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ORIGINAL CONTRIBUTION

Association of surrogate and direct measures of adiposity with risk of metabolic syndrome in rural Chinese women

Fengxiu Ouyang · Jonathan Necheles · Binyan Wang · Wei Ma · Zhiping Li · Xue Liu · Genfu Tang · Houxun Xing · Xiping Xu · Scott A. Venners · Wendy J. Brickman · Katherine Kaufer Christoffel · Donald Zimmerman · Xiaobin Wang

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Abstract
Background Most studies linking obesity and metabolic syndrome (MS) have used body mass index (BMI) and waist circumference (WC) to measure obesity. While BMI is correlated with direct measures of total and central adiposity, it is influenced by lean body and bone mass. We hypothesize that direct measures of adiposity may help develop further insight into the link between obesity and MS, thus more accurately identifying individuals at high risk for MS.
Aim of the study We examined how surrogate and direct measures of adiposity were associated with MS risk and if direct adiposity measures enhanced BMI and WC identification of MS risk.
Methods 3,734 Chinese female twins aged 20–39 years were studied. Percent body fat (%BF) and proportion of trunk fat to total BF (%TF) were assessed by DEXA. Graphic plots and generalized estimating equations were used to examine the associations of adiposity measures with MS and its components. Concordance of adiposity measures and MS abnormalities between monozygotic (MZ) and dizygotic (DZ) twin pairs were compared.
Results The prevalence of MS increased for high BMI ($\geq$23 kg/m^2), %BF ($\geq$32), WC ($\geq$80 cm), and (to a lesser degree) %TF ($\geq$50). Below those thresholds, the prevalence of MS was low (0–5.3%). %TF was independently associated with higher risk of MS and its components even after adjusting for BMI and WC. As a result, among women with normal BMI and WC, high %TF was associated with 1.3–2.0-fold elevated risk of MS components. In contrast, women with high BMI but normal WC and

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F. Ouyang · J. Necheles · B. Wang · K. K. Christoffel · X. Wang (✉)
Mary Ann and J. Milburn Smith Child Health Research Program, Department of Pediatrics, Northwestern University Feinberg School of Medicine and Children's Memorial Hospital and Children's Memorial Research Center, Box 157, 2300 Children's Plaza, Chicago, IL 60614, USA
e-mail: xbwang@childrensmemorial.org

J. Necheles · K. K. Christoffel
Division of General Academic Pediatrics, Northwestern University Feinberg School of Medicine and Children's Memorial Hospital, Chicago, IL, USA

W. Ma
Department of Cardiology, Beijing University First Affiliated Hospital, Beijing, China

Z. Li · X. Liu · G. Tang · H. Xing
Institute for Biomedicine, Anhui Medical University, Hefei, China

X. Xu · S. A. Venners
Center for Population Genetics, University of Illinois at Chicago School of Public Health, Chicago, IL, USA

W. J. Brickman · D. Zimmerman
Division of Endocrinology, Department of Pediatrics, Northwestern University Feinberg School of Medicine and Children's Memorial Hospital, Chicago, IL, USA

%TF neither have significantly increased risk of MS, nor for any component other than high BP. MZ twins showed higher concordance for MS and its components than DZ twins.

Conclusions In this lean Chinese rural female sample, BMI $\geq$ 23 and WC $\geq$ 80 were associated with a markedly increased risk of MS, which was further enhanced by elevated %TF. Even in women with a normal BMI and WC, %TF was independently associated with MS and its components. Twin analysis findings suggest that adiposity measurements and MS risk are influenced by genetics.

Keywords Body mass index · Waist circumference · Body composition · Metabolic syndrome · Chinese women · Twins

Introduction

The metabolic syndrome (MS) has been recognized as an independent risk factor for type 2 diabetes, cardiovascular disease, and early cardiovascular mortality, especially for women [16, 45]. Women are disproportionately affected by MS-conferred cardiovascular risk [16]. Early identification of individuals at increased risk of MS is needed to initiate intervention and mitigate the harmful health consequences [45].

Obesity is associated with insulin resistance and MS. There are numerous studies investigating the relationships between adiposity and MS; however, most were conducted in high income and non-Asian populations [24]. In addition, considerable controversy exists regarding optimal body weight in varied populations [44]. An improved understanding of the association between adiposity and MS requires studies in multiple distinct populations.

As compared to Caucasian females, Asian females have a higher percentage of body fat and higher amounts of visceral adipose tissue (VAT) for a given BMI [30]. In addition, obesity-related disorders increase at a lower BMI in Asians [10]. Our prior investigations have demonstrated strong associations between body weight and cardiovascular disease (CVD) risk factors (i.e., blood pressure, blood lipids, and fasting glucose) in relatively lean Chinese populations [22, 39]. However, few MS studies in Chinese populations have been published and very few on rural Chinese women [11, 18].

Most studies linking obesity and MS have used body mass index (BMI) or waist circumference (WC) to measure obesity [20, 24]. While BMI is a convenient surrogate for adiposity [24], variations in body composition by race, age, gender, and menopausal status underscore the need for population-specific BMI cut-off values to identify individuals at-risk for MS [42]. BMI does not distinguish between fat and lean body mass or distinguish between central and peripheral adiposity [34], a better correlate of insulin resistance (IR) [17]. WC is a better measure of abdominal fat accumulation than BMI [34]. It remains unclear if direct measures of adiposity, as from DEXA [34], provide information on risk for MS and its components, above and beyond BMI and WC.

This study utilizes epidemiological, clinical and laboratory data from a large cohort of rural Chinese female twins. There are compelling reasons to study this population. China is in the midst of economic and nutritional transition. Although obesity prevalence in rural China is low, rising obesity rates in these regions are outpacing those in urban areas [47]. Given these trends, the prevalence of overweight and obesity in China will likely increase as will the associated illnesses and health costs. Definition of current patterns is essential for later analysis of changes in MS risk as cultural patterns, and associated dietary and physical activity behaviors change. Further, rural residents constitute a large segment of the Chinese population (64%), [7] as well as the world's total population. Finally, the twin design allows us to perform some unique analysis that is not possible in general populations; yet statistical approaches are available that assure adiposity–MS associations not interfered when twins were analyzed as individuals.

This study obtained adiposity measures of surrogates (BMI and WC, derived from anthropometry) and direct measures (percent body fat, %BF and percent trunk fat, %TF, derived from dual-energy X-ray absorptiometry, DEXA). We analyzed the associations of all of these measures of adiposity with MS and its components. We were particularly interested to learn whether direct adiposity measures improve the risk assessment for MS or its components beyond the information provided by BMI and WC.

Methods

Study population

Data were collected from a population-based twin cohort recruited during 1998–2000 to study complex human diseases including MS. Eligible twins lived in eight counties of the Anqing region, Anhui Province, China. The population size was approximately 6.11 million, including 10% urban and 90% rural population [36]. Few women drank alcohol or smoked cigarettes.

Recruited twins met the following eligibility criteria: (1) 6 years or older; (2) both consented to participate; and (3) were not nursing or pregnant. Twins were invited to a central office to complete a questionnaire interview, blood draw, physical exam and DEXA measurements as described in detail by Wang et al. [39].

This analysis focused on premenopausal females aged 20–39 years. From a total of 4,167 women, 433 were excluded because they smoked ($n = 35$), consumed alcohol ($n = 85$), or had missing DEXA ($n = 313$) scans. This report included 3,734 who reported no tobacco or alcohol use.

The study protocol was approved by the Institutional Review Boards of Children's Memorial Hospital and the Institute of Biomedicine, Anhui Medical University in Hefei, China.

Zygosity ascertainment

Zygosity was determined by microsatellite probes, or 'DNA fingerprinting' techniques, which has an accuracy rate exceeding 99% [39]. Of 1,138 twin pairs ($n = 2,276$) in whom zygosity was determined, 786 pairs were monozygotic (MZ) and 352 pairs were dizygotic (DZ).

Anthropometric and DEXA measures of adiposity

Body weight and height were measured using standard protocols [39] without shoes or outerwear. WC was measured at the level of the umbilicus to the nearest centimeter. Each anthropometric measure was taken three times and the mean value was used. BMI was calculated as weight/height^2 (kg/m^2).

A standard whole-body scan was performed by DEXA (DPX-GE-lunar MD, USA) to measure total BF and TF (TF: chest, abdomen and pelvis) [32]. %BF was calculated as (total BF in kg/body weight in kg) $\times$ 100; and %TF as (trunk fat in kg/total BF in kg) $\times$ 100.

Blood pressure assessment

Blood pressure (BP) was assessed as previously described [48]. The mean value of three BP measures was used in the analysis of systolic (SBP) and diastolic BP (DBP).

Laboratory measurements

Venous blood samples were collected after a 12-h overnight fast [39]. Triglycerides (TG) were measured by an enzymatic method (Boehringer Mannheim, Mannheim, Germany); high density lipoproteins (HDL) by the same enzymatic method after precipitation with dextran sulphate/magnesium chloride; and fasting plasma glucose (FPG) by the glucose oxidase method with an automated biochemical analyzer (Model 7020, Hitachi Company, Japan).

Definition of metabolic syndrome

Women were classified according to the standard definition for Asian women [19]. Specifically, MS was defined if three or more of the following five components were present: (1) WC $\geq$ 80 cm; (2) TG $\geq$ 150 mg/dl; (3) HDL $<$ 50 mg/dl; (4) high BP: SBP $\geq$ 130 mmHg and/or DBP $\geq$ 85 mmHg; or (5) FPG $\geq$ 100 mg/dl.

Covariate assessment

Detailed information was collected during the standard questionnaire interview on sociodemographic characteristics, education, occupation, smoking history (active and passive), and alcohol use.

Statistical methods

Spearman correlation coefficients between adiposity measures were calculated. To examine their relationships with MS risk, BMI, WC, %BF and %TF values were plotted against prevalence of MS. Due to a small sample size, we grouped BMI values $\leq$17 kg/m^2 together, and also grouped BMI values $\geq$28 kg/m^2 together. Similar combinations were used for other adiposity measures. Based on the plots, we visually identified thresholds where MS prevalence markedly increased: BMI $\geq$ 23, WC $\geq$ 80, or %BF $\geq$ 32, and to a lesser degree for %TF $\geq$ 50. Values below the cut points are referred to as "low" and those above as "high" [for %TF, the median %TF was 50 (same as the threshold of %TF), so %TF below the median was classified as low %TF; %TF equal to or above the median was classified as high %TF].

Logistic regressions were performed to evaluate the association of each adiposity measure (either as a continuous or binary variable) with MS and its components (outcome variables), and to determine if DEXA-derived measures confer additional risk of MS and its components beyond BMI (and WC).

First, examined as a continuous variable, each adiposity measure was expressed as a z score to ensure comparability. A z score is calculated as an observed value minus the samples' mean value, divided by the samples' standard deviation. For example, a z score of 1.0 for BMI in this sample is equivalent to a 2.6 kg/m^2 BMI increase above the average. Model 1 estimated the associations of each adiposity measure with the outcome variables. Model 2 evaluated the associations of WC, %BF, and %TF with the outcome variables while adjusting for BMI. Model 3 evaluated the associations of %BF and %TF with outcome variables while adjusting for BMI and WC. Odds ratios (OR) were computed for 1-SD change in each adiposity measurement.

We also examined each adiposity measurement as a binary variable based on the thresholds identified by the graphic plots. We categorized participants into six groups: (1) BMI $<$ 23, WC $<$ 80 and low %TF (reference group); (2) BMI $<$ 23, WC $<$ 80 and high %TF; (3) BMI $<$ 23 and

WC $\geq$ 80; (4) BMI $\geq$ 23, WC $<$ 80 and low %TF; (5) BMI $\geq$ 23, WC $<$ 80 and high %TF; (6) BMI $\geq$ 23, WC $\geq$ 80. We estimated the risk of MS and its component for groups 2 to 6, using group 1 as a reference.

In addition, all regression models also adjusted for the following covariates: passive smoking (yes/no), education (illiterate, elementary school, or junior high or higher), occupation (farmer/other), and age group (20–24, 25–29, 30–34, $\geq$35 years). A generalized estimating equation (GEE) was applied to all regression models to account for correlations in measurements within the twin pairs assuming an independent correlation structure to model the correlations [49].

Finally, probandwise concordance rates were calculated for MS, each MS component and each adiposity measure among MZ and DZ twin pairs separately as $2a/(2a + b)$, where a is the number of pairs in which both twins are affected and b is the number of pairs in which only one twin is affected.

Results

Sociodemographic characteristics

Table 1 shows the characteristics of the sample. The mean age of participants was 29.8 (SD 5.1) years. The majority of women was aged 25–34 (59.4%), and was farmers (61.4%). More than half of the participants reported exposure to passive smoke (56.5%) and had less than a junior high school education (69.3%).

Anthropometric measures

As shown in Table 1, the mean BMI was 21.8 (SD 2.6) kg/m^2; the median was almost the same (21.5). More than one-fourth of the sample (27.5%) had a BMI $\geq$ 23 kg/m^2, 17.7% had a BMI $\geq$ 24 kg/m^2 (the Chinese criterion for overweight [51]), and 10.9% had a BMI $\geq$ 25 kg/m^2 (the WHO criterion for overweight). The prevalence of

Table 1 Epidemiological and clinical characteristics of 3,734 non-smoking, non-alcohol-using rural Chinese women aged 20–39 years, Anqing, China, 1998–2000

Variable	Mean (SD)	10th percentile	Median	90th percentile
Anthropometric characteristics				
Height (cm)	153.7 (5.5)	146.8	153.6	160.6
Weight (kg)	51.5 (7.2)	43.5	50.6	61.0
BMI (kg/m^2)	21.8 (2.6)	18.8	21.5	25.2
Adiposity measures by DEXA				
Total body fat (kg)	13.2 (4.8)	7.8	12.6	19.7
% BF	25.1 (6.1)	17.2	25.0	33.1
Trunk fat (kg)	6.6 (2.7)	3.5	6.2	10.4
%TF	49.3 (4.5)	43.4	49.6	54.9
Major MS components				
Waist circumference (cm)	71.3 (7.3)	63.0	70.0	81.0
Systolic BP (mmHg)	109.5 (9.7)	98.2	108.9	121.3
Diastolic BP (mmHg)	65.7 (8.2)	56.0	65.1	76.0
Triglycerides (mg/dl)	67.1 (39.1)	27.5	58.5	117.8
HDL (mg/dl)	53.3 (12.0)	39.4	52.6	66.9
Fasting glucose (mg/dl)	83.9 (15.3)	66.7	82.5	104.3
Sociodemographic characteristics, *n* (%)				
Age (years)				
20–24	786 (21.0)			
25–29	1,125 (30.1)			
30–34	1,093 (29.3)			
35–39	730 (19.6)			
Education				
Illiterate	1,281 (34.4)			
Elementary school	1,299 (34.9)			
Junior high school and above	1,142 (30.7)			
Occupation				
Farmer	2,282 (61.4)			
Others	1,437 (38.6)			
Passive smoking, yes	2,081 (56.5)			

% BF: total body fat $\times$ 100/body weight; % TF: trunk fat $\times$ 100/total body fat

DEXA dual-energy X-ray absorptiometry

Table 2 Correlations of BMI, waist circumference and body composition measures in 3,734 non-smoking, non-alcohol-using rural Chinese women, Anqing, China, 1998–2000

	Spearman correlation coefficients*				
	%BF	%TF	Total body fat (kg)	Trunk fat (kg)	Waist circumference (cm)
BMI (kg/m^2)	0.75	0.49	0.84	0.84	0.74
%BF		0.52	0.96	0.94	0.65
%TF			0.53	0.68	0.53
Total body fat (kg)				0.98	0.74
Trunk fat (kg)					0.76

%TF: trunk fat × 100/total body fat

*p values for all of the coefficients were <0.0001

HDL ≤ 50 mg/dl (41.0%) was high in this sample. This sample shows a high prevalence of low HDL and FPG ≥ 100, although the prevalence of WC ≥ 80 and the prevalence of MS were low (online Table 2).

As shown in Table 2, %BF and BMI were highly correlated ($r = 0.75$), as were WC and BMI ($r = 0.74$). In contrast, %TF and BMI ($r = 0.49$) and %TF and WC ($r = 0.53$) were only moderately correlated; so was the correlation between %BF and %TF ($r = 0.52$).

Thresholds of adiposity measures for increased risk of MS (Fig. 1)

The prevalence of MS was low among individuals with a BMI less than 22 (range 0.3–0.8%). At a BMI of 23, it increased by an order of magnitude to 3.3%. Thereafter, the risk of MS increased with higher BMI values (Fig. 1, left top panel). BMI ≥ 23 identifies 86.3% of women with MS (113/131).

Similarly, MS prevalence was low (0–1.4%) for a WC ≤ 78 cm, and it increased to 4.3% at a WC of 79 cm, and to 11.0% at a WC of 80 cm (Fig. 1, right top panel). WC ≥ 80 identifies 86.3% of women with MS (113/131).

Risk of MS increased with %BF. For %BF < 32, MS prevalence ranged from 0 to 5.3%. At %BF = 32, MS prevalence was 9.4%. Thereafter, MS risk increased markedly with higher %BF (Fig. 1, left bottom panel).

The risk of MS increased with higher %TF values. For %TF ≤ 49, prevalence of MS ranged from 0 to 1.6%. At a %TF of 50 (median %TF), prevalence of MS increased to 5.6% (Fig. 1, right bottom panel).

Independent association of DEXA-derived adiposity measures (%BF and %TF) with the risk of metabolic syndrome and its components (Table 3)

Table 3 shows the three sets of logistic regression models performed, all incorporating continuous adiposity variables.

In Model 1, with each adiposity measurement examined individually, all measurements were strongly associated with increased risk of MS and its components (four for WC, five for the others). The magnitude of associations between the different adiposity measures and the separate MS components was quite consistent (e.g., for high TG, ORs were 1.8–2.0; for high FPG, ORs were 1.2–1.3).

In Model 2, adjusting for BMI, WC, and %TF were still positively associated with risk of MS and with three or four MS components (excluding high BP), but %BF was associated with only two MS components, high WC and high TG.

In Model 3, adjusting for BMI and WC, %TF remained associated with increased risk of MS and three MS components (excluding high BP), but %BF was no longer associated with MS and remained associated only one MS component, high TG.

MS and components in subject subgroups based on adiposity measures (Table 4)

The lowest risk of MS was observed among women with normal BMI (<23), normal WC (<80), and low %TF (MS prevalence 0.3%).

More than one-third (38.7%) of subjects with normal BMI and WC had high %TF which were associated with 1.3–2.0-fold elevated risk for four MS components (all of those other than WC).

In striking contrast, women with high BMI (≥23) but without elevated WC and %TF had no significant elevation in risk of MS and an elevated risk for only one MS component, high BP.

Women with high BMI and high WC showed the highest risk for MS and its components (other than WC). For example, compared to the lowest risk reference group, women with high BMI and WC had an odds ratio of 7.5 (95% CI 4.6–12.3) of high TG. "WC ≥ 80 cm and/or BMI ≥ 23 kg/m^2" identifies 91.6% of women with MS (120/131).

Concordance between the MZ and DZ twin pairs

When we examine the concordance between the MZ and DZ twin pairs, MZ twins showed higher concordance rates for MS, MS components and adiposity measures (high BMI, high %BF and high %TF) than DZ twins (online Table 1). This suggests that adiposity measurements and MS risk are influenced by genetics.

Discussion

Our study is unique in its analysis of the relative contributions of %BF, %TF, BMI and WC with the MS and its

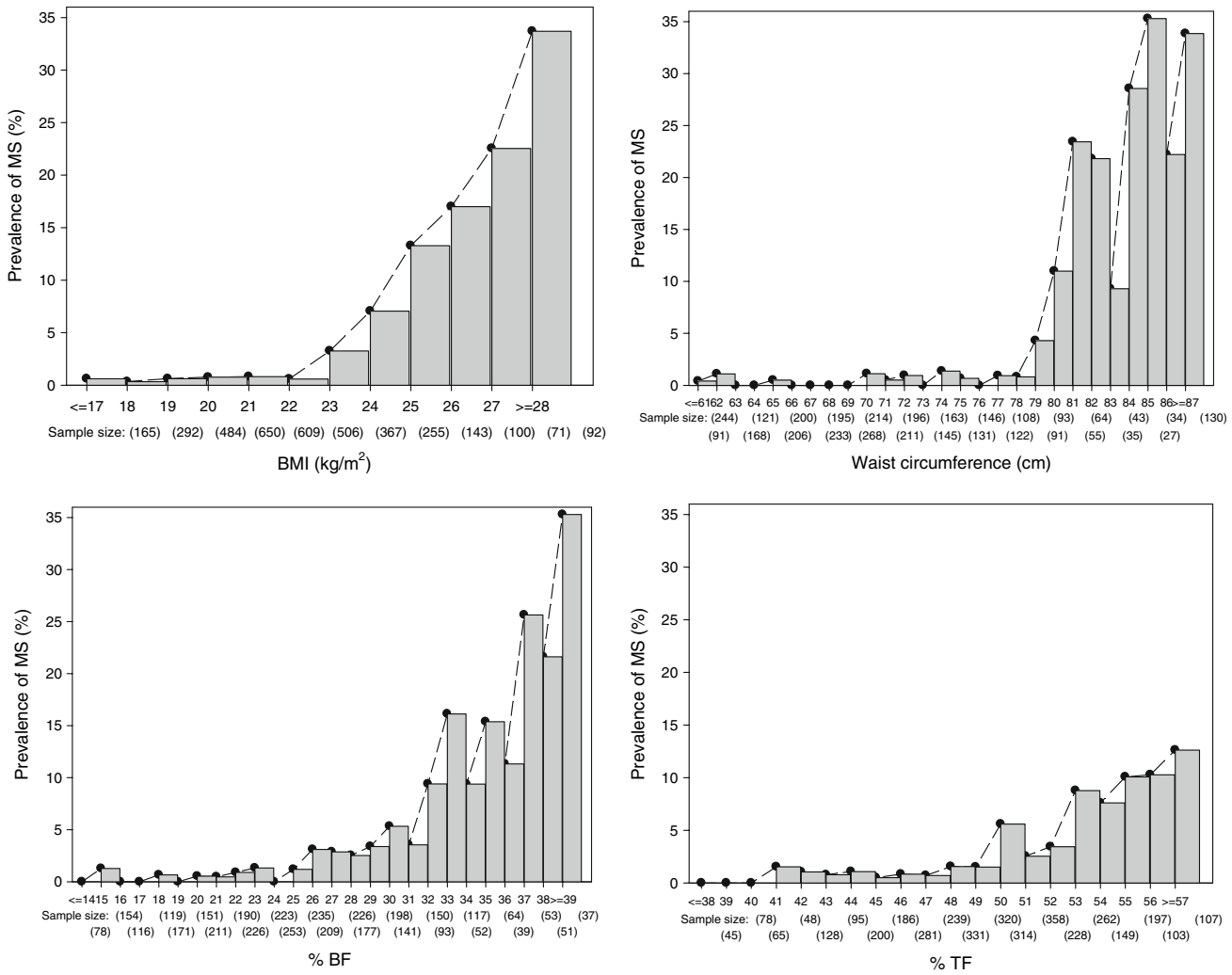

Fig. 1 Prevalence of metabolic syndrome (MS) by body mass index (BMI), waist circumference (WC), percent body fat (%BF) and percent trunk fat (%TF) among 3,734 rural Chinese women aged 20–39 years. Integer values were used for BMI, WC, %BF and %TF

components. The study was conducted in a lean Chinese rural female sample, and thus provides information on these relationships in a relatively lean population, and in a Chinese population before industrialization. Our study has revealed several novel findings.

In this sample, the pattern of prevalence of MS and its components was distinct, when compared to women aged 20–39 years in previous [9]. The prevalence of low HDL (40.95%) was similar to those in Finland (40.8%) [29] and in the United States (31.2–45.6%, depending on race/ethnicity) [31]. However, the prevalence of FPG $\geq$ 100 (13.9%) was about double that in Finland (6.6%) [29]. The MS prevalence (3.5%) was comparable to that reported in Taiwan (3.5% for 20- to 39-year olds) [23], but much lower than that reported in Finland (13.0%) [29], Iran (17.1%) [2], and in US women aged 20–39 years (18.6–23.7%, depending on race/ethnicity) [13–15]. Compared with women in other studies, WC was smaller in this study sample. 12.8% had WC $\geq$ 80 in this study, while 37.2% had WC $\geq$ 80 in Finland, [29]; 23.6–40.7% in the US [31] and 18–35% in Iran [2] had WC $\geq$ 88. Overall, the present study sample shows high prevalence of low HDL and FPG $\geq$ 100, despite low prevalence of WC $\geq$ 80 and of MS, confirming that metabolic disorders among Asian women are observed at a lower level of WC than in Caucasian women.

The most commonly used BMI cutoff for classifying overweight for Chinese populations is $\geq$24 (Chinese standard, 2002) [51] and $\geq$25 (WHO standard, 2000) [41], which appears to be too high for this rural Chinese sample. In studies of Chinese samples in varied locations (e.g., Shanghai, Hong Kong and Taiwan), BMI cut-off points for increased MS or CVD risk factors have varied between 22–24 kg/m^2 [23, 25–27]. The variation could reflect study designs and subject ages. In the present

Table 3 Logistic regression of metabolic syndrome (MS) and its individual components as a function of each *z* scored adiposity measurement with and without adjustment of BMI and waist circumference (WC) among 3,734 rural Chinese women, Anqing, China, 1998–2000

	BMI *z* score			WC *z* score			%BF *z* score			%TF *z* score		
	OR	95% CI	*p* value	OR	95% CI	*p* value	OR	95% CI	*p* value	OR	95% CI	*p* value
Model 1: adjusted for covariates												
MS	3.4	2.9, 4.1	<0.001	4.4	3.6, 5.5	<0.001	4.3	3.5, 5.4	<0.001	2.7	2.1, 3.3	<0.001
High WC	8.8	7.3, 10.5	<0.001	–	–	–	8.9	7.4, 10.7	<0.001	3.1	2.7, 3.6	<0.001
High TG	1.8	1.5, 2.1	<0.001	1.8	1.6, 2.1	<0.001	1.9	1.6, 2.3	<0.001	2.0	1.6, 2.4	<0.001
Low HDL	1.4	1.3, 1.5	<0.001	1.4	1.3, 1.5	<0.001	1.3	1.2, 1.4	<0.001	1.4	1.3, 1.5	<0.001
High BP	1.8	1.5, 2.1	<0.001	1.7	1.4, 1.9	<0.001	1.6	1.3, 2.0	<0.001	1.4	1.2, 1.8	<0.001
High FPG	1.2	1.1, 1.3	<0.001	1.3	1.2, 1.4	<0.001	1.2	1.1, 1.3	0.004	1.2	1.1, 1.4	<0.001
Model 2: adjusted for BMI + covariates												
MS				3.4	2.5, 4.5	<0.001	1.9	1.3, 2.9	0.001	1.8	1.3, 2.3	<0.001
High WC				–	–	–	2.9	2.2, 3.7	<0.001	1.9	1.6, 2.3	<0.001
High TG				1.4	1.1, 1.9	0.007	1.5	1.1, 2.0	0.006	1.6	1.3, 2.0	<0.001
Low HDL				1.2	1.1, 1.4	<0.001	1.0	0.9, 1.2	0.56	1.3	1.2, 1.4	<0.001
High BP				1.1	0.9, 1.4	0.423	0.9	0.7, 1.3	0.58	1.1	0.9, 1.4	0.466
High FPG				1.3	1.1, 1.5	0.001	1.0	0.9, 1.2	0.844	1.2	1.0, 1.3	0.006
Model 3: adjusted for BMI + WC + covariates												
MS							1.4	0.9, 2.1	0.123	1.4	1.1, 1.8	0.016
High WC							–	–	–	–	–	–
High TG							1.4	1.0, 1.9	0.032	1.6	1.2, 2.0	<0.001
Low HDL							1.0	0.9, 1.1	0.738	1.3	1.2, 1.4	<0.001
High BP							0.9	0.6, 1.2	0.462	1.1	0.8, 1.4	0.557
High FPG							0.9	0.8, 1.1	0.546	1.1	1.0, 1.3	0.042

All logistic regression models adjusted for covariates: passive smoking exposure (yes/no), education categories (illiterate, elementary school, or junior high or higher), occupation (farmer/others), and age group (20-, 25-, 30-, 35+); the *z* score of each adiposity measurement (BMI, WC, %BF and %TF) was calculated as (observed value –sample mean)/standard deviation

– not available if WC was included as a predictor variable in the model

sample, MS prevalence was elevated (3.3%) at a BMI of 23, and higher (7.1%) at a BMI of 24, consistent with the recommendation of BMI $\geq$ 23 as the overweight definition for Asians recommended by the WHO [43].

Our analyses show that WC adds important information on risk for MS and its components, beyond the information provided by BMI alone. Although BMI captured a considerable portion of the variation in adiposity, as measured by correlation with DEXA-derived measures of body fat, WC improved identification of subjects with MS. Results observed in this lean rural Chinese sample are in agreement with previous studies conducted in a heavier western sample (more than half with BMI $\geq$ 25) [24]. Our analyses suggest that a cutoff of $\geq$80 for WC [more strict than 88 cm, National Cholesterol Education Program (NCEP) Adult Treatment Panel III (ATPIII) criterion] [19] is most appropriate for Chinese women.

When analyzed individually, the prevalence of MS increased for women with elevations in BMI, %BF, or WC, and to a lesser degree among those with elevated %TF $\geq$ 50. These findings are consistent with a longitudinal study conducted in young Caucasian adults (followed from 13- to 36-year olds) which demonstrated that participants with MS had a higher mean BMI (2.1–3.76 kg/m^2 higher), total BF (assessed by skin-fold measures) and subcutaneous TF (assessed by skin-fold ratios) than those without MS, and that these elevation in BMI, total BF and TF occurred about 15 years before the identification of MS [12].

When analyzed simultaneously with other measures of adiposity, elevated %TF was independently associated with higher risk of abnormalities in all MS components. In this study, more than one-third of women with normal BMI and WC had a high %TF; the MS in this group (0.6%) would be overlooked if assessment is based solely on BMI and WC. At the same time, 17% women with a high BMI had a low WC and %TF, and had no significant increased risk of MS or its components, except for high BP, which suggest that in Chinese women, measurement of WC and trunk fat (TF) with DEXA may define some obese subjects with a low risk for MS. Further research will be needed to assess the cost/benefit ratio for DEXA scans to aid in these assessments.

Table 4 Odds of metabolic syndrome (MS) and its four non-waist circumference (WC) components by body mass index (BMI), waist circumference (WC) and percent trunk fat (%TF) categories among 3,734 rural Chinese women aged 20–39 years, Anqing, China, 1998–2000

	BMI < 23			BMI ≥ 23		
	WC < 80		WC ≥ 80 ($n = 60$)	WC < 80		WC ≥ 80 ($n = 419$)
	Low TF% ($n = 1,621$)	High TF% ($n = 1,025$)		Low TF% ($n = 174$)	High TF% ($n = 435$)	
n(%)						
MS	5 (0.3%)	6 (0.6%)	7 (11.7%)	1 (0.6%)	6 (1.4%)	106 (25.3%)
High TG	31 (1.9%)	35 (3.4%)	4 (6.7%)	7 (4.0%)	27 (6.2%)	56 (13.4%)
Low HDL	526 (32.4%)	470 (45.9%)	26 (43.3%)	54 (31.0%)	217 (49.9%)	236 (56.3%)
High BP	27 (1.7%)	32 (3.1%)	2 (3.3%)	13 (7.5%)	22 (5.1%)	36 (8.6%)
High FPG	191 (11.8%)	142 (13.9%)	12 (20%)	22 (12.6%)	68 (15.6%)	82 (19.6%)
OR (95% CI)						
MS	1 (ref.)	1.9 (0.6, 6.4)	34.9 (9.7, 125.8)[§]	1.7 (0.2, 15.3)	4.4 (1.3, 14.7)[†]	108 (42.9, 271.6)[§]
High TG	1 (ref.)	1.9 (1.1, 3.1)[†]	3.1 (1.0, 9.2)[†]	2.0 (0.8, 4.6)	3.5 (2.0, 6.0)[§]	7.5 (4.6, 12.3)[§]
Low HDL	1 (ref.)	1.8 (1.5, 2.2)[§]	1.6 (0.9, 2.7)	1.0 (0.7, 1.3)	2.1 (1.7, 2.6)[§]	2.7 (2.1, 3.5)[§]
High BP	1 (ref.)	2.0 (1.2, 3.2)[‡]	1.5 (0.3, 6.6)	4.2 (2.0, 9.0)[§]	2.9 (1.6, 5.1)[§]	4.8 (2.8, 8.1)[§]
High FPG	1 (ref.)	1.3 (1.0, 1.6)[†]	1.8 (0.9, 3.6)	1.1 (0.7, 1.8)	1.4 (1.0, 1.9)[†]	1.9 (1.4, 2.5)[§]

%TF: trunk fat × 100/total body fat; low %TF: %TF < median of %TF (50), high %TF: %TF ≥ 50; all logistic regression models were adjusted for passive smoking exposure (yes/no), education categories (illiterate, elementary school, or junior high or higher), occupation (farmer/others), and age group (20-, 25-, 30-, 35+). Women with low BMI, low WC and low %TF were used as reference group

[†] $p < 0.05$, [‡] $p < 0.01$, [§] $p < 0.001$

The positive association between BMI and BP in this population was consistent with our recent study on body fat and BP in rural Chinese adolescents [40]. High BP is one of the most controversial characteristics of MS and might reflect the effects of lean body mass more than body fat [4, 40]. High levels of lean body mass might influence BP through mechanisms such as increased peripheral resistance, increased left ventricular hypertrophy and elevated insulin levels.

More longitudinal studies are needed to determine the role of lean versus fat mass in the development of high BP.

Our findings shed light on the utility of different measures of body fat. The correlation between total body fat and truncal fat was high (0.98) in this study, but the %BF and %TF were only moderately correlated ($r = 0.52$). Percent TF indicates the proportion of fat that deposits in the truncal region, while %BF indicates whole body fat composition. The available literature suggests that the role of %TF and %BF in MS may be different [34], and that the determinants of these measures may also be different [37]. Body fat and truncal fat levels increase with age and differ by menopause status [37] and ethnicity [6, 46]. With increasing age, the increment of truncal fat per decade was greater in Asian women (~0.33 kg/10 years) than that observed in Caucasian or African-American women (~0.07 kg/10 years) [46]. A recent study shows that the association between total body fat and truncal fat was a curvilinear relationship and differed by ethnicity [46]. Age, ethnicity, total body fat and the square root of total body fat were all independent predictors of truncal fat (adjusted $R^2 = 0.964$) [46]. Further research will be needed to clarify the utility of these two measures in MS risk assessment.

Our findings, which show that WC and %TF are strong markers of MS, are biologically plausible. Excess adiposity, particularly central fat [38] is closely associated with chronic inflammation and increased IR [21]. Central adiposity is strongly correlated with hyperglycemia, hypertension, and dyslipidemia [28]. Indeed, it is one of the distinctive features of MS [5] and is included in the definition of MS by the International Diabetes Federation (IDF) [1]. BMI, a function of body weight and height, includes adipose, lean and bone tissue. A well-trained body builder can have a low percentage of BF and a BMI in the overweight range due to a high lean body mass [34]. High % lean body mass and lower %BF could be associated with higher insulin sensitivity [33], regardless of BMI. Future studies of MS should routinely include measurements of central adiposity.

In this community-based twin population, MZ twins showed higher concordance rates for all MS components and adiposity measures than DZ twins. Our findings suggest that genetic factors may play a role in MS components and adiposity measures. This is supported by the results of a genetic analysis of Danish twin pairs, where all metabolic components and BMI showed moderate to high heritability [3]. Further studies are needed to improve our understanding on the genetic and environmental determinants

underlying the association between adiposity measures and MS.

This study has several strengths. (1) It was done in a relatively homogenous population and its sample size was very large. The study subjects were relatively young (20–39 years) and lean, premenopausal, and denied tobacco and alcohol use, thus the association between adiposity and MS was less likely biased by these potential confounders [19]. (2) Body composition was directly measured by DEXA, a technique that can accurately measure tissue type and location [34]. DEXA measures of truncal adiposity are excellent but cannot distinguish visceral and subcutaneous fat [8]. However, the elevation in abdominal fat is largely due to the accumulation of visceral (or intra-abdominal) fat [34].

Study limitations include: (1) The cross-sectional analysis limits any temporal or cause-effect conclusions. (2) Caution is needed in generalizing our findings to other age, ethnic or gender groups since body composition and MS risk differ by these variables. (3) This is a twin cohort, and factors that are increased among twins—such as pre-maturity, intrauterine growth restriction, birth weight, gestational age, and early postnatal growth—could influence risk for metabolic disorders. However, our study participants had a comparable mean BMI to other Southern Chinese studies conducted in similar age and gender populations [20, 50], and the MS prevalence (3.5%) was comparable to other Chinese populations (2.9–5.5%) [11, 35]. Also, GEE was used in all logistic regression models to account for potential intra-twin correlations in MS and its components. Therefore, the relationships between adiposity measures and MS in this report are likely representative of the general Chinese female population of the same age in the study area.

In summary, in this lean Chinese rural female sample, BMI $\geq$ 23 and WC $\geq$ 80 were associated with a markedly increased risk of MS. A subset of women with a normal BMI and WC had high %TF and were at increased risk of MS and its components. In contrast, women with high BMI but normal %TF did not show increased risk of MS. Our data suggest that a combination of BMI, WC and %TF is most specifically associated with MS. Our findings, in keeping with those of others, suggest that %TF might be useful in identifying individuals at high risk of MS who would be missed if risk is based on BMI and WC alone. Further research, including longitudinal studies, is needed to assess the costs and benefits of adding DEXA to assessment based on BMI and WC.

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