholesterol, elevated plasma glucose and abdominal obesity were statistically significantly associated with an increased prevalence of CKD or elevated serum creatinine. Furthermore, there was a significant dose-response relationship between the number of metabolic syndrome components and the prevalence of CKD or elevated serum creatinine ($P < 0.0001$ and $P = 0.002$, respectively, Figure 1).

Age, sex-adjusted and multivariate-adjusted odds ratios of CKD associated with individual and multiple components of the metabolic syndrome are presented in Table 3. In the multivariate models, elevated fasting

Table 1. Age and sex-adjusted characteristics of the study participants with and without the metabolic syndrome

Characteristics[a]	Participants with the metabolic syndrome ($n = 2479$)	Participants without the metabolic syndrome ($n = 12\,681$)	*P*-Value
Age, years	53.5 ± 0.3	49.6 ± 0.1	<0.0001
Men (%)	39.3 ± 1.5	53.7 ± 0.6	<0.0001
High school education (%)	34.6 ± 2.0	20.0 ± 0.5	<0.0001
Physical activity (%)	41.2 ± 2.3	58.1 ± 0.7	<0.0001
Current smoking (%)	53.4 ± 2.4	61.0 ± 0.8	<0.0001
NSAID use in the past month (%)	12.0 ± 1.5	3.6 ± 0.3	<0.0001
Systolic blood pressure, mmHg	137.4 ± 1.0	125.1 ± 0.3	<0.0001
Diastolic blood pressure, mmHg	87.9 ± 0.5	79.6 ± 0.2	<0.0001
Body mass index, kg/m^2	26.1 ± 0.2	22.8 ± 0.1	<0.0001
Waist circumference, cm	88.2 ± 0.5	78.7 ± 0.1	<0.0001
Plasma glucose level, mmol/l (mg/dl)	6.54 ± 0.09 (117.9 ± 1.7)	5.33 ± 0.02 (96.0 ± 0.3)	<0.0001
Serum HDL cholesterol level, mmol/l (mg/dl)	0.98 ± 0.01 (37.7 ± 0.5)	1.36 ± 0.01 (52.5 ± 0.2)	<0.0001
Serum triglyceride level, mmol/l (mg/dl)	3.07 ± 0.09 (271.5 ± 7.8)	1.28 ± 0.01 (113.7 ± 1.0)	<0.0001
Serum creatinine level, μmol/l (mg/dl)	80.4 ± 0.5 (0.91 ± 0.01)	79.6 ± 0.4 (0.90 ± 0.00)	0.55
Elevated serum creatinine[b] (%)	7.2 ± 1.1	5.7 ± 0.3	0.02
Estimated GFR, ml/min per 1.73 m^2	98.6 ± 0.3	100.2 ± 1.1	0.007
Chronic kidney disease[b] (%)	3.3 ± 0.9	1.2 ± 0.2	0.04

[a]Values are expressed as mean ± SE or proportion ± SE. Except for age and sex, other means and proportions are age and sex-adjusted.
[b]Elevated serum creatinine was defined as serum creatinine $\geq$100.8 μmol/l (1.14 mg/dl) in men and $\geq$85.7 μmol/l (0.97 mg/dl) in women. Chronic kidney disease was defined as estimated GFR < 60 ml/min/1.73 m^2.
NSAID, non-steroidal anti-inflammatory drug; HDL, high-density lipoprotein; GFR, glomerular filtration rate. Système international (SI) conversion factors: glucose 1 mg/dl = 0.0555 mmol/l; HDL cholesterol 1 mg/dl = 0.0259 mmol/l; triglyceride 1 mg/dl = 0.0113 mmol/dl; and creatinine 1 mg/dl = 88.4 μmol/l.

Table 2. Age and sex-adjusted prevalence of chronic kidney disease and elevated serum creatinine among participants with and without components of the metabolic syndrome

Component	Participants	Chronic kidney disease		Elevated serum creatinine	
	No.	Prevalence ± SE (%)	*P*-Value	Prevalence ± SE (%)	*P*-Value
Blood pressure ≥130/85 mmHg[a]					
Yes	6233	2.9 ± 0.3	0.34	6.2 ± 0.4	0.59
No	8927	2.4 ± 0.2		5.6 ± 0.3	
Serum HDL cholesterol <1.04 mmol/l (40 mg/dl) in men or <1.30 mmol/l (50 mg/dl) in women					
Yes	5884	3.3 ± 0.3	0.05	7.3 ± 0.5	<0.01
No	9276	2.3 ± 0.2		5.2 ± 0.3	
Serum triglycerides ≥1.70 mmol/l (150 mg/dl)					
Yes	4199	2.6 ± 0.3	0.53	5.5 ± 0.4	0.20
No	10961	2.6 ± 0.2		5.9 ± 0.3	
Plasma glucose ≥6.11 mmol/l (110 mg/dl)[b]					
Yes	2068	4.2 ± 0.5	<0.01	8.6 ± 0.8	<0.01
No	13092	2.3 ± 0.2		5.3 ± 0.2	
Waist circumference >102 cm in men or >88 cm in women					
Yes	1369	2.9 ± 0.5	0.04	5.1 ± 0.8	0.07
No	13791	2.4 ± 0.2		5.6 ± 0.2	

[a]Systolic blood pressure ≥130 mmHg or diastolic blood pressure ≥85 mmHg or taking antihypertensive medication.
[b]Fasting glucose level ≥6.11 mmol/l (110 mg/dl) or use of insulin or hypoglycaemic medication.

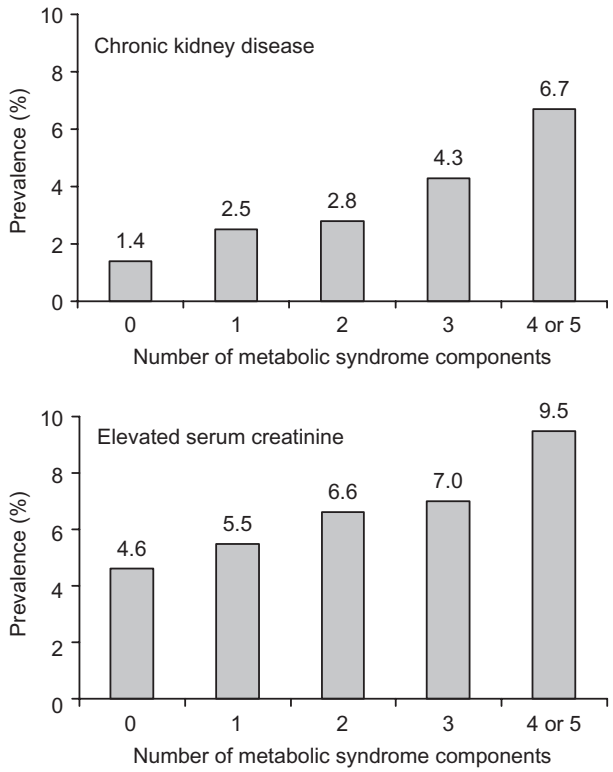

Fig. 1. Prevalence of chronic kidney disease (top) and elevated serum creatinine (bottom) by number of the metabolic syndrome components. Chronic kidney disease is defined as an estimated-GFR <60 ml/min, and elevated serum creatinine is defined as a serum creatinine ≥100.8 μmol/l (1.14 mg/dl) in men and ≥85.7 μmol/l (0.97 mg/dl) in women. The metabolic sndrome components include waist circumference >102 cm in men or >88 cm in women; serum triglyceride ≥1.70 mmol/l (150 mg/dl); HDL cholesterol <1.04 mmol/l (40 mg/dl) in men or <1.30 mmol/l (50 mg/dl) in women; blood pressure ≥130/85 mmHg; or plasma glucose ≥6.11 mmol/l (110 mg/dl).

plasma glucose and abdominal obesity were statistically significantly associated with an increased odds ratio of CKD, while low HDL-cholesterol was borderline significantly associated with an increased odds ratio of CKD. Participants with 1, 2, 3 and 4 or 5 components of the metabolic syndrome had a 1.51, 1.50, 2.13 and 2.72-fold increased odds of CKD, respectively, compared with those without any component. Overall, persons with the metabolic syndrome had a 64% increase in the odds of CKD compared with their counterparts without the metabolic syndrome. Similarly, a low HDL-cholesterol, elevated fasting plasma glucose and abdominal obesity were statistically significantly associated with an increased risk of elevated serum creatinine (Table 4). There was a positive and graded association between the numbers of metabolic syndrome components and the odds of elevated serum creatinine. Compared with those without the metabolic syndrome, persons with the metabolic syndrome had a 36% increase in the odds of elevated serum creatinine. The associations between metabolic syndrome and CKD or elevated serum creatinine were consistent in men and women (data not shown).

Sensitivity analysis

After excluding study participants with hypertension, the metabolic syndrome was significantly associated with an increased odds of CKD (odds ratio 1.74; 95% CI 1.00–3.02; $P = 0.05$) and borderline significantly associated with an increased odds of elevated serum creatinine (odds ratio 1.38; 95% CI 0.94–2.02; $P = 0.1$) in the multivariate-adjusted models. After excluding patients with treated diabetes, the metabolic syndrome was significantly associated with increased odds of

Table 3. Adjusted odds ratios of chronic kidney disease associated with individual or multiple components of the metabolic syndrome

	Odds Ratio (95% Confidence Interval)			
	Age- and sex-adjusted	*P*-value	Multivariate adjusted[a]	*P*-value
Blood pressure ≥130/85 mmHg[b]	1.14 (0.87, 1.51)	0.34	1.17 (0.88, 1.56)	0.27
Serum HDL cholesterol <1.04 mmol/l (40 mg/dl) in men or < 1.30 mmol/l (50 mg/dl) in women	1.33 (1.00, 1.78)	0.05	1.34 (0.98, 1.83)	0.06
Serum triglyceride ≥1.70 mmol/l (150 mg/dl)	0.91 (0.67, 1.23)	0.53	0.92 (0.68, 1.24)	0.58
Plasma glucose ≥6.11 mmol/l (110 mg/dl)[c]	1.91 (1.39, 2.61)	<0.01	1.93 (1.40, 2.67)	<0.01
Waist >102 cm in men or >88 cm in women	1.45 (1.02, 2.07)	0.04	1.95 (1.21, 3.14)	0.01
1 component[d]	1.45 (0.98, 2.13)	0.06	1.51 (1.02, 2.23)	0.04
2 components[d]	1.34 (0.89, 2.04)	0.16	1.50 (0.97, 2.32)	0.07
3 components[d]	1.79 (1.11, 2.91)	0.02	2.13 (1.30, 3.50)	<0.01
4 or 5 components[d]	2.13 (1.27, 3.58)	<0.01	2.72 (1.50, 4.93)	<0.01
Metabolic syndrome[e]	1.48 (1.08, 2.03)	0.02	1.64 (1.16, 2.32)	<0.01

[a]Adjusted for age, gender, NSAID use, high school education, physical activity, cigarette smoking, alcohol drinking and body mass index.
[b]Systolic blood pressure ≥130 mmHg and/or diastolic blood pressure ≥85 mmHg and/or use of antihypertensive medication.
[c]Fasting glucose level ≥6.11 mmol/l (110 mg/dl) or use of insulin or hypoglycaemic medication.
[d]Compared with those with 0 component.
[e]Compared with those with <3 components.

Table 4. Adjusted odds ratios of elevated serum creatinine associated with individual or multiple components of the metabolic syndrome

	Odds Ratio (95% Confidence Interval)			
	Age, sex adjusted	*P*-value	Multivariate adjusted[a]	*P*-value
Blood pressure ≥130/85 mmHg[b]	1.05 (0.88, 1.26)	0.59	1.08 (0.90, 1.31)	0.41
Serum HDL cholesterol <1.04 mmol/l (40 mg/dl) in men or < 1.30 mmol/l (50 mg/dl) in women	1.38 (1.15, 1.65)	<0.01	1.39 (1.15, 1.68)	<0.01
Serum triglyceride ≥1.70 mmol/l (150 mg/dl)	0.88 (0.73, 1.07)	0.20	0.90 (0.74, 1.09)	0.27
Plasma glucose ≥6.11 mmol/l (110 mg/dl)[c]	1.60 (1.29, 1.99)	<0.01	1.62 (1.30, 2.03)	<0.01
Waist >102 cm in men or >88 cm in women	1.30 (0.98, 1.72)	0.07	1.61 (1.15, 2.27)	0.01
1 component[d]	1.06 (0.85, 1.33)	0.59	1.11 (0.88, 1.40)	0.37
2 components[d]	1.28 (1.01, 1.63)	0.04	1.39 (1.07, 1.81)	0.01
3 components[d]	1.29 (0.95, 1.75)	0.10	1.47 (1.06, 2.04)	0.02
4 or 5 components[d]	1.62 (1.12, 2.34)	0.01	2.00 (1.32, 3.03)	<0.01
Metabolic syndrome[e]	1.26 (1.04, 1.05)	0.04	1.36 (1.07, 1.73)	0.01

[a]Adjusted for age, gender, NSAID use, high school education, physical activity, cigarette smoking, alcohol drinking and body mass index.
[b]Systolic blood pressure ≥130 mmHg and/or diastolic blood pressure ≥85 mmHg and/or use of antihypertensive medication.
[c]Fasting glucose level ≥6.11 mmol/l (110 mg/dl) or use of insulin or hypoglycaemic medication.
[d]Compared with those with 0 component.
[e]Compared with those with <3 components.

CKD (odds ratio 1.46; 95% CI 1.02–2.07; $P = 0.04$) or increased odds of elevated serum creatinine (odds ratio 1.29; 95% CI 1.01–1.64; $P = 0.04$) in the multivariate-adjusted models.

The metabolic syndrome according to the IDF definition was similarly associated with an increased risk of CKD and elevated serum creatinine. For example, the odds ratio (95% CI) associated with the metabolic syndrome was 1.50 (1.03–2.18; $P = 0.03$) for CKD and 1.42 (1.11–1.82; $P = 0.01$) for elevated serum creatinine, respectively, after adjustment for age, sex, NSAID use, high school education, physical inactivity, alcohol drinking, cigarette smoking and BMI.

Discussion

The present study identified a strong, positive, and significant relationship between the metabolic syndrome and risk of CKD in the general adult population of China. The risk of CKD increased progressively with a higher number of components of the metabolic syndrome. These relationships were independent of age, sex, and other potential risk factors for CKD, including NSAID use, education, physical activity, alcohol drinking, cigarette smoking and BMI. Our findings are noteworthy because they are based on a large, representative sample of the Chinese general adult population. In addition, careful measures of study exposure and outcome variables allowed for precise estimation of the association.

To our knowledge, this study is the first to report a strong relationship between the metabolic syndrome and the risk of CKD among Chinese adults. These findings have important clinical and public health implications because the metabolic syndrome and CKD are becoming common in the Chinese general population [3,11]. The current study provides new and

important information regarding the relationship between the metabolic syndrome and risk of CKD in a representative sample of the Chinese general adult population and suggests that prevention and treatment of the metabolic syndrome should be an important priority for reducing the prevalence of CKD and its associated disease burden in China.

Several studies have examined the association between insulin resistance, metabolic syndrome, and risk of CKD [9,10,17]. We reported that the metabolic syndrome was associated with a 2.60- and 1.89-fold increased risk of CKD and microalbuminuria, respectively, in US adults [9]. Tanaka and colleagues found that metabolic syndrome was significantly associated with CKD (odds ratio 1.54, 95% CI 1.28–1.85, $P < 0.0001$) among 6980 participants aged 30–79 years in a hospital-based screening program in Okinawa, Japan [17]. In the current study, the odds ratio of CKD associated with the metabolic syndrome was not as high as in the US, but similar to Japanese adult populations. In the US, diabetes and hypertension are the most common underlying causes of CKD [2,4]. However, it has been reported that glomerulonephritis is the most common cause of CKD in the Chinese population [18]. This might also explain the lack of a significant association between elevated BP and CKD in the present study.

A few epidemiology studies examined the association between obesity and risk of CKD and reported inconsistent findings [19–22]. In a cohort study of 101 516 Japanese men and women, BMI was inversely related to risk of ESRD in women but not in men [19]. In a cross-sectional analysis of the MDRD experience, percentage of body fat and BMI was positively associated with GFR in patients with renal disease [20]. In an analysis of data from 9082 US adults aged 30–74 years, who participated in the second National Health and Nutrition Examination Survey (NHANES II), Stengel and colleagues [21] reported that severe obesity (BMI ≥ 35) was associated with a significantly elevated risk of ESRD, but overweight (BMI 25.0–29.9) and obesity (BMI 30–34.9) were not. Vupputuri and Sandler [22] reported a positive and significant association between BMI and nephrosclerosis in women only. BMI was not associated with other types of CKD in that case-control study. In the present study, waist circumference was associated with an increased risk of CKD, which was consistent with our previous findings from NHANES III [9]. These data suggest that abdominal obesity might be an important modifiable risk factor for CKD.

Our study has several limitations. First, the cross-sectional study design in the InterASIA study makes it difficult to draw inferences regarding causality between the metabolic syndrome and risk of CKD. Second, GFR was not directly measured and estimated-GFRs using a serum creatinine-based equation were used to define CKD in our study. The MDRD-equation might have overestimated or underestimated the actual GFR in the Chinese population because it was developed primarily in Caucasian populations in the US [23]. However, we identified a similar relationship between the metabolic syndrome and elevated serum creatinine. Serum creatinine levels and GFR estimated by the MDRD equation have been used widely in clinical practice for the assessment of CKD. Therefore, the findings from our study are applicable to clinical and public health practice settings. In addition, we did not measure urinary protein excretion in this study population which certainly underestimated the prevalence of CKD. Furthermore, a single serum creatinine value was used to estimate kidney function which might lead to the misclassification of CKD. This random measurement error, due to day-to-day variation in serum creatinine levels in individuals, is likely to bias the association toward zero. Finally, the ATP III definition of metabolic syndrome might not be suitable for a Chinese population. Using the IDF definition, however, we also documented a positive and significant association between the metabolic syndrome and risk of CKD in the present study.

In conclusion, our study indicates that the metabolic syndrome is a strong and independent risk factor for CKD in the Chinese general adult population. In addition, there is a graded relationship between the number of the metabolic syndrome components and risk of CKD. These findings warrant future prospective and interventional studies to test the impact of preventing and treating the metabolic syndrome on the risk of CKD.

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Conflict of Interest Statement. None declared.

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