Associations of Body Shapes with Insulin Resistance and Cardiometabolic Risk in Middle-aged and Elderly Chinese

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Research

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Abstract

Background: We aimed to define refined body shapes by using multiple anthropometric traits that represent fat distribution, and evaluate their associations with risk of insulin resistance (IR) and cardiometabolic disorders in a Chinese population.

Methods: We performed a cross-sectional analysis in 6570 community-based participants aged ≥ 40 years. Four body circumferences (neck, waist, hip and thigh) and their ratios were put simultaneously into an open-source Waikato Environment for Knowledge Analysis platform to select the worthiest indicators in determining IR. The ratio of the top 3 fat distribution indicators were used to define the refined body shapes.

Results: We defined 8 distinct body shapes based on sex-specific combinations of waist-to-hip ratio (WHR), waist-to-thigh ratio (WTR) and waist-to-neck ratio (WNR), which differed in participants' distribution and risk of IR and related cardiometabolic disorders. In women, as compared to the low WHR-low WTR-low WNR shape, all body shapes were significantly associated with IR and related cardiometabolic disorders; while in men, the low WHR-high WTR-high WNR shape and the higher WHR related shapes were significantly associated with IR and related cardiometabolic disorders. Stratified by WHR, the results were consistent in women; however, no significant associations were detected in men.

Conclusions: We defined 8 distinct body shapes by taking WHR, WTR, and WNR, simultaneously into account, which differed in association with risk of IR and related cardioembolic disorders in women. This study suggest that body shapes defined by multiple anthropometrics traits could provide a useful, convenient and easily available method for identification cardiometabolic risk.

Background

Obesity is a global public health concern. More than 1 billion adults suffer from overweight, and 650 million adults and 124 million adolescents suffer from obesity worldwide [1]. Obesity and related cardiometabolic disorders, such as insulin resistance, metabolic syndrome, hyperlipidemia, etc., are responsible for type 2 diabetes, cancers, cardiovascular diseases and related mortality [2-4]. To better identify and define obesity is extremely essential for prevention and management of the comorbidity and mortality.

Anthropometric trait such as body mass index (BMI), waist circumference, and waist-to-hip ratio (WHR) is widely used to classify obesity and body shapes (apple or pear), which plays a pivotal role in evaluating cardiometabolic risk [5-7]. However, these traits cannot adequately discriminate regional fat distribution or evaluate individual cardiometabolic risk [8]. Integrating multiple anthropometric information will help to achieve a more accurate characterization of cardiometabolic risk, including coronary heart disease, heart failure and mortality [9-13]. The previous study reported that when incorporated the calf circumference into definition of metabolic syndrome, it demonstrated a higher cardiovascular and all-cause mortality risk than the traditional definition of metabolic syndrome alone [12]. A very recent meta-analysis of 72 prospective cohort studies with 2,528,297 participants evaluated the association of central fatness with risk of all-cause mortality, and found that most indices of central fatness, including waist circumference, WHR, waist-to-height ratio, body adiposity index, and a body shape index, were positively and significantly associated with a higher all-cause mortality risk independent of overall adiposity [13]. Measures of central adiposity could be used as a supplementary approach, in combination with BMI, to determine the risk of premature death [13]. These studies suggested that adopting multiple anthropometric traits to evaluate cardiometabolic risk would benefit to early identification of susceptible individuals and improve prevention and management strategies of cardiometabolic diseases.

In the present study, we aimed, firstly to define the body shapes based on three ratios, WHR, WTR, and WNR, simultaneously; secondly, to evaluate the associations of these body shapes with risk of insulin resistance and several major cardiometabolic disorders. The study will provide refined body shapes and further stratify individuals into different stratification of cardiometabolic risk based on these distinct body shapes.

Methods

Study population

The current cross-sectional analysis were based on one of the follow-up circles of our previous community-based cohort studies [14,15]. Briefly, between August 2014 and May 2015, 6570 registered permanent residents aged ≥ 40 years from Jiading district, Shanghai, China, participated in the health examination aimed to explore the effects of risk factors on type 2 diabetes and related chronic diseases. Participants missing data on anthropometric traits including height, weight, waist circumference, hip circumference, thigh circumference and neck circumference (n=167), or missing data on biochemical measurements including systolic and diastolic blood pressure, fasting and 2h-OGTT plasma glucose, fasting serum insulin, total cholesterol, triglycerides, high-density lipoprotein cholesterol and low-density lipoprotein cholesterol (n=163) were excluded. Finally, 6240 participants were included in the current analysis.

The study protocol was approved by the Institutional Review Board of Rui-Jin Hospital affiliated to Shanghai Jiao Tong University School of Medicine. All participants consented for the study and signed informed consent.

Anthropometric measurements

A standard questionnaire was used to collect information on sociodemographic characteristics, chronic diseases and medical history, physical activity and lifestyle factors (e.g. smoking and alcohol status). If participants consumed any kinds of cigarettes or alcohol regularly in the past 6 months, the current smoking or drinking status was defined as ‘yes’. Physical activity in term of MET hour/week was acquired and calculated according to the short form of the International Physical Activity Questionnaire (IPAQ) [16].

Anthropometric traits including height, weight, neck circumference, waist circumference, hip circumference and thigh circumference were measured by well-trained physicians according to a standard protocol. BMI was calculated as body weight in kilograms divided by body height squared in meters (kg/m^2). Waist circumference was measured at the level of the umbilicus with the patient in the standing position. Hip circumference was measured at the tip of the bone around the greater trochanter of the femur. Thigh circumference was measured on the right leg directly below the gluteal fold [17]. Neck circumference was measured in the midway of the neck, below the laryngeal prominence [18]. Systolic and diastolic blood pressure were measured at the nondominant arm with an automated electronic device (OMRON Model HEM-752 FUZZY, Omron Company, Dalian, China) three times consecutively with 1-minute interval after at least 10-minute rest in the seated position. The average value of the three measurements was used in our analysis.

Biochemical measurements

All participants underwent a standard 75-g oral glucose tolerance tests (OGTT) after an overnight fasting of more than 10 hours. Fasting and 2h-OGTT plasma glucose concentrations were measured using the glucose oxidase method through an autoanalyzer (Modular P800; Roche, Basel, Switzerland). Fasting and 2h-OGTT serum insulin concentrations, and serum lipid profiles including total cholesterol, triglycerides, high-density lipoprotein (HDL) cholesterol and low-density lipoprotein cholesterol were measured using an electrochemiluminescence assay (Modular E170; Roche, Basel, Switzerland).

Definitions

Insulin resistance index (homeostasis model assessment of insulin resistance, HOMA-IR) was calculated as fasting serum insulin (μIU/mL) × fasting plasma glucose (mmol/L) / 22.5. Excluding individuals treated with insulin or hypoglycemic agents, insulin resistance was defined as HOMA-IR ≥ 2.61, which was the highest quartile of HOMA-IR. Diabetes was defined as fasting plasma glucose ≥ 7.0 mmol/L or 2h-OGTT plasma glucose ≥ 11.1 mmol/L or use of anti-diabetic agents. Metabolic syndrome was diagnosed based on the National Cholesterol Education Program Adult Treatment Panel III criteria. Individuals with three or more of the following five components were diagnosed to have metabolic syndrome: (1) blood pressure ≥ 130/85 mmHg or taking antihypertensive drugs; (2) waist circumference ≥ 80 cm for women (≥ 90 cm for men); (3) serum triglyceride level ≥ 2.26 mmol/L; (4) serum HDL cholesterol level < 1.04 mmol/L; (5) fasting plasma glucose level ≥ 6.1 mmol/L or confirmed diagnosis of diabetes.

Define of body shapes

Automated feature selection was performed by using the information gain attribute ranking method on the open-source Waikato Environment for Knowledge Analysis platform [19]. Information gain ranking was used to evaluate the worth of each variable (usually the clinical indicator) by measuring the entropy gain to the outcome. The greater the information gain a clinical indicator has, the more important the indicator is in the classification process. The model was built with logistic regression analysis based on the data set. The regression coefficient of each significant variable was regard as the contribution level (**Supplementary Figure 1 A**) [19].

In the present study, we used insulin resistance as the outcome to evaluate the potential dominant anthropometric traits. Anthropometric traits including BMI,

WHR, WTR, WNR, waist-to-neck ratio, neck-to-thigh ratio, neck-to-hip ratio, thigh-to-hip ratio were put into the selection process. As a result, BMI, WHR, WTR and WNR were the top 4 ranked features for determining insulin resistance in both men and women **(Supplementary Figure 1 B).** We finally chose WHR, WTR and WNR as the candidate indicators to define the body shapes.

We calculated the medians of these 3 traits sex-specifically. The corresponding median value for WHR was 0.87 in women and 0.91 in men, for WTR was 1.66 in women and 1.74 in men, and for WNR was 2.48 in women and 2.34 in men. Individuals were divided into the high and low level groups according to the medians of WHR, WTR, and WNR, respectively. Based on the 3 derived ratios, WHR, WTR, and WNR, we defined 8 distinct body shapes (**Figure 1**).

Statistical analysis

Data were summarized as means ± standard deviation (SD) or median (inter-quartile ranges) for continuous variables, and numbers (percentages) for categorical variables. Multiple variable logistic regression analysis was performed to evaluate associations of body shapes with insulin resistance and cardiometabolic disorders in sex-specific samples. Odds ratios (ORs) and the corresponding 95% confidence intervals (CI) was calculated. The adjustments included age (years), BMI (kg/m^2), current smoking (yes or no), current drinking (yes or no) and physical activity (MET-h/wk).

All the statistical analysis were performed with SAS version 9.4 (SAS Institute Inc, Cary, NC, USA). Statistical significance was set to a two-sided P value < 0.05.

Results

Characteristics of study participants

The present study including 3961 (63.4%) women and 2279 (36.3%) men with average BMI was 25.0 ± 5.9 kg/m^2 for women and 25.1 ± 3.5 kg/m^2 for men. Compared with men, women were younger, had lower level of several major anthropometric traits including neck circumference, waist circumference, hip circumference, thigh circumference, WHR, WTR, neck-to-hip ratio, and neck-to-thigh ratio; higher level of HOMA-IR, systolic blood pressure, LDL- and HDL cholesterol and triglycerides (All $P < 0.05$, **Table 1**).

Distribution of body shapes

The 8 distinct body shapes and their proportions by sex were shown in **Figure 1**. 29.6% women and 28.0% men were assigned to the high WHR-high WTR-high WNR shape, 28.2% women and 27.1% men were the low WHR-low WTR-low WNR shape. Less individuals were assigned to the low WHR-high WTR-high WNR shape (women vs. men: 4.7% vs. 5.5%) or the high WHR-low WTR-low WNR shape (women vs. men: 5.9% vs. 6.8%). The proportions of other body shapes varied from 7.3% to 9.1% **(Figure 1).**

Body shape in relation to insulin resistance and cardiometabolic disorders

The prevalence of insulin resistance and metabolic syndrome according to the 8 body shapes by sex were shown in **Figure 2**. In women, as compared to low WHR-low WTR-low WNR shape, all body shapes were positively associated with insulin resistance. These associations were strongest for the high WHR-high WTR-low WNR shape (OR [95% CI] was 3.71 [2.79-4.93], $P < 0.0001$, **Table 2**). In men, as compared to low WHR-low WTR-low WNR shape, low WHR-high WTR-high WNR shape and the higher WHR related shapes were positively associated with insulin resistance. These associations were strongest for the high WHR-high WTR-low WNR shape (OR [95% CI] was 3.00 [1.98-4.55], $P < 0.0001$, **Table 2**).

The stability of body shapes was validated by the associations of body shapes with several major cardiometabolic disorders. In women, all body shapes were positively associated with metabolic syndrome and its components (elevated fasting blood glucose, high blood pressure, high triglycerides and low HDL cholesterol). These associations were strongest for the high WHR-high WTR-low WNR shape (**Table 2**). In men, low WHR-high WTR-high WNR shape and the higher WHR related shapes were associated with the higher risk of metabolic syndrome and its components (**Table 2**). It cannot discriminate the strongest associations among the 4 higher WHR body shapes in relation to the cardiometabolic traits.

On consideration that WHR was the dominant determination indicator of insulin resistance and related cardiometabolic disorders. We further stratified the analysis by the WHR high- and low- levels (**Table 3**). In women, both in the high and low-WHR groups, those with high WTR shapes were significantly associated a high risk of insulin resistance and related cardiometabolic disorders. In men, nearly all the body shape were not associated with insulin resistance and the related cardiometabolic disorders when stratified by WHR level (all $P > 0.05$, **Table 3**).

Predictive values of anthropometric traits

The area under the receiver operator characteristic curve (AUROC) was used to evaluate the predictive values of these anthropometric traits defining the 8 body shapes for diagnosing cardiometabolic disorders beyond BMI (**Supplemental Table 1**). In women, the AUROC (95% CI) of the predictive models of BMI was 0.740 (0.724-0.756) for insulin resistance. The sequential inclusion of WHR, WTR and WNR to the insulin resistance predictive models increased the AUROC for predicting the risk of insulin resistance ($P \leq 0.0009$ for group difference); the AUROC (95% CI) of the predictive models of BMI was 0.743 (0.728-0.759) for metabolic syndrome. The sequential inclusion of WHR, WTR and WNR to the metabolic syndrome predictive models increased the AUROC for predicting the risk of metabolic syndrome ($P <$ 0.0001 for group difference). In men, we observed similar results in the metabolic syndrome predictive models but not in insulin resistance predictive models.

Discussion

In this cross-sectional study of 6240 community-dwelling Chinese adults, we defined 8 distinct body shapes based on sex-specific combinations of WHR, WTR and WNR, which differed in participants' distribution and risk of insulin resistance and cardiometabolic disorders. In women, as compared to the low WHR-low WTR-low WNR shape, all the body shapes were significantly associated with a higher risk of IR and related cardiometabolic disorders. In men, as compared to low WHR-low WTR-low WNR shape, low WHR-high WTR-high WNR shape and the higher WHR related shapes were positively associated with insulin resistance and related cardiometabolic disorders.

Emerging studies had illustrated that conventional anthropometric traits were well-established predictors for insulin resistance, metabolic syndrome, type 2 diabetes and cardiovascular disease [7,10,12,20]. For example, neck circumference and thinner thigh circumference was associated with an increased risk of peripheral arterial disease, cardiometabolic diseases and premature death [21,22]. However, these studies only focused on solitary index rather than whole-body shape measured by multiple anthropometric traits. In current study, we take 3 ratios, WHR, WTR, and WNR, simultaneously into account to define 8 distinct body shapes, and evaluate their associations with risk of insulin resistance and cardiometabolic disorders. These body shapes showed distinct cardiometabolic risk in women. Our study suggested that multiple anthropometrics traits defined body shapes could be helpful to evaluated the difference of disease susceptibility and provide a useful, convenient and easily available method for identification cardiometabolic risk.

Mechanically, muscle mass loss of extremity circumference could influence insulin sensitivity, fat oxidation, and glucose metabolism and promote metabolic disorders [23,24]. Neck fat accumulations could increase secretion of proinflammatory cytokine, elevated free fatty acid production, exacerbated systematic inflammation and impact the glucose and lipid metabolism [25,26]. These factors together exacerbated the risk of insulin resistance and related cardiometabolic disorders.

WHR was the dominant determination indicator of insulin resistance and related cardiometabolic disorders. In addition to WHR level, the WTR was the secondary determination indicator of insulin resistance and related cardiometabolic disorders in women. These results indicated that WTR may play a complementary role to WHR in predicting risk for cardiometabolic disorders. However, no significant associations were detected in men when stratified by the WHR level. Plausible explanations were biological differences between men and women, such as sex hormones metabolism, immune system responses, redistribution of body fat, muscle capacity and physical function [27,28].

To the best of our knowledge, it is the first study to define a refined body shapes by using multiple anthropometric traits simultaneously. The WHR, WTR, and WNR can represent the upper-, central- and lower- body fat distribution, and their measurements are convenient, simple, low cost, and harmless, which may benefit to refine define body shape and suit for large-scale population-based study. Besides, the well-defined community setting, fair sized sample volume, and desirable population homogeneity was a great foundation for current analysis. Several limitations should be acknowledged. Firstly, we could not establish a causal relationship between body shapes and the cardiometabolic risk because of the cross-sectional nature of the present study. The prospective follow up studies are warranted to further evaluate the association of body shape with cardiometabolic risk. Secondly, the onset of cardiometabolic diseases is insidious, mostly occurring aged 40 years or above. Body composition changed with ageing. Our study was conducted in middle and elderly adults, and it should be cautious to interpret the results to the youngers.

Conclusions

In conclusion, we defined 8 distinct body shapes by taking WHR, WTR, and WNR, simultaneously into account in a Chinese community-based cohort. The 8 body shapes differing in risk of insulin resistance and cardioembolic disorders in women, which suggest that multiple anthropometrics traits defined body shapes could be helpful to evaluate the difference of disease susceptibility and provide a useful, convenient and easily available method for identification cardiometabolic risk.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Institutional Review Board of Ruijin Hospital, Shanghai Jiao Tong University School of Medicine and procedures were in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki declaration of 1975, as revised in 1983. Written informed consent was obtained from each study participant.

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analyzed during this study are included in this published article (and its supplementary information files).

Competing interest

The authors declare that they have no competing interests

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Author contributions.

Y.Z., Y.H., Z.Z., and M.X. conceived and designed the study. Y.Z., and Y.H. did the statistical analysis. Y.H., and M.X. drafted the manuscript. Z.Z., Y.B., and M.X. supervised the study. H.D., M.L., H.L., S.W., Y.X., J.L., Y.C., and W.W., contributed to acquisition, analysis, or interpretation of data. All authors revised the report and approved the final version before submission. M.X. is guarantor of this work and, as such, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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Tables

Table 1. Characteristics of study participants in sex-specific samples.

	Total	Women	Men	*P* value
n (%)	6240	3961 (63.4)	2279 (36.3)	
Age (years)	62.2 ± 8.74	61.9 ± 8.56	62.9 ± 9.03	< 0.0001
Systolic blood pressure (mmHg)	134.8 ± 17.3	135.1 ± 17.7	134.2 ± 16.5	0.03
Diastolic blood pressure (mmHg)	76.3 ± 9.5	75.4 ± 9.5	77.8 ± 9.7	< 0.0001
Current smoking, n (%)	1224 (19.2)	20 (0.5)	1204 (51.5)	< 0.0001
Current drinking, n (%)	900 (14.1)	45 (1.11)	855 (36.5)	< 0.0001
Physical activity (MET-h/wk)	18 (4.5-21.0)	21.0 (6.0-21.0)	15.0 (0.0-21.0)	0.60
Biochemical measurements				
Fasting plasma glucose (mmol/L)	6.15 ± 1.47	6.06 ± 1.34	6.29 ± 1.66	< 0.0001
HOMA-IR	1.89 (1.27-2.83)	1.97 (1.34-2.91)	1.74 (1.13-2.61)	< 0.0001
Total cholesterol (mmol/L)	5.95 ± 0.96	6.54 ± 0.96	4.95 ± 0.89	0.26
LDL cholesterol (mmol/L)	3.67 ± 4.13	3.83 ± 5.16	3.39 ± 0.71	< 0.0001
HDL cholesterol (mmol/L)	1.34 ± 0.29	1.39 ± 0.30	1.25 ± 0.29	< 0.0001
Triglycerides (mmol/L)	1.51 (1.09-2.14)	1.55 (1.12-2.19)	1.43 (1.03-2.04)	< 0.0001
Anthropometric measurements				
Body mass index (kg/m^2)	25.0 ± 5.2	25.0 ± 5.9	25.1 ± 3.5	0.41
Waist circumference (cm)	83.6 ± 9.9	81.8 ± 10.0	86.7 ± 9.8	< 0.0001
Neck circumference (cm)	34.4 ± 3.2	33.0 ± 3.2	36.9 ± 3.3	< 0.0001
Hip circumference (cm)	93.9 ± 7.7	93.2 ± 8.0	95.0 ± 7.1	< 0.0001
Thigh circumference (cm)	49.2 ± 5.4	48.9 ± 5.4	49.8 ± 5.3	< 0.0001

Waist-to-hip ratio	0.89 ± 0.11	0.88 ± 0.12	0.91 ± 0.09	< 0.0001
Neck-to-hip ratio	0.37 ± 0.05	0.36 ± 0.05	0.39 ± 0.04	< 0.0001
Waist-to-thigh ratio	1.71 ± 0.22	1.69 ± 0.23	1.75 ± 0.21	< 0.0001
Neck-to-thigh ratio	0.71 ± 0.09	0.68 ± 0.09	0.75 ± 0.09	< 0.0001
Waist-to-neck ratio	2.43 ± 0.24	2.48 ± 0.25	2.35 ± 0.23	< 0.0001
Hip-to-thigh ratio	1.92 ± 0.21	1.92 ± 0.22	1.92 ± 0.20	0.82
Cardiometabolic disorders				
Insulin resistance, n (%)	1814 (29.1)	1246 (31.5)	568 (24.9)	< 0.0001
Metabolic syndrome, n (%)	2077 (33.2)	1371 (34.6)	706 (31.0)	0.003
Elevated fasting blood glucose, including diabetes, n (%)	2423 (38.8)	1467 (37.0)	956 (42.0)	0.0001
High blood pressure, n (%)	4424 (70.9)	2795 (70.6)	1629 (71.5)	0.44
High triglyceride, n (%)	1385 (22.2)	926 (23.4)	459 (20.1)	0.003
Low HDL cholesterol, n (%)	893 (14.3)	386 (9.8)	507 (22.3)	< 0.0001

Data are presented as means ± standard deviation (SD), or medians (inter-quartile ranges) for skewed variables, or number (proportions) for categorical variables. *P* values were calculated from one-way analysis of variance (ANOVA) for continuous variables and chi-square test for categorical variables. Insulin resistance was defined as HOMA-IR ≥ 2.61, which is the cut-off point for the highest quartile of the total participants. Abbreviations: MET, metabolic equivalent task; HOMA-IR indicates homeostasis model assessment of insulin resistance; LDL cholesterol, low-density lipoprotein cholesterol; HDL cholesterol, high-density lipoprotein cholesterol.

Table 2. Association of body shape with risk of cardiovascular diseases in sex-specific samples

Body shape	Insulin resistance	Metabolic syndrome	Elevated fasting blood glucose, including diabetes	High blood pressure	High triglycerides	Low HDL cholesterol
Women						
Low WHR-low WTR-low WNR	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Low WHR-low WTR-high WNR	1.49 (0.89-1.75)*	2.16 (1.53-3.03)*	0.99 (0.74-1.34)	0.85 (0.65-1.12)	1.34 (0.95-1.88)	0.68 (0.37-1.25)
Low WHR-high WTR-low WNR	2.09 (1.51-2.88)*	1.87 (1.31-2.67)*	1.77 (1.34-2.33)*	1.59 (1.18-2.14)*	1.54 (1.10-2.15)*	1.63 (1.03-2.59)*
Low WHR-high WTR-high WNR	2.09 (1.44-3.02)*	4.44 (3.08-6.40)*	2.32 (1.67-3.23)*	1.27 (0.88-1.84)	1.57 (1.05-2.34)*	1.56 (0.89-2.74)
High WHR-low WTR-low WNR	2.02 (1.44-2.84)*	3.95 (2.81-5.56)*	1.31 (0.96-1.80)	1.54 (1.13-2.12)*	2.35 (1.69-3.27)*	2.18 (1.38-3.42)*
High WHR-low WTR-high WNR	1.92 (1.41-2.61)*	5.35 (3.92-7.03)*	1.37 (1.03-1.83)*	1.78 (1.31-2.40)*	2.36 (1.74-3.19)*	2.13 (1.40-3.23)*
High WHR-high WTR-low WNR	3.71 (2.79-4.93)*	6.95 (5.16-9.36)*	2.36 (1.82-3.06)*	2.23 (1.63-3.06)*	2.95 (2.12-3.93)*	2.55 (1.72-3.79)*
High WHR-high WTR-high WNR	2.84 (2.25-3.58)*	6.55 (5.12-8.37)*	1.94 (1.59-2.38)*	1.85 (1.49-2.30)*	2.44 (1.95-3.06)*	2.06 (1.50-2.83)*
Men						
Low WHR-low WTR-low WNR	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Low WHR-low WTR-high WNR	1.23 (0.76-1.98)	0.80 (0.48-1.33)	0.73 (0.51-1.05)	0.78 (0.55-1.11)	0.92 (0.56-1.53)	0.97 (0.62-1.53)
Low WHR-high WTR-low WNR	1.49 (0.91-2.44)	1.39 (0.86-2.27)	1.30 (0.91-1.85)	1.08 (0.74-1.58)	1.70 (1.06-2.72)*	1.30 (0.83-2.04)
Low WHR-high WTR-high WNR	2.41 (1.48-3.93)*	1.80 (1.09-2.96)*	1.25 (0.84-1.87)	1.00 (0.65-1.54)	1.32 (0.76-2.31)	1.04 (0.61-1.77)
High WHR-low WTR-	2.11 (1.38-	2.83 (1.84-	1.83 (1.27-2.64)*	1.29 (0.86-	2.61 (1.70-4.03)*	2.02 (1.33-3.06)*

low WNR	3.32)*	4.35)*		1.93)		
High WHR-low WTR-high WNR	2.11 (1.39-3.20)*	2.95 (1.98-4.39)*	1.37 (0.98-1.92)	1.01 (0.70-1.47)	1.95 (1.29-2.95)*	2.11 (1.44-3.11)*
High WHR-high WTR-low WNR	3.00 (1.98-4.55)*	3.26 (2.17-4.90)*	1.81 (1.28-2.57)*	2.01 (1.30-3.11)*	2.22 (1.45-3.39)*	2.00 (1.34-2.99)*
High WHR-high WTR-high WNR	2.62 (1.87-3.66)*	4.20 (3.05-5.78)*	1.51 (1.17-1.94)*	1.70 (1.26-2.28)*	2.02 (1.45-2.81)*	1.43 (1.04-1.96)*

Data were presented as odds ratio (OR) and 95% confidence interval (CI). *P* values were calculated from multivariable logistic regression analysis. Adjusted age (years), body mass index (kg/m^2), current smoking (yes or no), current drinking (yes or no), and physical activity (MET-h/wk). According to the medians, WHR, WTR, and WNR were divided into high and low levels. The corresponding median value for WHR is 0.87 in women and 0.91 for men, for WTR is 1.66 in women and 1.74 for men, and for WNR is 2.48 in women and 2.34 in men. Abbreviation: *: $P < 0.05$; HDL cholesterol, high-density lipoprotein cholesterol; WHR, waist-to-hip circumference ratio; WTR, waist-to-thigh circumference ratio; WNR, waist-to-neck circumference ratio.

Table 3. Stratified analysis for associations body shape with insulin resistance and cardiometabolic disorders by WHR

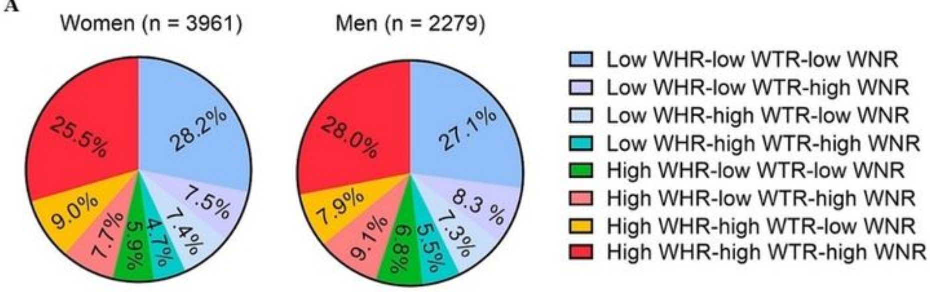
Body shape	Insulin resistance	Metabolic syndrome	Elevated fasting blood glucose, including diabetes	High blood pressure	High triglycerides	Low HDL cholesterol
Women						
Low WHR-low WTR-low WNR	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Low WHR-low WTR-high WNR	1.49 (0.89-1.75)	2.16 (1.53-3.03)*	0.99 (0.74-1.34)	0.85 (0.65-1.12)	1.34 (0.95-1.88)	0.68 (0.37-1.25)
Low WHR-high WTR-low WNR	2.10 (1.51-2.88)*	1.87 (1.31-2.67)*	1.77 (1.34-2.33)*	1.59 (1.18-2.14)*	1.54 (1.10-2.15)*	1.63 (1.03-2.59)*
Low WHR-high WTR-high WNR	2.09 (1.44-3.02)*	4.44 (3.08-6.40)*	2.32 (1.67-3.23)*	1.27 (0.88-1.84)	1.57 (1.05-2.34)*	1.56 (0.89-2.74)
High WHR-low WTR-low WNR	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
High WHR-low WTR-high WNR	0.95 (0.65-1.39)	1.35 (0.94-1.94)	1.05 (0.72-1.51)	1.15 (0.78-1.70)	1.00 (0.69-1.46)	0.98 (0.59-1.63)
High WHR-high WTR-low WNR	1.84 (1.28-2.64)*	1.76 (1.24-2.50)*	1.79 (1.26-2.55)*	1.45 (0.97-2.16)	1.26 (0.87-1.81)	1.17 (0.72-1.92)
High WHR-high WTR-high WNR	1.41 (1.02-1.93)*	1.66 (1.22-2.45)*	1.49 (1.09-2.01)*	1.20 (0.86-1.67)	1.04 (0.76-1.43)	0.95 (0.61-1.46)
Men						
Low WHR-low WTR-low WNR	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Low WHR-low WTR-high WNR	1.23 (0.76-1.98)	0.80 (0.48-1.33)	0.73 (0.51-1.05)	0.78 (0.55-1.11)	0.92 (0.56-1.53)	0.97 (0.62-1.53)
Low WHR-high WTR-low WNR	1.49 (0.91-2.44)	1.39 (0.86-2.27)	1.30 (0.91-1.85)	1.08 (0.74-1.58)	1.70 (1.06-2.72)*	1.30 (0.83-2.04)
Low WHR-high WTR-high WNR	2.41 (1.48-3.93)	1.80 (1.09-2.96)*	1.25 (0.84-1.87)	1.00 (0.65-1.54)	1.32 (0.76-2.31)	1.04 (0.61-1.77)
High WHR-low WTR-	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.

low WNR						
High WHR-low WTR-high WNR	1.00 (0.62-1.61)	1.04 (0.67-1.63)	0.75 (0.40-1.14)	0.79 (0.49-1.27)	0.75 (0.47-1.20)	1.05 (0.66-1.65)
High WHR-high WTR-low WNR	1.42 (0.88-2.30)	1.15 (0.73-1.83)	0.99 (0.64-1.53)	1.56 (0.92-2.66)	0.85 (0.52-1.39)	0.99 (0.62-1.59)
High WHR-high WTR-high WNR	1.24 (0.83-1.87)	1.48 (1.01-2.18)*	0.82 (0.57-1.18)	1.32 (0.86-2.01)	0.77 (0.52-1.39)	0.71 (0.47-1.05)

Data were presented as odds ratio (OR) and 95% confidence interval (CI). *P* values were calculated from multivariable logistic regression analysis. Adjusted age (years), body mass index (kg/m^2), current smoking (yes or no), current drinking (yes or no), and physical activity (MET-h/wk). According to the medians, WHR, WTR, and WNR were divided into high and low levels. The corresponding median value for WHR is 0.87 in women and 0.91 for men, for WTR is 1.66 in women and 1.74 for men, and for WNR is 2.48 in women and 2.34 in men. Abbreviation: *: $P < 0.05$; HDL cholesterol, high-density lipoprotein cholesterol; WHR, waist-to-hip circumference ratio; WTR, waist-to-thigh circumference ratio; WNR, waist-to-neck circumference ratio.

Figures

A



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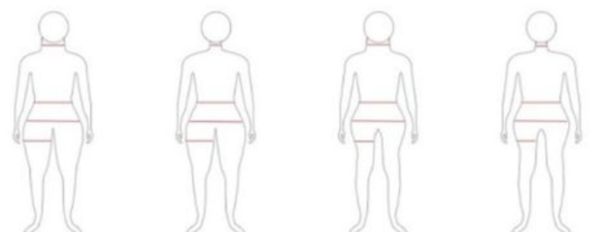
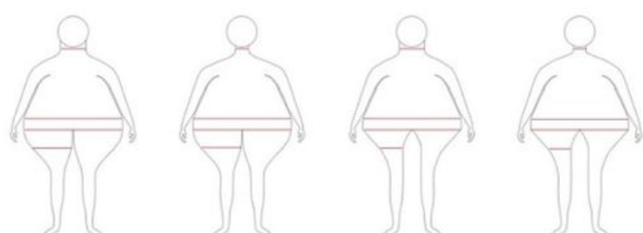


Body shape	Low WHR-low WTR-low WNR	Low WHR-low WTR-high WNR	Low WHR-high WTR-low WNR	Low WHR-high WTR-high WNR
Women, n (%)	1118 (28.2)	296 (7.5)	294 (7.4)	186 (4.7)
Men, n (%)	618 (27.1)	189 (8.3)	167 (7.3)	125 (5.5)

C



Body shape	High WHR-low WTR-low WNR	High WHR-low WTR-high WNR	High WHR-high WTR-low WNR	High WHR-high WTR-high WNR
Women, n (%)	234 (5.9)	305 (7.7)	356 (9.9)	1172 (29.6)
Men, n (%)	154 (6.8)	207 (9.1)	180 (7.9)	639 (28.0)

Figure 1

The distribution of body shapes in sex-specific groups. The individuals were divided into high and low level groups according to the medians of WHR, WTR, and WNR, respectively. Based on the 3 derived ratios, WHR, WTR, and WNR, we defined 8 distinct body shapes. The corresponding median value for WHR is 0.87 in women and 0.91 in men, for WTR is 1.66 in women and 1.74 in men, and for WNR is 2.48

in women and 2.34 in men. Abbreviation: WHR, waist-to hip ratio; WTR, waist-to-thigh ratio; WNR, waist-to-neck ratio.

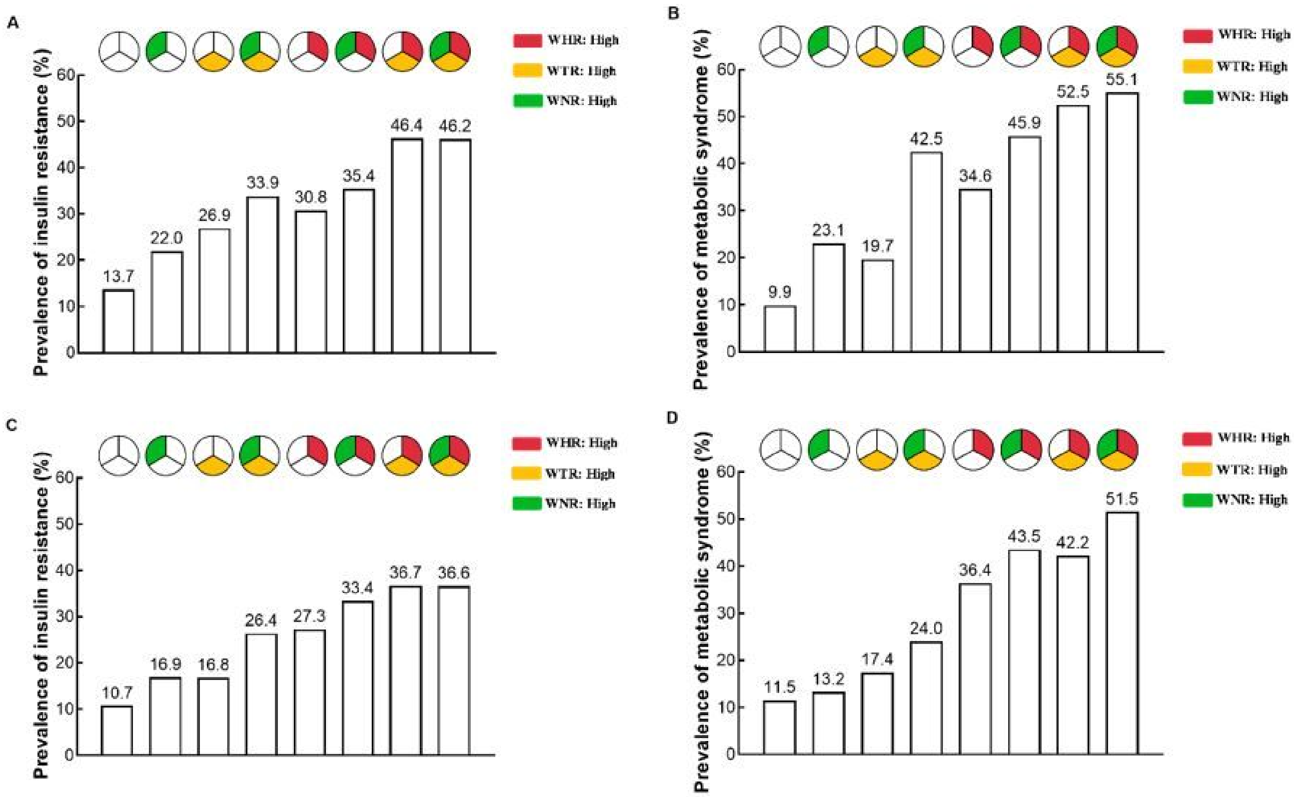


Figure 2

The prevalence of insulin resistance and metabolic syndrome according to 8 body shapes by sex. A: The prevalence of insulin resistance in women. B: The prevalence of metabolic syndrome in women. C: The prevalence of insulin resistance in men. D: The prevalence of metabolic syndrome in men. Abbreviation: WHR, waist-to hip ratio; WTR, waist-to-thigh ratio; WNR, waist-to-neck ratio.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementalmaterials.docx