

Associations between Body Composition Indices and Metabolic Disorders in Chinese Adults: A Cross-Sectional Observational Study

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Abstract

Background: Obesity induces dyslipidemia, hypertension, glucose intolerance, and inflammatory state, which results in atherogenic processes, diabetes, and cardiovascular disease. We usually use body composition indices, such as body mass index (BMI), body fat percentage (BFP), waist circumference-height ratio (WHtR), and waist-hip ratio (WHR) to reflect the obesity. The aim of this large population-based cross-sectional study was to investigate the associations between body composition indices and metabolic parameters in Chinese adults.

Methods: A total of 12,018 Chinese adults were included. Body composition indices, such as BMI, BFP, WHtR, and WHR, and metabolic parameters, such as systolic blood pressure (SBP), diastolic blood pressure (DBP), total cholesterol (TC), triglyceride (TG), low-density lipoprotein-cholesterol (LDL-C), high-density lipoprotein-cholesterol (HDL-C), fasting blood glucose (FBG), 2 h postprandial blood glucose (2h PBG), glycosylated hemoglobin (HbA1c), fasting insulin (FINS), insulin resistance index (HOMA-IR), high-sensitivity C-reactive protein (hs-CRP), and white blood cell count (WBC), were measured and analyzed. All analyses were stratified by gender.

Results: All body composition indices and metabolic parameters except 2h PBG differed significantly between males and females (all $P < 0.001$). BMI was positively associated with SBP, DBP, LDL-C, TC, TG, FBG, 2h PBG, HbA1c, FINS, HOMA-IR, hs-CRP, and WBC, and inversely associated with HDL-C; similar relationships were identified between the metabolic parameters and BFP, WHtR, and WHR. In the multivariate analysis, the odds of impaired glucose regulation, dyslipidemia, insulin resistance, and increased hs-CRP were 1.36, 1.92, 3.44, and 1.27 times greater in the overweight group than those in the normal weight group, respectively, and 1.66, 3.26, 7.53, and 1.70 times greater in the obese group than those in the normal weight group, respectively. The odds of dyslipidemia and hs-CRP were 1.29 and 1.38 times greater in the BFP $\geq 28.0\%$ group than in the BFP $< 28.0\%$ group, respectively. The odds of dyslipidemia, HOMA-IR, and hs-CRP were 1.55, 1.26, and 1.48 times greater in the WHtR ≥ 0.96 group than in the WHtR < 0.96 group, respectively. Among males, the odds of HOMA-IR were 1.46 times greater in the WHR ≥ 0.54 group than in the WHR < 0.54 group. Similar results were observed in females.

Conclusions: This study identified positive associations between all evaluated body composition indices and metabolic parameters in Chinese adults. Among the body composition indices, BMI predicted four of the five evaluated metabolic disorders in both gender groups.

Key words: Adults; Body Composition; Body Mass Index; Cardiovascular Disease; Metabolism

INTRODUCTION

Obesity induces adipocyte dysfunction, with the secretion of adipokines and macrophage activation leading to inflammatory cytokine production, which results in a cascade of reactions that influence metabolic parameters, atherogenic processes, and insulin sensitivity.^[1] In addition to its contribution as an independent cardiovascular

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disease (CVD) risk factor, obesity promotes alterations in other intermediate risk factors for CVD, such as dyslipidemia, hypertension (HTN), glucose intolerance, inflammatory states, obstructive sleep apnea hypoventilation syndrome, and a prothrombotic state; in addition, it is possible that many additional unknown mechanisms exist.^[2] Obesity also has been found to induce a variety of structural adaptations/alterations in cardiovascular structures/functions.^[3] Each year, 28 million individuals die as a consequence of overweight or obesity worldwide.^[3]

Body composition indices, such as the body mass index (BMI), body fat percentage (BFP), waist-hip ratio (WHR), and waist circumference-height ratio (WHtR), can be used as simple and inexpensive proxy measures of abdominal obesity. However, the determination of which measure is the best body composition index for predicting metabolic disorders and cardiovascular risk among Chinese adults remains under investigation.

In this large population-based cross-sectional study, we identified associations between different body composition indices (including BMI, BFP, WHR, and WHtR) and metabolic parameters and assessed which index was the best predictor of metabolic parameters.

METHODS

Ethical approval

The study was conducted in accordance with the *Declaration of Helsinki* and was approved by the Institutional Review Board of Chinese PLA General Hospital, Beijing, China. Informed written consent was obtained from all participants prior to their enrolment in this study.

Subjects

This cross-sectional study was conducted in the Physical Examination Center of Chinese PLA General Hospital using data from a completed national health survey that was carried out with the aim of determining the associations between body composition indices, such as BMI, BFP, WHtR, and WHR, and metabolic parameters in Chinese adults. The primary concerns of BMI, BFP, WHtR, and WHR are weight, fat content, abdominal obesity, and the central obesity, respectively. All participants were enrolled at the Physical Examination Center of Chinese PLA General Hospital between 2010 and 2013. The samples included 7185 males (mean age: 46.0 ± 8.8 years) and 4133 females (mean age: 46.4 ± 9.4 years). Participants were excluded if they did not have information available on demographic characteristics; body composition indices, such as weight, height, waist circumference (WC), hip circumference (HC), fat-free body mass, and BFP; or metabolic parameters, such as low-density lipoprotein-cholesterol (LDL-C), high-density lipoprotein-cholesterol (HDL-C), total cholesterol (TC), triglyceride (TG), fasting blood glucose (FBG), 2 h postprandial blood glucose (2h PBG), glycosylated hemoglobin (HbA1c), fasting insulin (FINS), insulin resistance index (HOMA-IR), high-sensitivity C-reactive

protein level (hs-CRP), and white blood cell count (WBC). The exclusion criteria included the following: history of cancer, CVD, diabetes, liver disease, HTN, hematologic disease, chronic kidney disease, hypothyroidism, endocrine diseases, Cushing's syndrome, or polycystic ovary disease; use of anti-inflammatory drugs, antipsychotic drugs, steroids, or medications that promoted changes in adiposity; use of drug for regulating lipid; and pregnant or lactating status.

Measurements

Anthropometric measurements were obtained from all participants while they were bare foot and dressed in light clothing. Body weight (measured to the nearest 0.1 kg) and height (measured to the nearest 0.1 cm) were measured. WC (measured to the nearest 0.1 cm) was measured midway between the inferior margin of the last rib and the crest of the ilium in a horizontal plane. We measured HC around the widest portion of the buttocks using a nonelastic tape to the nearest 0.1 cm. BMI was calculated by dividing weight (kg) by height squared (m^2). WHtR was calculated as WC (cm) divided by height (cm). WHR was calculated as HC (cm) divided by height (cm). BFP was measured using a tetra-polar bioelectrical impedance device (ARTEMIS body composition analyzer HRV system, Korea).^[4] Blood pressure was measured in the right arm 5 min after rest using a recently calibrated electronic sphygmomanometer while the participant was in the supine position. All anthropometric measurements were obtained by trained staff using standardized protocols.

Blood samples were obtained before breakfast to measure the levels of FBG, LDL-C, HDL-C, TC, TG, 2h PBG, HbA1c, FINS, hs-CRP, and WBC. Two hours after breakfast, peripheral venous blood samples were obtained to measure 2h PBG, and HOMA-IR was calculated using the following formula: $(\text{insulin [mU/ml]} \times \text{glucose [mmol/L]})/22.5$. All blood samples were analyzed at the laboratory of the Physical Examination Center of Chinese PLA General Hospital. The laboratory was affiliated with a top tertiary hospital and utilized a standardized and certified method of blood testing.

Definitions and classification of obesity

Current recommendations suggest that "BMI cutoff points should be set differently for Asian populations" and "BMI should be established on the basis of ethnic and racial background."^[5] Thus, we used the recommended cutoff values for overweight and obesity in Chinese populations, as follows: $18.5 \text{ kg/m}^2 \leq \text{BMI} \leq 24.0 \text{ kg/m}^2$ (normal weight), $24.0 \text{ kg/m}^2 < \text{BMI} < 28.0 \text{ kg/m}^2$ (overweight), and $\geq 28.0 \text{ kg/m}^2$ (obesity).^[6] We then stratified all participants into normal weight, overweight, and obese groups according to BMI. The criterion for obesity, as defined by BFP, was having a BFP in the top tertile defined for each gender, which was $\geq 28.0\%$ in males and $\geq 35.0\%$ in females. We stratified all participants by BFP category as being of normal weight (BFP $< 28.0\%$ in males and $< 35.0\%$ in females) or obesity (BFP $\geq 28.0\%$ in males and $\geq 35.0\%$ in females). The criterion for obesity, as defined by WHtR, was having a WHtR in the top tertile defined for each gender,

which was ≥ 0.96 in males and ≥ 0.85 in females. We stratified all participants into the following WHtR category: normal weight (WHtR < 0.96 in males and < 0.85 in females) and obesity (WHtR ≥ 0.96 in males and ≥ 0.85 in females). The criterion for obesity, as defined by WHR, was having a WHR in the top tertile defined for each gender, which was ≥ 0.54 in males and ≥ 0.51 in females. We stratified all participants into these WHR category as being of normal weight (WHR < 0.54 in males and < 0.51 in females) or obesity (WHR ≥ 0.54 in males and ≥ 0.51 in females).

Definition of metabolic disorders

Impaired glucose regulation (IGR) was defined as having FBG level ≥ 6.1 mmol/L and < 7.0 mmol/L and/or 2h PBG level ≥ 7.8 mmol/L and < 11.1 mmol/L.^[7] Dyslipidemia was defined as having TC ≥ 5.18 mmol/L (2000 mg/L) and ≤ 6.18 mmol/L (2390 mg/L); TG ≥ 1.70 mmol/L (1500 mg/L) and ≤ 2.25 mmol/L (1990 mg/L); LDL-C ≥ 3.37 mmol/L (1300 mg/L) and ≤ 4.12 mmol/L (1590 mg/L); and/or HDL-C < 1.04 mmol/L (400 mg/L).^[8] The criterion for IR was having an IR in the top tertile of the HOMA-IR defined for each gender, which was ≥ 2.9 in males and ≥ 2.2 in females. The criterion for hs-CRP was having a hs-CRP in the top tertile defined for each gender, which was ≥ 0.19 mg/L in males and ≥ 0.16 mg/L in females. The criterion for WBC was having a WBC in top tertile defined for each gender, which was $\geq 6.5 \times 10^9/L$ in males and $\geq 5.8 \times 10^9/L$ in females.

Statistical analysis

Data are expressed as mean \pm standard deviation (SD). The distributions of all variables were tested for normality. Variables with abnormal distributions are presented as

median (Q1, Q3) and were logarithmically transformed before analyses. Participants were categorized and analyzed by gender in all analyses. The differences in age, BMI, BFP, WHtR, WHR, systolic blood pressure (SBP), diastolic blood pressure (DBP), FBG, 2h PBG, LDL-C, HDL-C, TC, TG, HbA1c, FINS, hs-CRP, and WBC between males and females were compared using the one-way analysis of variance (ANOVA). Pearson's tests were performed to investigate the correlations between the four different body composition indices and metabolic parameters. Differences between the metabolic parametric values identified in the overweight/obese groups (as defined by BMI, BFP, WHtR, and WHR) and in the normal weight group were evaluated using the one-way ANOVA in each gender group. Finally, the metabolic parameters were divided into five sectors (dyslipidemia, IGR, IR, increased hs-CRP, and increased WBC). We calculated odds ratios for the comparisons of dyslipidemia, IGR, IR, and increased hs-CRP between the overweight/obese group and normal weight group when defined by BMI, BFP, WHtR, and WHR using multivariate logistic regression models. All statistical analyses were performed using SPSS version 19.0 software (SPSS Inc., Chicago, IL, USA), and a $P < 0.05$ was considered statistically significant.

RESULTS

Participant characteristics

The general and clinical characteristics of the study participants are listed in Table 1. All parameters (age, BMI, BFP, WHtR, WHR, SBP, DBP, FBG, LDL-C, HDL-C, TC, TG, HbA1c, FINS, hs-CRP, and WBC)

Table 1: Demographic and clinical characteristics of all participants in the study

Characteristics	Males (n = 7185)	Females (n = 4833)	F	P
Age (years)	46.0 \pm 8.8	46.4 \pm 9.4	5.268	0.022
BMI (kg/m ²)	25.6 \pm 3.1	23.4 \pm 3.2	1404.995	<0.001
BFP (%)	26.1 \pm 6.8	32.6 \pm 6.8	2564.495	<0.001
WHtR	0.52 \pm 0.05	0.49 \pm 0.06	1321.615	<0.001
WHR	0.94 \pm 0.07	0.83 \pm 0.07	5975.654	<0.001
SBP (mmHg)	119 \pm 16	112 \pm 17	609.085	<0.001
DBP (mmHg)	77 \pm 10	73 \pm 10	576.129	<0.001
LDL-C (mmol/L)	3.18 \pm 0.82	3.09 \pm 0.84	43.198	<0.001
TC (mmol/L)	4.97 \pm 0.95	4.88 \pm 0.95	25.452	<0.001
TG (mmol/L)	1.62 (1.14, 2.44)	1.06 (0.77, 1.49)	716.504	<0.001
HDL-C (mmol/L)	1.13 \pm 0.29	1.42 \pm 0.35	2465.845	<0.001
FBG (mmol/L)	5.50 \pm 0.93	5.17 \pm 0.69	453.902	<0.001
2 h PBG (mmol/L)	7.05 \pm 2.05	7.09 \pm 1.74	0.959	0.328
HbA1c (%)	5.60 \pm 0.59	5.51 \pm 0.49	70.189	<0.001
FINS	9.56 (6.70, 13.61)	7.67 (5.51, 10.69)	378.317	<0.001
HOMA-IR	2.30 (1.55, 3.39)	1.73 (1.21, 2.52)	403.884	<0.001
Hs-CRP (mg/L)	0.14 (0.09, 0.22)	0.12 (0.08, 0.19)	37.426	<0.001
WBC ($\times 10^9/L$)	6.1 \pm 1.5	5.4 \pm 1.4	639.232	<0.001

The data are shown as mean \pm SD or median (Q1, Q3). BMI: Body mass index; BFP: Body fat percentage; WHtR: Waist circumference-height ratio; WHR: Waist-hip ratio; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; LDL-C: Low-density lipoprotein-cholesterol; HDL-C: High-density lipoprotein-cholesterol; TC: Total cholesterol; TG: Triglyceride; FBG: Fasting blood glucose; 2 h PBG: 2 h postprandial blood glucose; HbA1c: Glycated hemoglobin; FINS: Fasting insulin; HOMA-IR: Insulin resistance index; hs-CRP: High-sensitivity C-reactive protein; WBC: White blood cell; SD: Standard deviation.

except 2h PBG differed significantly between males and females (all $P < 0.05$). Compared to males, females were older; had lower body composition index values, including BMI, WHtR, and WHR; and had lower values identified for all metabolic parameters except BFP and HDL-C.

Correlations between body composition indices and metabolic parameters

Correlations between body composition indices and metabolic parameters are listed in Table 2. Among males, body composition indices, such as BMI, BFP, WHtR, and WHR, were correlated with SBP, DBP, LDL-C, TC, TG, HDL-C, FBG, 2h PBG, HbA1c, FINS, HOMA-IR, hs-CRP, and WBC. BMI was more strongly correlated with SBP, TG, HDL-C, FBG, and HOMA-IR than other metabolic parameters; BFP was more strongly correlated with DBP, LDL-C, TC, and hs-CRP; WHtR and WHR were more strongly correlated with WBC and 2h PBG, respectively. Among females, adiposity measurements, such as BMI, BFP, WHtR, and WHR, were also correlated with SBP, DBP, LDL-C, TC, TG, HDL-C, FBG, 2h PBG, HbA1c, FINS, HOMA-IR, hs-CRP, and WBC. BMI was more strongly correlated with HDL-C, FINS, and WBC; WHR was most strongly correlated with SBP, DBP, LDL-C, TC, FBG, 2h PBG, and hs-CRP.

One-way analysis of variance of associations between body composition indices and metabolic parameters

Comparisons of metabolic parametric values in participants stratified by body composition indices (BMI, BFP, WHtR, and WHR) are listed in Tables 3–6, respectively. When we stratified the participants by BMI as being of normal weight, overweight, or obese, the values for SBP, DBP, LDL-C, HDL-C, TC, TG, FBG, 2h PBG, HbA1c, FINS, HOMA-IR, hs-CRP, and WBC differed significantly among the normal weight, overweight and obese groups in both males and females. Similarly, the values for SBP, DBP, LDL-C, HDL-C, TC, TG, FBG, 2h PBG, HbA1c, FINS, HOMA-IR, hs-CRP, and WBC were also significantly different between the obese group and normal

weight group when the groups were defined by BFP, WHtR, and WHR.

Multivariate logistic regression analysis of the associations between body composition indices and metabolic disorders

Multivariate logistic regression analyses of the associations between body composition indices and metabolic disorders are listed in Table 7. In the multivariate analyses adjusted for age, SBP, BMI, BFP, WHtR, and WHR, among males, the odds of having IGR, dyslipidemia, HOMA-IR, and increased hs-CRP were 1.36, 1.92, 3.44, and 1.27 times greater in the overweight group and 1.66, 3.26, 7.53, and 1.70 times greater in the obese group, respectively, when those of normal weight were used as the reference group. The odds of WBC did not differ significantly between the overweight group and the normal weight group, as defined by BMI. The odds of dyslipidemia and hs-CRP in the BFP $\geq 28.0\%$ group were 1.29 and 1.38 times greater than those of the BFP $< 28.0\%$ group, respectively, while the odds of IGR, HOMA-IR, and increased WBC did not differ significantly between these two groups. The odds of dyslipidemia, HOMA-IR, and increased hs-CRP in the WHtR ≥ 0.96 group were 1.55, 1.26, and 1.48 times greater than those of the WHtR < 0.96 group, while the odds of IGR and increased WBC did not differ significantly between two groups. The odds of HOMA-IR in the WHR ≥ 0.54 group were 1.46 times greater than that of the WHR < 0.54 group, while the odds of dyslipidemia, IGR, increased WBC, and increased hs-CRP did not differ significantly between the two groups.

Among females, the odds of HOMA-IR, hs-CRP, and increased WBC were 2.60, 1.48, and 1.64 times greater in the overweight group and 3.59, 2.63, and 2.25 times greater in the obese group, respectively, when those of normal weight were used as the reference group. The odds of dyslipidemia in the overweight group were 1.57 times greater than that of the normal weight group, as defined by BMI. The odds of IGR did not differ significantly between these groups. The odds of increased hs-CRP and WBC in the BFP $\geq 35.0\%$

Table 2: Correlations between body composition indices and metabolic parameters

Items	BMI	BFP	WHtR	WHR	SBP	DBP	LDL-C	TC	TG	HDL-C	FBG	2 h PBG	HOMA-IR	hs-CRP	WBC
Males															
BMI	1.000	0.558*	0.809*	0.710*	0.281*	0.264*	0.096*	0.111*	0.327*	-0.295*	0.252*	0.121*	0.552*	0.206*	0.108*
BFP	0.558*	1.000	0.522*	0.792*	0.248*	0.290*	0.137*	0.137*	0.224*	-0.140*	0.200*	0.143*	0.390*	0.241*	0.101*
WHtR	0.809*	0.522*	1.000	0.655*	0.254*	0.234*	0.102*	0.119*	0.315*	-0.255*	0.237*	0.155*	0.495*	0.210*	0.113*
WHR	0.710*	0.792*	0.655*	1.000	0.220*	0.242*	0.124*	0.120*	0.247*	-0.202*	0.239*	0.175*	0.440*	0.218*	0.080*
Females															
BMI	1.000	0.618*	0.773*	0.814*	0.325*	0.287*	0.236*	0.161*	0.395*	-0.347*	0.286*	0.188*	0.484*	0.340*	0.173*
BFP	0.618*	1.000	0.535*	0.851*	0.402*	0.343*	0.236*	0.189*	0.299*	-0.188*	0.266*	0.186*	0.345*	0.326*	0.137*
WHtR	0.773*	0.535*	1.000	0.679*	0.324*	0.261*	0.247*	0.175*	0.415*	-0.327*	0.256*	0.214*	0.424*	0.316*	0.142*
WHR	0.814*	0.851*	0.679*	1.000	0.414*	0.357*	0.265*	0.203*	0.364*	-0.259*	0.301*	0.220*	0.410*	0.350*	0.143*

* $P < 0.001$. BMI: Body mass index; BFP: Body fat percentage; WHtR: Waist circumference-height ratio; WHR: Waist-hip ratio; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; LDL-C: Low-density lipoprotein-cholesterol; HDL-C: High-density lipoprotein-cholesterol; TC: Total cholesterol; TG: Triglyceride; FBG: Fasting blood glucose; 2 h PBG: 2 h postprandial blood glucose; HOMA-IR: Insulin resistance index; hs-CRP: High-sensitivity C-reactive protein; WBC: White blood cell.

Table 3: Comparisons of metabolic parameter values by BMI category among the study participants

Parameters	Males (N = 7185)			F	P
	Normal weight group (n = 2013)	Overweight group (n = 3540)	Obese group (n = 1418)		
LDL-C (mmol/L)	3.09 ± 0.79	3.22 ± 0.83	3.25 ± 0.83	20.025	<0.001
TC (mmol/L)	4.85 ± 0.92	5.01 ± 0.96	5.07 ± 0.95	27.811	<0.001
TG (mmol/L)	1.27 (0.92, 1.85)	1.69 (1.23, 2.54)	2.01 (1.43, 2.93)	92.696	<0.001
HDL-C (mmol/L)	1.25 ± 0.32	1.11 ± 0.26	1.02 ± 0.23	308.396	<0.001
FBG (mmol/L)	5.26 ± 0.76	5.55 ± 0.89	5.74 ± 1.14	123.125	<0.001
2 h PBG (mmol/L)	6.75 ± 2.00	7.09 ± 2.03	7.32 ± 2.13	30.579	<0.001
HOMA-IR	1.50 (1.06, 2.13)	2.44 (1.78, 3.37)	3.58 (2.60, 4.93)	650.501	<0.001
WBC (×10 ⁹ /L)	5.97 ± 1.60	6.08 ± 1.50	6.37 ± 1.53	30.356	<0.001
hs-CRP (mg/L)	0.12 (0.07, 0.18)	0.14 (0.09, 0.22)	0.18 (0.11, 0.29)	7.060	<0.001

Parameters	Females (N = 4833)			F	P
	Normal weight group (n = 2808)	Overweight group (n = 1510)	Obese group (n = 360)		
LDL-C (mmol/L)	2.96 ± 0.81	3.23 ± 0.82	3.39 ± 0.82	81.159	<0.001
TC (mmol/L)	4.78 ± 0.94	4.99 ± 0.94	5.13 ± 0.95	39.273	<0.001
TG (mmol/L)	0.91 (0.69, 1.27)	1.29 (0.93, 1.73)	1.47 (1.12, 1.93)	124.030	<0.001
HDL-C (mmol/L)	1.50 ± 0.36	1.31 ± 0.31	1.23 ± 0.28	209.731	<0.001
FBG (mmol/L)	5.06 ± 0.63	5.29 ± 0.74	5.52 ± 0.81	108.676	<0.001
2 h PBG (mmol/L)	6.88 ± 1.69	7.35 ± 1.76	7.51 ± 1.78	44.049	<0.001
HOMA-IR	1.46 (1.05, 2.04)	2.18 (1.57, 2.92)	3.27 (2.22, 4.68)	545.364	<0.001
WBC (×10 ⁹ /L)	5.25 ± 1.27	5.57 ± 1.39	6.07 ± 1.55	75.081	<0.001
hs-CRP (mg/L)	0.11 (0.07, 0.15)	0.14 (0.10, 0.22)	0.22 (0.14, 0.40)	70.168	<0.001

The data are shown as mean ± SD or median (Q1, Q3). BMI: Body mass index; LDL-C: Low-density lipoprotein-cholesterol; HDL-C: High-density lipoprotein-cholesterol; TC: Total cholesterol; TG: Triglyceride; FBG: Fasting blood glucose; 2 h PBG: 2 h postprandial blood glucose; HOMA-IR: Insulin resistance index; hs-CRP: High-sensitivity C-reactive protein; WBC: White blood cell; SD: Standard deviation.

Table 4: Comparisons of metabolic parametric values by BFP category among the study participants

Parameters	Males (N = 6954)				Females (N = 4668)			
	Normal weight group (n = 4745)	Obese group (n = 2209)	F	P	Normal weight group (n = 3175)	Obese group (n = 1493)	F	P
LDL-C (mmol/L)	3.14 ± 0.81	3.30 ± 0.83	55.309	<0.001	3.00 ± 0.82	3.25 ± 0.82	94.294	<0.001
TC (mmol/L)	4.92 ± 0.95	5.09 ± 0.94	46.888	<0.001	4.80 ± 0.94	5.04 ± 0.94	65.804	<0.001
TG (mmol/L)	1.69 (1.07, 2.42)	1.82 (1.30, 2.69)	17.401	<0.001	0.99 (0.72, 1.38)	1.24 (0.89, 1.69)	87.663	<0.001
HDL-C (mmol/L)	1.14 ± 0.29	1.10 ± 0.27	40.893	<0.001	1.44 ± 0.36	1.37 ± 0.34	48.812	<0.001
FBG (mmol/L)	5.44 ± 0.88	5.66 ± 1.02	87.502	<0.001	5.11 ± 0.70	5.31 ± 0.67	87.303	<0.001
2 h PBG (mmol/L)	6.91 ± 2.01	7.31 ± 2.10	53.444	<0.001	6.94 ± 1.70	7.38 ± 1.77	57.571	<0.001
HOMA-IR	2.07 (1.42, 3.03)	2.90 (1.98, 4.2)	324.538	<0.001	1.60 (1.13, 2.3)	2.15 (1.47, 3.06)	244.985	<0.001
WBC (×10 ⁹ /L)	6.03 ± 1.55	6.27 ± 1.51	37.069	<0.001	5.33 ± 1.32	5.61 ± 1.41	44.157	<0.001
Hs-CRP (mg/L)	0.13 (0.08, 0.20)	0.17 (0.11, 0.27)	54.969	<0.001	0.11 (0.07, 0.16)	0.15 (0.1, 0.25)	77.413	<0.001

The data are shown as mean ± SD or median (Q1, Q3). BFP: Body fat percentage; LDL-C: Low-density lipoprotein-cholesterol; HDL-C: High-density lipoprotein-cholesterol; TC: Total cholesterol; TG: Triglyceride; FBG: Fasting blood glucose; 2 h PBG: 2 h postprandial blood glucose; HOMA-IR: Insulin resistance index; hs-CRP: High-sensitivity C-reactive protein; WBC: White blood cell; SD: Standard deviation.

group were 1.28 and 1.27 times greater than those of the BFP <35.0% group, while the odds of dyslipidemia, IGR, and HOMA-IR did not differ significantly between the two groups. The odds of dyslipidemia, hs-CRP, and increased WBC in the WHtR ≥0.85 group were 1.40, 1.42, and 1.36 times greater than those of the WHtR <0.85 group; however, significant differences were not identified in IGR and HOMA-IR. The odds of IR and increased hs-CRP in the WHR ≥0.51 group were 1.27 and 1.25 times greater than those of the WHR <0.51 group, while the odds of dyslipidemia and increased WBC did not differ significantly between the two groups.

DISCUSSION

Statistically significant gender differences were identified in the metabolic parameters. These data demonstrated the presence of significant linear correlations between body composition indices and metabolic parameters in each gender group. Among males, we observed that BMI, rather than BFP, WHtR, and WHR, was the best predictor of IGR, dyslipidemia, HOMA-IR, and increased hs-CRP. Among females, BMI was the best predictor of IGR, dyslipidemia, HOMA-IR, increased hs-CRP, and increased WBC. Our findings suggest that BMI, an adiposity indicator, was associated with the majority of metabolic parameters, thus

Table 5: Comparisons of metabolic parametric values by WHtR category among the study participants

Parameters	Males (N = 6941)				Females (N = 4649)			
	Normal weight group (n = 4554)	Obese group (n = 2387)	F	P	Normal weight group (n = 3155)	Obese group (n = 1494)	F	P
LDL-C (mmol/L)	3.15 ± 0.81	3.27 ± 0.83	37.647	<0.001	2.98 ± 0.81	3.29 ± 0.84	150.607	<0.001
TC (mmol/L)	4.91 ± 0.94	5.09 ± 0.96	51.742	<0.001	4.79 ± 0.92	5.06 ± 0.97	83.862	<0.001
TG (mmol/L)	1.46 (1.05, 2.19)	1.93 (1.39, 2.85)	103.816	<0.001	0.94 (0.70, 1.32)	1.35 (0.98, 1.81)	232.690	<0.001
HDL-C (mmol/L)	1.17 ± 0.30	1.06 ± 0.25	250.112	<0.001	1.47 ± 0.35	1.30 ± 0.31	261.234	<0.001
FBG (mmol/L)	5.41 ± 0.86	5.68 ± 1.02	133.828	<0.001	5.08 ± 0.57	5.36 ± 0.88	178.359	<0.001
2 h PBG (mmol/L)	6.89 ± 2.00	7.30 ± 2.10	54.825	<0.001	6.88 ± 1.61	7.50 ± 1.92	117.931	<0.001
HOMA-IR	1.96 (1.34, 2.83)	3.13 (2.19, 4.42)	741.041	<0.001	1.53 (0.07, 0.16)	2.32 (1.64, 3.32)	546.735	<0.001
WBC (×10 ⁹ /L)	6.02 ± 1.54	6.27 ± 1.53	43.173	<0.001	5.31 ± 1.32	5.63 ± 1.41	57.414	<0.001
Hs-CRP (mg/L)	0.13 (0.08, 0.2)	0.17 (0.11, 0.27)	19.165	<0.001	0.11 (0.07, 0.16)	0.16 (0.11, 0.25)	97.884	<0.001

The data are shown as mean ± SD or median (Q1, Q3). WHtR: Waist circumference-height ratio; LDL-C: Low-density lipoprotein-cholesterol; HDL-C: High-density lipoprotein-cholesterol; TC: Total cholesterol; TG: Triglyceride; FBG: Fasting blood glucose; 2 h PBG: 2 h postprandial blood glucose; HOMA-IR: Insulin resistance index; hs-CRP: High-sensitivity C-reactive protein; WBC: White blood cell; SD: Standard deviation.

Table 6: Comparisons of metabolic parametric values by WHR category among the study participants

Parameters	Males (N = 6954)				Females (N = 4668)			
	Normal weight group (n = 4534)	Obese group (n = 2420)	F	P	Normal weight group (n = 2983)	Obese group (n = 1685)	F	P
LDL-C (mmol/L)	3.13 ± 0.81	3.29 ± 0.82	60.080	<0.001	2.96 ± 0.81	3.28 ± 0.83	166.081	<0.001
TC (mmol/L)	1.49 (1.06, 2.24)	1.87 (1.35, 2.77)	51.467	<0.001	0.94 (0.70, 1.34)	1.28 (0.93, 1.71)	107.185	<0.001
TG (mmol/L)	2.02 ± 2.17	2.37 ± 2.05	44.629	<0.001	1.15 ± 0.85	1.48 ± 1.03	134.791	<0.001
HDL-C (mmol/L)	1.16 ± 0.30	1.07 ± 0.25	159.871	<0.001	1.46 ± 0.36	1.34 ± 0.32	134.200	<0.001
FBG (mmol/L)	5.40 ± 0.84	5.71 ± 1.05	176.695	<0.001	5.07 ± 0.64	5.35 ± 0.76	183.423	<0.001
2 h PBG (mmol/L)	6.85 ± 2.00	7.38 ± 2.10	95.771	<0.001	6.85 ± 1.61	7.48 ± 1.86	128.325	<0.001
HOMA-IR	1.97 (1.35, 2.87)	3.06 (2.14, 4.36)	575.592	<0.001	1.53 (1.09, 2.16)	2.25 (1.55, 3.16)	443.684	<0.001
WBC (×10 ⁹ /L)	6.02 ± 1.56	6.26 ± 1.50	37.235	<0.001	5.31 ± 1.32	5.61 ± 1.39	52.165	<0.001
Hs-CRP (mg/L)	0.12 (0.08, 0.20)	0.17 (0.11, 0.26)	22.982	<0.001	0.11 (0.07, 0.15)	0.16 (0.11, 0.25)	110.946	<0.001

The data are shown as mean ± SD or median (Q1, Q3). WHR: Waist-hip ratio; LDL-C: Low-density lipoprotein-cholesterol; HDL-C: High-density lipoprotein-cholesterol; TC: Total cholesterol; TG: Triglyceride; FBG: Fasting blood glucose; 2 h PBG: 2 h postprandial blood glucose; HOMA-IR: Insulin resistance index; hs-CRP: High-sensitivity C-reactive protein; WBC: White blood cell; SD: Standard deviation.

servicing as an adequate tool for the detection of individuals at high risk for CVD.

Global BMI cutoff points for overweight (BMI ≥25.0 kg/m²) and obesity (BMI ≥30.0 kg/m²) have been set by the World Health Organization (WHO).^[9] Several studies in Asian populations have reported an association between increased atherogenic risk factors and having a BMI >22.3 kg/m².^[10] The studies suggested that Asians had higher body fat content and were at greater risk of diabetes, high blood pressure, and heart disease than people with the same BMI of other ethnicities.^[11] Lowering the BMI limits for Asian ethnic groups has been presented in several original articles^[12-17] and reviews^[18-23] and considered by the WHO.^[24,25] Current recommendations state that “BMI cutoff points should be set differently for Asian populations” and “BMI should be established on the basis of ethnic and racial background.”^[5] Therefore, we used the BMI cutoff values recommended for Asian populations.

Yoon *et al.*^[26] reported that impaired insulin secretion might be induced by insufficient β-cell mass, and BMI has been found to be linearly correlated with β-cell mass in normal

and type 2 diabetic patients. Das *et al.*^[27] found that both obese males and females demonstrated higher fasting serum glucose and HbA1c levels. Positive correlations have been observed between BMI and both fasting serum glucose and HbA1c. Among obese persons, higher BMI values may be directly associated with an increase in the risk of metabolic diseases, such as type 2 diabetes mellitus (DM). Netjasov *et al.*^[28] found that BMI and glucose level were significantly and positively correlated among the obese and overweight females with a BMI ≥25.0 kg/m². Khoo *et al.*^[29] found that BMI was directly associated with HOMA-IR across all ethnic groups. The associations between BMI and its metabolic pathways were significantly stronger in Chinese than other ethnic group populations (Malays and Asian-Indians). The increase in HOMA-IR associated with each unit increase in BMI was greater among Chinese individuals than that of other ethnic groups; therefore, maintaining normal BMI may be important in the effort to prevent early onset of type 2 DM.^[29] In the prospective study conducted by Blüher *et al.*,^[30] stronger associations were observed between BMI and both insulin and HOMA-IR, rather than either WC or total fat mass, as measured by dual-energy X-ray

Table 7: Multivariate logistic regression analyses of the associations between body composition indices and metabolic disorders

	IGR		Dyslipidemia		HOMA-IR	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Males						
24.0 kg/m ² < BMI < 28.0 kg/m ²	1.36 (1.17–1.58)	<0.001	1.92 (1.68–2.21)	<0.001	3.44 (2.90–4.91)	<0.001
BMI ≥28.0 kg/m ²	1.66 (1.29–2.14)	<0.001	3.26 (2.40–4.44)	<0.001	7.53 (5.85–9.69)	<0.001
BFP ≥28.0%	1.04 (0.88–1.23)	0.677	1.29 (1.08–1.55)	0.006	1.03 (0.87–1.22)	0.712
WHtR ≥0.96	0.91 (0.77–1.10)	0.286	1.55 (1.28–1.88)	<0.001	1.48 (1.28–1.74)	<0.001
WHR ≥0.54	1.12 (0.95–1.32)	0.170	1.10 (0.91–1.33)	0.339	1.46 (1.24–1.71)	<0.001
Females						
24.0 kg/m ² < BMI < 28.0 kg/m ²	1.11 (0.91–1.35)	0.293	1.57 (1.33–1.86)	<0.001	2.60 (2.19–3.09)	<0.001
BMI ≥28 kg/m ²	1.12 (0.59–2.15)	0.722	1.51 (0.86–2.64)	0.151	3.59 (2.05–6.28)	<0.001
BFP ≥35.0%	0.92 (0.74–1.16)	0.491	1.16 (0.96–1.41)	0.126	1.04 (0.84–1.28)	0.731
WHtR ≥0.85	1.01 (0.82–1.02)	0.941	1.40 (1.17–1.68)	<0.001	1.56 (1.30–1.88)	<0.001
WHR ≥0.51	1.27 (1.02–1.59)	0.033	1.02 (0.84–1.25)	0.815	1.25 (1.01–1.53)	0.037
	hs-CRP		WBC			
	OR (95% CI)	P	OR (95% CI)	P		
Males						
24.0 kg/m ² < BMI < 28.0 kg/m ²	1.27 (1.10–1.45)	0.001	0.98 (0.86–1.12)	0.766		
BMI ≥28.0 kg/m ²	1.70 (1.35–2.15)	<0.001	0.97 (0.77–1.22)	0.774		
BFP ≥28.0%	1.38 (1.18–1.61)	<0.001	1.14 (0.98–1.33)	0.096		
WHtR ≥0.96	1.26 (1.08–1.47)	0.004	1.14 (0.97–1.33)	0.105		
WHR ≥0.54	1.11 (0.95–1.30)	0.171	1.15 (0.98–1.34)	0.079		
Females						
24.0 kg/m ² < BMI < 28.0 kg/m ²	1.48 (1.24–1.76)	<0.001	1.64 (1.38–1.95)	<0.001		
BMI ≥28 kg/m ²	2.63 (1.52–4.56)	0.001	2.25 (1.30–3.89)	0.004		
BFP ≥35.0%	1.28 (1.04–1.56)	0.018	1.27 (1.04–1.55)	0.022		
WHtR ≥0.85	1.42 (1.18–1.71)	<0.001	1.36 (1.13–1.64)	0.001		
WHR ≥0.51	1.39 (1.14–1.70)	0.001	0.84 (0.68–1.03)	0.092		

Age, SBP, BMI, BFP, WHtR, and WHR were adjusted in all models. SBP: Systolic blood pressure; BMI: Body mass index; BFP: Body fat percentage; IGR: Impaired glucose regulation; WHtR: Waist circumference–height ratio; WHR: Waist–hip ratio; HOMA-IR: Insulin resistance index; hs-CRP: High-sensitivity C-reactive protein; WBC: White blood cell; OR: Odds ratio; CI: Confidence interval.

absorptiometry. DeLoach *et al.*^[31] concluded that BMI alone would be sufficient to estimate cardiovascular risk in children and adults. In adolescents, insulin resistance has been found to be strongly associated with BMI.^[31] In our cross-sectional study, we found that the prevalence of insulin resistance in the overweight group was 3.44 times greater than that of the normal weight group, while in the obese group, the prevalence of HOMA-IR was 7.53 times greater than that identified in the normal weight group when groups were defined by BMI. In addition, among females, the prevalence of insulin resistance in the overweight group was 1.48 times greater than that identified in the normal weight group, while in the obese group, the prevalence of HOMA-IR was 3.59 times greater than the prevalence observed in the normal weight group.

Increases in BMI might affect lipid parameters.^[32] In India, a significant relationship was identified between BMI and lipid profile (higher concentrations of TC, LDL, and TG) in obese children.^[33] Abnormal lipid levels were also observed in a much larger population of children with overweight in the United States, and in that study, the children with the highest BMI levels had the lowest HDL levels.^[34] Torng

et al.^[35] showed that menopause was associated with significant increases in TC, LDL-C, and TG. TC, LDL-C, and TG increased consistently in association with BMI in middle-aged females, regardless of menopausal status. Furthermore, Netjasov *et al.*^[28] reported the identification of significant negative correlations between BMI and HDL in obese and overweight females with a BMI ≥25.0 kg/m². Gaining weight was associated with dyslipidemia in another study, confirming the increased incidence of metabolic abnormalities during menopause. In a lipid glucose study conducted in Tehran, significant associations between BMI and various types of dyslipidemia were observed; however, WHR only maintained a significant association with hypertriglyceridemia and low HDL-C.^[36,37] In China, increased BMI was found to be associated with increased TC and TG, and a negative association was ascertained between HDL and BMI.^[38] We found that there were significant correlations between BMI and lipid levels (LDL-C, HDL-C, TC, and TG), and when compared with the normal weight group, as defined by BMI, the odds of dyslipidemia in the overweight and obese groups were 2.60 and 3.59 times greater, respectively.

Khoo *et al.*^[29] found that BMI was directly associated with CRP across all evaluated ethnic groups. When compared with Chinese and Malay individuals, Asian-Indian persons were found to have higher CRP levels. The increase in CRP associated with each unit increase in BMI was greater in Chinese than that in other ethnic group populations. Other authors have reported that there was an association between CRP and BMI or between CRP and WHR.^[39] Among middle-aged and elderly African-Americans enrolled in the Jackson Heart Study, in which hs-CRP was used as a measure of inflammation, there was a strong correlation between BMI and CRP. Studies have shown that higher BMI levels were associated with higher CRP levels.^[29]

Other studies have indicated that the WBC was independently associated with obesity.^[40-42] Pratley *et al.*^[43] found that WBC was positively correlated with BMI when researching the relationships between WBC and obesity in persons of different races and genders. Increases in total WBC and WBC subtypes were found to be positively associated with the presence of metabolic syndrome in Chinese people.^[44] In addition, in our study, BMI was correlated with hs-CRP and WBC. We stratified females and males by BMI into normal weight, overweight, and obese groups. The measures for hs-CRP and WBC differed significantly among the normal weight, overweight and obese groups. Among males, when groups were defined by BMI, hs-CRP was 1.27 times greater in the overweight group and 1.70 times greater in the obese group than that of the normal weight group. Among females, the odds of hs-CRP and WBC were 1.48 and 1.64 times greater in the overweight group and 2.63 and 2.25 times greater in the obese group, respectively, when those of normal weight were used as the reference group.

Increased BMI has been found to be associated with the development of cardiovascular risk factors, such as HTN, dyslipidemia, insulin resistance, and DM, potentially leading to ischemic stroke and CVDs, including angina, myocardial infarction (MI), heart failure, and sudden death.^[2,45-49] These comorbidities have been found to develop proportionately with increases in BMI, and obesity has been considered an independent risk factor for CVD.^[50,51] A recent large study included a cohort of 111,847 patients with non-ST elevation MI (NSTEMI). In that study, a strong, inverse linear relationship between BMI and age at first NSTEMI was observed.^[52] In children, increased BMI was found to be positively associated with the risk of premature death in a population of American-Indians born between 1945 and 1984 and followed between February 1966 and December 2003.^[53] Another study including older children also identified a close relationship between BMI at adolescence and the rate of all-cause mortality during adulthood.^[54]

To our knowledge, a large population-based cross-sectional study has not previously been conducted to compare the predictive abilities of BMI, BFP, WHR, and WHtR in the assessment of cardiometabolic risk factors in a population of Chinese adults. Based on the results of this study, we suggested that BMI might be more effective in the detection

of metabolic disorders (IGR, dyslipidemia, insulin resistance, hs-CRP, and WBC) than the other evaluated indices. BMI is an adiposity indicator that was associated with the majority of the metabolic parameters studied, suggesting that BMI may serve as a better tool for cardiovascular risk factor detection than the other anthropometric measures included in our study. Thus, BMI might be of paramount importance for the prevention, optimum management, and prognostication of metabolic disorders and cardiometabolic risk factors. BMIs are inexpensive to measure, easy to use, and noninvasive and, therefore, can be widely used.

Several limitations of our study should be considered. First, the use of a cross-sectional design did not allow us to infer causality. Second, the results of our study may not be generalizable to other racial and ethnic groups because only Chinese adults were enrolled. Finally, participants were enrolled from a single center, which not only enhanced the internal validity of the comparisons, but also created some limitations in terms of generalizability.

In conclusion, this study analyzed data from 12,018 Chinese adults and identified positive associations between all evaluated body composition indices and metabolic parameters in both males and females. Among the body composition indices, BMI predicted almost all metabolic disorders in both gender groups. Our findings suggest that BMI could be regarded as an adequate tool for the detection of individuals at high risk for CVD.

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Conflicts of interest

There are no conflicts of interest.

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中国成人身体成分指标和代谢参数之间的关系:横断面研究

摘要

背景: 肥胖可导致血脂异常, 血压升高, 糖代谢异常, 炎症状态, 由此引发动脉粥样硬化, 糖尿病, 心血管疾病。我们通常用身体成分指标, 如身体质量指数 (BMI), 体脂百分比 (BFP), 腰高比 (WHtR) 和腰臀比 (WHR) 反映肥胖程度。本文通过对中国成人的横断面研究揭示身体成分指标和代谢参数之间的关系。

方法: 研究对象包括12018中国成年人。身体成分指标包括: BMI, BFP, WHtR, WHR。代谢参数包括: 收缩压 (SBP), 舒张压 (DBP), 总胆固醇 (TC), 甘油三酯 (TG), 低密度脂蛋白胆固醇 (LDL-C), 高密度脂蛋白胆固醇 (HDL-C), 空腹血糖 (FBG), 餐后2 h血糖 (2h PBG), 糖化血红蛋白 (HbA1c), 空腹胰岛素 (FINS), 胰岛素抵抗指数 (HOMA-IR), 高敏c反应蛋白 (hs-CRP), 和白细胞计数 (WBC)。所有分析都按性别分层。

结果: 中国成年男性和女性相比, 除了2h PBG外, 所有身体成分指标及代谢参数之间存在显著统计学差异 ($P < 0.001$)。BMI (WHtR, WHR) 与SBP, DBP, LDL-C, TC, TG, FBG, 2h PBG, HbA1c, FINS, HOMA-IR, hs-CRP 和WBC呈正相关, 与高密度脂蛋白胆固醇呈负相关。多变量分析显示男性中, 以BMI为分组标准, 超重组的葡萄糖调节受损 (IGR), 血脂异常, 胰岛素抵抗和升高的高敏c反应蛋白 (hs-CRP) 分别为正常体重组的 1.36, 1.92, 3.44, 和 1.27 倍; 肥胖组分别为正常组的 1.66, 3.26, 7.53, 和 1.70 倍。以BFP为分组标准, BFP \geq 28.0%组血脂异常, hs-CRP异常的比例分别是 BFP $<$ 28.0%组的 1.29 和 1.38 倍。以WHtR为分组标准, WHtR \geq 0.96组血脂异常, HOMA-IR, hs-CRP 分别是 WHtR $<$ 0.96组的 1.55, 1.26, 和 1.48 倍。以WHR为分组标准, WHR \geq 0.54组HOMA-IR是 WHR $<$ 0.54组的 1.46 倍。在女性中也观察到类似的结果。

结论: 本研究发现在中国成年人中身体成分指标和代谢参数之间存在正相关。在不同性别中, 身体成分指标 BMI 可以预测五个代谢紊乱参数中的四个。