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ORIGINAL ARTICLE

Serum 25-hydroxyvitamin D, parathyroid hormone, and their association with metabolic syndrome in Chinese

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Abstract Increasing evidence suggests that 25-hydroxyvitamin D [25(OH)D] and parathyroid hormone (PTH) levels are associated with metabolic syndrome (MetS). In 2010, we explored the association of serum 25(OH)D and PTH levels with MetS in 1,390 Chinese participants, aged 20–83 years. Anthropometric phenotypes, blood pressure, and the incidence of MetS were evaluated. In addition, serum lipids, 25(OH)D, and PTH were measured. The median concentration of 25(OH)D and PTH were 55.3 nmol/l and 2.8 pmol/l, respectively. The prevalence of vitamin D deficiency (<50 nmol/l) was 39.9 %, with 34.5 % in men and 47.8 % in women. After accounting for confounding factors and serum PTH, a 10 nmol/l higher serum 25(OH)D level was associated with a 10 % lower risk of MetS (OR = 0.90, 95 % CI 0.84–0.96, $P = 0.0007$). Furthermore, participants with vitamin D sufficiency had a 35 % lower risk of MetS than those with vitamin D deficiency (OR = 0.65, 95 % CI 0.51–0.84, $P = 0.0009$). PTH was not associated with the risk of MetS after adjustment for confounding factors. These results were confirmed in both men and women. Thus in this cohort of Chinese individuals, vitamin D deficiency is common and optimal vitamin D level is inversely associated with MetS, independent of several confounders and PTH level. The clinical significance of these findings warrants further study.

Keywords 25-hydroxyvitamin D · Parathyroid hormone · Metabolic syndrome · Chinese

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Abbreviations

25(OH)D	25-hydroxyvitamin D
PTH	Parathyroid hormone
MetS	Metabolic syndrome
GFR	Glomerular filtration rate
OR	Odds ratio
95 % CI	95 % Confidence interval

Introduction

Metabolic syndrome (MetS) is characterized by a set of cardiovascular risk factors, including abdominal obesity, raised blood pressure, atherogenic dyslipidemia, insulin resistance, and glucose intolerance. MetS is associated with an increased risk of diabetes, cardiovascular diseases, and mortality [1–4]. Vitamin D, a fat-soluble vitamin produced in skin following sun exposure and retrieved from diet and supplementation, has been widely related to insulin resistance, obesity, hypertension, MetS, dyslipidemia, diabetes mellitus, and mortality [5–9]. Increasing evidence suggests that vitamin D deficiency may be a novel risk factor for MetS. Although recent studies have shown that 25(OH)D level is inversely associated with MetS components or risk of MetS in obese subjects or general population [9–16], other studies have produced conflicting results [17–19]. In addition, some studies showing significant association between vitamin D and risk of MetS have failed to adjust for serum PTH [10, 11, 15], an important calcium-regulating hormone. Actually, some studies have indicated that serum PTH is positively correlated with MetS components and risk of MetS, even in normal PTH range [12, 17, 19–21]. However, other studies report no significant association between PTH and MetS [9, 13, 14, 16, 18]. Furthermore,

no epidemiologic study of MetS has examined both serum vitamin D and PTH levels in the Chinese population.

With the rapid growth of economy and unfavorable lifestyle changes in its population during recent decades, China is experiencing MetS epidemic and increased incidence of related cardiovascular diseases. Data from the InterASIA study reveal that 64 million (or 13.7 %) Chinese adults aged 35–74 years have MetS as defined by the U.S. National Cholesterol Education Program's Adult Treatment Panel III (ATP III) [22]; in addition, the age-standardized prevalence of MetS as defined by the International Diabetes Federation (IDF) and revised-ATP III definitions are 16.5 and 23.3 %, respectively [23]. We hypothesized that vitamin D deficiency and increased PTH level are associated with MetS in the Chinese population. We measured 25-hydroxyvitamin D [25(OH)D] level in our subjects since this is the main storage form of vitamin D in the body and the most commonly used marker to evaluate vitamin D status [24]. Then, we conducted this cross-sectional study to evaluate the association of serum 25(OH)D and PTH levels with MetS components and risk of MetS in the Chinese population.

Research design and methods

Population

The present analysis was based on a cross-sectional study involving comprehensive cardiovascular health examinations for all employees of a factory in Dali, Yunnan Province (latitude 25° north). We invited all employees and retired workers to take part in this study from March to May 2010. All employees and retired workers were in the same social class. We did not apply any inclusion or exclusion criteria for our study. Of the 1,643 eligible individuals, 1,443 (87.8 %) agreed to participate in the study. In addition, 53 participants were excluded because of inadequate blood sample to test for 25(OH)D or PTH levels, or lack of demographic data. Thus, a total of 1,390 participants were included in the present analysis. All subjects gave written informed consent. The study protocol was approved by the Ethics Committee of the Affiliated Hospital of Dali University.

Data collection

One physician measured each participant's blood pressure three times consecutively using an automatic blood pressure monitor (Omron HEM 7011, Japan), after the subjects have rested for at least 5 min in the sitting position. The three blood pressure readings were averaged for analysis. The same observer also administered a standardized questionnaire to collect information on medical history, smoking habits, alcohol consumption, and the use of medications. Hypertension was defined as sitting systolic blood pressure $\geq$140 mmHg or diastolic blood pressure $\geq$90 mmHg, or current taking of antihypertensive drugs. Diabetes mellitus was defined as a fasting blood glucose $\geq$7.0 mmol/l, or as current use of oral hypoglycemic agents or insulin. Current smoking was defined as at least 1 cigarette smoked per day. Current alcohol intake was defined as consumption of at least 1 drink per week. A trained technician performed anthropometric measurements, including body height, body weight, and waist and hip circumferences. Body weight and body height were measured with the participant barefoot and wearing light clothes. Body mass index was calculated as body weight in kilograms divided by body height in meters. Waist-to-hip ratio (WHR) was defined as waist circumference divided by hip circumference. Overweight and obesity were defined as a body mass index of 25 kg/m^2 and higher. Waist circumference was measured at the smallest circumference between the ribs and iliac crest, and hip circumference was measured at the maximum circumference between the iliac crest and crotch to the nearest 0.1 cm.

Laboratory methods

Venous blood samples were drawn after overnight fasting for biochemical measurements. Serum glucose was measured with a modified hexokinase enzymatic method using the Hitachi automatic clinical analyzer (Hitachi 7180, Japan). Concentrations of total cholesterol, triglycerides, and HDL cholesterol were assayed enzymatically with commercially available reagents. Serum was also stored at -30 °C for the measurement of 25(OH)D and PTH levels. Though it is recommended to store samples at -80 °C for the measurement of 25(OH)D level, studies have demonstrated the stability of 25(OH)D in serum samples under different conditions [25, 26]. Serum 25(OH)D was determined by radioimmunoassay (Diasorin Inc., Stillwater, Minnesota, USA) in the Clinical Laboratory of the Affiliated Hospital of Dali University in May, 2011. The intra- and interassay coefficients of variance were 6.0 and 5.6 %, respectively. Serum PTH was measured using the chemiluminescence method (DPC 2000, Siemens, Germany). The intra- and interassay coefficients of variance were 3.9 and 6.0 %, respectively. The analytic sensitivity of the assays for measuring serum 25(OH)D and PTH levels were 3.8 nmol/l and 0.32 pmol/l, respectively. Vitamin D deficiency was defined as having serum 25(OH)D <50 nmol/l [27]. Glomerular filtration rate (GFR) was calculated using the modification of diet in renal disease (MDRD) Study equation: $\mathrm{GFR} = 186 \times (\text{serum creatinine, mg/dl})^{-1.154} \times (\text{age, years})^{-0.203} \times (0.742 \text{ if female})$ [28].

Definition of metabolic syndrome

Metabolic syndrome was defined according to the updated ATP III criteria for Asian Americans [29] as the presence of three or more of the following components: (1) waist circumference ≥90 cm for men or ≥80 cm for women; (2) blood pressure ≥130/85 mmHg or currently using of antihypertensive drugs; (3) triglyceride ≥1.7 mmol/l; (4) HDL cholesterol <1.03 mmol/l for men or <1.29 mmol/l for women; (5) fasting glucose ≥5.6 mmol/l or if currently using drugs to treat hyperglycemia.

Statistical analysis

For database management and statistical analysis, we used the SAS software (version 9.1.3, SAS Institute, Cary, NC). The extent of departure from normality was evaluated by Shapiro–Wilk's test. Participant characteristics were compared by gender using the independent sample Student's *t* test for continuous variables and Fisher's exact test for categorical variables, respectively. Multivariable adjusted linear regression models were used to calculate the coefficients for MetS components with a 10 nmol/l and a 1 pmol/l increase in serum 25(OH)D and PTH levels, respectively. Unadjusted and multivariable adjusted logistic regression models were used to estimate the odds ratios (ORs) and 95 % confidence intervals (CI) for MetS. Linear regression analyses were stratified by gender; logistics regression analyses were stratified by gender and body weight status (normal weight vs. overweight/obesity). *P* values were two-sided, and $P \leq 0.05$ was considered significant.

Results

Characteristics of the participants

The 1,390 participants included 559 women (40.2 %), and 472 (34.0 %) hypertensive patients, of whom 211 (44.7 %) took antihypertensive drugs. Three hundred sixty six (26.3 %) individuals met the criteria for MetS, and the prevalence of MetS was similar between men and women (27.0 vs. 25.4 %, $P = 0.52$). The prevalence of vitamin D deficiency was 39.9 %, with 34.5 % in men and 47.8 % in women. The prevalence of MetS decreased significantly with increasing tertiles of serum 25(OH)D level in men ($P = 0.004$) and women ($P = 0.01$). However, the prevalence of MetS increased significantly with increasing tertiles of serum PTH level in women ($P = 0.03$) but not in men ($P = 0.10$) (Fig. 1).

Because vitamin D is a fat-soluble vitamin, fat distribution might be associated with vitamin D status. We also analyzed differences in serum 25(OH)D and PTH levels in subjects with android (WHR >0.9 for men and >0.85 for women, $n = 563$) and gynecoid fat distribution (WHR ≤0.9 for men and ≤0.85 for women, $n = 827$). There were significant differences in serum 25(OH)D (54.6 vs. 58.2 nmol/l, $P = 0.001$) and PTH (3.4 vs. 3.0 pmol/l, $P = 0.001$) levels between subjects with android and gynecoid fat distribution.

Table 1 shows the population characteristics by gender. Men exhibited higher values for the following parameters than women: age, body mass index, waist circumference, hip circumference, waist-to-hip ratio, systolic and diastolic blood pressure, fasting triglyceride, fasting glucose, 25(OH)D, and proportion of individuals currently consuming alcohol or cigarettes and with hypertension ($P \leq 0.04$). However, men had lower HDL cholesterol, GFR and lower proportion of individuals with vitamin D deficiency ($P < 0.0001$) than women. Men and women had similar total cholesterol, LDL cholesterol, PTH, and similar proportion of individuals with diabetes mellitus and MetS (Table 1).

Association of serum 25(OH)D and PTH levels with MetS components

Gender-specific association of serum 25(OH)D and PTH levels with MetS components are shown in Table 2. In men, a 10 nmol/l higher serum 25(OH)D level was negatively associated with waist circumference ($P = 0.02$) and fasting triglyceride ($P < 0.0001$), and positively associated with HDL cholesterol ($P = 0.004$) after accounting for age, current alcohol intake, current smoking, working status, day of blood sampling, GFR, and serum PTH. A one unit higher PTH level was positively associated with diastolic blood pressure ($P = 0.02$) and waist circumference ($P = 0.03$) in multivariable adjusted analyses. In women, a 10 nmol/l higher serum 25(OH)D level was negatively associated with triglyceride level ($P = 0.0002$) and positively associated with HDL cholesterol level ($P = 0.03$), while a one unit higher PTH level was positively associated with systolic ($P = 0.002$) and diastolic blood pressure ($P = 0.02$), and negatively associated with triglyceride level ($P = 0.02$) in multivariable adjusted analyses.

Association of serum 25(OH)D and PTH levels with the risk of MetS

Gender-specific association of serum 25(OH)D and PTH levels with the risk of MetS are shown in Table 3. A 10 nmol/l higher serum 25(OH)D level was associated with a 10 % lower risk of MetS after adjusting for age, current alcohol intake, current smoking, working status, day of blood sampling, GFR, and serum PTH. Adjusting additionally for

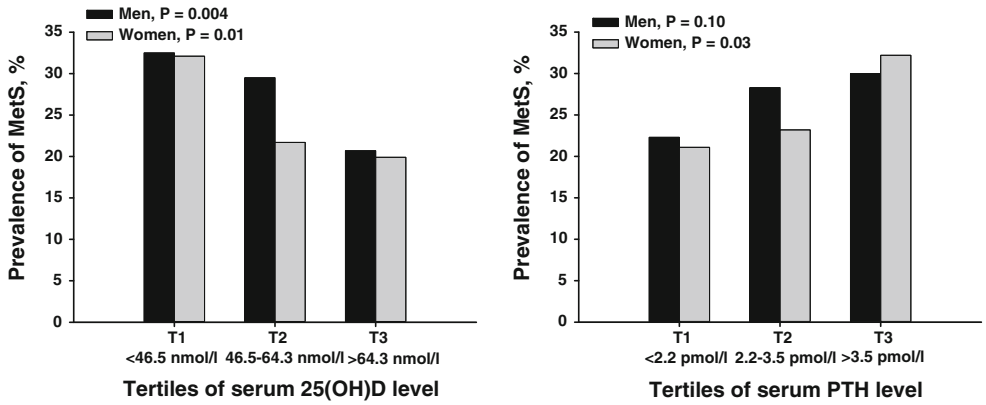

Fig. 1 Gender-specific prevalence of metabolic syndrome across tertiles of serum 25(OH)D and PTH levels *black* and *gray bar* represent prevalence of MetS for men and women, respectively, according to the tertiles of serum 25(OH)D (*left panel*) and PTH levels (*right panel*). *P* values for trends for each group are given. *T1* tertile 1, *T2* tertile 2, *T3* tertile 3

Table 1 Characteristics of participants by gender

Variables	Men ($n = 831$)	Women ($n = 559$)	*P*
Age (years)	49.6 ± 13.5	48.2 ± 12.5	0.04
BMI (kg/m^2)	24.0 ± 3.3	22.8 ± 3.3	<0.0001
Waist circumference (cm)	82.2 ± 9.0	74.2 ± 9.5	<0.0001
Hip circumference (cm)	92.5 ± 6.2	89.8 ± 6.0	<0.0001
Waist-to-hip ratio	0.89 ± 0.06	0.83 ± 0.07	<0.0001
Systolic blood pressure (mmHg)	130.6 ± 20.2	124.0 ± 21.5	<0.0001
Diastolic blood pressure (mmHg)	81.4 ± 11.8	76.4 ± 11.3	<0.0001
Total cholesterol (mmol/l)	5.5 ± 1.0	5.4 ± 1.1	0.18
LDL cholesterol (mmol/l)	3.3 ± 0.9	3.2 ± 1.0	0.18
HDL cholesterol (mmol/l)	1.2 ± 0.3	1.5 ± 0.3	<0.0001
Fasting triglyceride (mmol/l)	2.5 ± 2.0	1.7 ± 1.2	<0.0001
Fasting serum glucose (mmol/l)	5.5 ± 1.9	5.3 ± 1.6	0.04
Glomerular filtration rate ml/min.1.73 m^2	91.8 ± 18.4	98.6 ± 21.5	<0.0001
Serum 25(OH)D (nmol/l)	59.4 ± 20.9	52.9 ± 19.8	<0.0001
Serum PTH (pmol/l)	3.2 ± 1.8	3.1 ± 1.8	0.09
Current alcohol intake (%)	36.6	2.0	<0.0001
Current smoking (%)	59.2	1.3	<0.0001
Hypertension (%)	37.2	29.2	0.002
Diabetes mellitus (%)	9.3	7.2	0.16
Metabolic syndrome (%)	27.0	25.4	0.52
Vitamin D deficiency (%)	34.5	47.8	<0.0001

Values are mean ± SD or percentage

LDL low density lipoprotein, *HDL* high-density lipoprotein

body mass index did not affect the strength of the association (OR = 0.88, 95 % CI 0.82–0.94, $P = 0.0004$). The results were confirmed in both men and women. Furthermore, participants with vitamin D sufficiency had a 35 % (OR = 0.65, 95 % CI 0.51–0.84, $P = 0.0009$) lower risk of MetS after multivariable adjustment than those with vitamin D deficiency. The odds ratios of MetS increased significantly with one unit increase of serum PTH level in men and women when no adjustment was applied. However, after further adjustment for covariates in the models, these associations were attenuated significantly and became statistically non-significant (Table 3).

We further analyzed the association of serum 25(OH)D and PTH levels with the risk of MetS according to weight status. Interestingly, a higher level of serum 25(OH)D was only associated with a lower risk of MetS in overweight/obese women ($P = 0.02$), but not in men or women of normal weight. A higher level of serum PTH was not associated with a higher risk of MetS in either normal weight or overweight/obese subjects (Table 4).

Table 2 Multivariable adjusted linear regression analyses of serum 25(OH)D (+10 nmol/l) and PTH (+1 pmol/l) with components of MetS

MetS components	All				Men				Women			
	25(OH)D		PTH		25(OH)D		PTH		25(OH)D		PTH	
	β	*P*	β	*P*	β	*P*	β	*P*	β	*P*	β	*P*
Systolic blood pressure (mmHg)	−0.12	0.62	0.91	0.001	0.01	0.98	0.63	0.08	−0.70	0.07	1.35	0.002
Diastolic blood pressure (mmHg)	−0.04	0.81	0.58	0.001	−0.08	0.69	0.52	0.02	−0.22	0.35	0.61	0.02
Waist circumference (cm)	−0.10	0.44	0.46	0.001	−0.36	0.02	0.37	0.03	−0.12	0.53	0.38	0.07
HDL cholesterol (mmol/l)	0.010	0.03	−0.004	0.43	0.014	0.01	−0.0002	0.98	0.016	0.03	−0.002	0.83
Fasting triglyceride (mmol/l)	−0.12	<0.0001	0.02	0.48	−0.15	<0.0001	0.05	0.15	−0.09	0.0002	−0.06	0.02
Fasting serum glucose (mmol/l)	−0.04	0.08	0.01	0.84	−0.05	0.08	0.03	0.47	−0.02	0.46	−0.03	0.39

Adjusted for age, current alcohol intake, current smoking, working status, day of blood sampling, glomerular filtration rate, and mutually adjusted serum PTH or 25(OH)D

HDL high-density lipoprotein

Discussions

Our results reveal the prevalence of vitamin D deficiency, and the negative and independent association of a higher serum 25(OH)D level with specific MetS components and the risk of MetS in the Chinese population. Though a number of MetS components were associated with serum PTH level after multivariable adjustment, there was no evidence of an association between serum PTH level and the risk of MetS. We also observed a significant gender-related difference in the association of 25(OH)D and PTH levels with MetS components.

Our finding that a higher 25(OH)D level is associated with a lower risk of MetS is consistent with most previous population studies. Among the 8,421 participants aged ≥20 years in NHANES III [10], the odds ratio for MetS among participants with the highest quintile of vitamin D compared with those in the lowest quintile was 0.49 (95 % CI 0.37–0.66) after multivariate adjustment. Among the 3,262 middle-aged and elderly Chinese enrolled from Beijing and Shanghai, Lu et al. [15] also found that vitamin D deficiency is common, and that a low 25(OH)D level is significantly associated with an increased risk of developing MetS and insulin resistance. In a study of 1,330 middle-aged Korean participants, Kim et al. [9] also found a strong inverse association of 25(OH)D with MetS.

We calculated the prevalence of MetS to be 26.3 %, which is higher than what is reported in the InterASIA study. In China, the prevalence of MetS and its major components have been rapidly rising, largely reflecting the transition in lifestyle and nutrition in the last two decades. MetS and related cardiovascular diseases have been major public health problems in China. In our study, subjects were recruited in the summer months and from low latitude areas. Thus, we expected less subjects with vitamin D deficiency due to more exposure to sun. However, vitamin D deficiency was still common in this population, especially in women and obese subjects. This is consistent with a previous Chinese study reporting poor vitamin D status in middle-aged and elderly Chinese [15]. Although little is known regarding to what extent vitamin D deficiency in our population could be explained by skin color, latitude, and/or genetic factors, plausible explanations might include: (1) use of vitamin D supplementation is rare among Chinese; (2) unlike in the western countries, Chinese people have not been exposed to vitamin D fortified food; (3) less sun exposure as the result of less outdoor activity, more air pollution, and increased sunscreen use especially for women; (4) increasing prevalence of obesity. Hence, attention should be paid to the vitamin D status of females and of individuals who are old, obese, and less physically active.

Vitamin D may modulate the risk of developing MetS and its components through several potential mechanisms.

Table 3 Association of serum 25(OH)D and PTH levels with the risk of MetS stratified by gender

	All	*P*	Men	*P*	Women	*P*
25(OH)D, +10 nmol/l						
Model 1	0.88(0.82–0.93)	<0.0001	0.88(0.82–0.95)	0.001	0.85(0.76–0.94)	0.002
Model 2	0.89(0.84–0.95)	0.0004	0.89(0.83–0.97)	0.004	0.89(0.79–0.99)	0.03
Model 3	0.90(0.84–0.96)	0.0007	0.90(0.83–0.97)	0.007	0.89(0.79–0.99)	0.04
PTH, +1 pmol/l						
Model 1	1.10(1.03–1.17)	0.003	1.09(1.01–1.18)	0.03	1.12(1.01–1.24)	0.04
Model 2	1.05(0.98–1.12)	0.15	1.06(0.97–1.15)	0.18	1.04(0.92–1.16)	0.55
Model 3	1.04(0.97–1.11)	0.28	1.04(0.96–1.13)	0.34	1.03(0.92–1.16)	0.64

Values are odds ratio (95 % CI)

Model 1 univariate analysis; *model 2* adjusted for age, current alcohol intake, current smoking, working status, day of blood sampling and glomerular filtration rate; *model 3* additionally mutually adjusted serum PTH or 25(OH)D

Table 4 Association of serum 25(OH)D and PTH levels with risk of MetS in normal weight and overweight/obese subjects

	Normal weight		Overweight/obese	
	OR(95 % CI)	*P*	OR(95 % CI)	*P*
25(OH)D, +10 nmol/l				
All	0.91(0.82–1.01)	0.06	0.86(0.78–0.95)	0.003
Men	0.89(0.78–1.02)	0.09	0.90(0.80–1.01)	0.06
Women	0.93(0.79–1.09)	0.37	0.78(0.63–0.96)	0.02
PTH, +1 pmol/l				
All	0.94(0.84–1.06)	0.33	1.06(0.96–1.18)	0.26
Men	0.85(0.72–1.02)	0.07	1.12(0.99–1.27)	0.07
Women	1.04(0.89–1.22)	0.64	0.87(0.69–1.08)	0.21

Adjusted for age, current alcohol intake, current smoking, working status, day of blood sampling, glomerular filtration rate, and mutually adjusted for serum PTH or 25(OH)D

Active vitamin D can inhibit the proliferation of preadipocytes, and suppress the expression of several differentiation markers and adipogenic-related genes [30]. Meanwhile, it is known that vitamin D promotes general activation of protein synthesis in pancreatic β-cells, enhances Ca^{2+} influx into β-cells and stimulates the conversion of proinsulin to insulin [31, 32]. The effect of vitamin D on lipids could be via suppression of PTH secretion as PTH has been reported to reduce lipolysis at least in vitro [33]. In addition, vitamin D could influence on the lipids through an increased calcium level which may reduce hepatic triglyceride formation and/or secretion [34, 35]. Indeed, our finding that a higher 25(OH)D level is associated with a favorable lipid profile, an observation not confounded by obesity, is consistent with previous studies. Jorde et al. [36] found a significant increase in serum HDL-C level and a significant decrease in serum triglyceride level across increasing serum 25(OH)D quartiles. In a longitudinal study, an increase in serum 25(OH)D level over 14 years is associated with a significant decrease in serum triglyceride [36]. Furthermore, in a prospective study of 4,330 subjects with a 5-year follow-up, a 10 nmol/l higher baseline level of vitamin D is associated with a decrease in triglyceride and very low density lipoprotein cholesterol levels by 0.52 and 0.66 %, respectively [7].

Given that vitamin D is believed to be sequestered in fat tissue as a result of its hydrophobic nature and to not be as readily available for 25-hydroxylation as in lean individuals, some studies have corrected for body mass index in multivariable analysis of the association with MetS [12, 37]. Because central obesity is a major component of MetS, it is somewhat controversial to account for adiposity in multivariable analysis. Even if we additionally adjusted for body mass index in logistic analyses, the association between 25(OH)D and MetS did not change substantially. Thus, we confirmed that the association between 25(OH)D and MetS is independent of adiposity. We further conducted subgroup analyses according to weight status. However, a higher serum 25(OH)D level only inversely associated with MetS in overweigh/obese women, but not in men or women of normal weight.

The reason for gender difference in the prevalence of MetS across increasing tertiles of serum PTH is unknown. Although we showed that serum PTH level is significantly associated with a number of components of MetS in men or women, we could not find an independent association between serum PTH level and risk of MetS after multivariable adjustment in both men and women. Previous studies that investigated the association between PTH level and MetS provided conflicting results [12, 17–20]. Moreover, previous studies with a positive association of PTH level with MetS have been conducted in populations restricted to elderly [12, 17, 20] or obese subjects [19]. Our present study was conducted in relatively young and lean subjects, which may partly account for the difference observed in the association between PTH level and MetS. In addition, the lack of independent association between serum PTH and MetS in our study is consistent with a

report in middle-aged Korean subjects [9]. Given the present inconsistencies in the literature, further study in this area is warranted.

To our knowledge, this is the first study to investigate the association of both 25(OH)D and PTH levels with MetS in the Chinese population. A strength of our study is its rapid completion, which minimized the seasonal variation of serum 25(OH)D and PTH levels. In addition, there was only one participant under calcium supplementation and none received vitamin D supplementation. However, our study has to be interpreted within the context of its limitations. First, we did not collect information on physical activity, dietary vitamin D intake, and sunlight exposure. However, we directly measured serum 25(OH)D level, an indicator of vitamin D status in the body and can reflect the cumulative effect of sunlight exposure and dietary intake of vitamin D. Second, the participants were not selected randomly from the general population. Therefore, the results may not be generalized to the general population. Third, we measured serum 25(OH)D level at only one timepoint; thus, our findings are not indicative of vitamin D status over the lifetime of the participant. Finally, our study was cross-sectional, and hence no causal inference could be taken.

Despite its limitations, our population study found that 25(OH)D is significantly and inversely associated with MetS. There is no association detected between PTH and MetS. Considering the high prevalence of MetS and vitamin D deficiency in the Chinese population, our results may have important implication for public health interventions. However, further research is needed to verify our findings.

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Conflict of interest None of the authors have a conflict of interest with regard to the data presented in this paper.

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