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The feasibility of two anthropometric indices to identify metabolic syndrome, insulin resistance and inflammatory factors in obese and overweight adults

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ABSTRACT

Objectives: A body shape index (ABSI) and body roundness index (BRI) were reported to predict diabetes and hypertension in general population, but their validity was regularly questioned. The aim of this study was to evaluate whether ABSI and BRI are the best anthropometric indices to reflect metabolic syndrome (MetS), insulin resistance (IR), and inflammatory factors in obese and overweight Chinese adults.

Methods: Cross-sectional data on sociodemographic, lifestyle, anthropometric indices, clinical characteristics, and biochemical measurements were collected for 1442 Chinese obese and overweight adults. Logistic regression analysis examined the associations between anthropometric indices with incidences of MetS and IR in both sexes. Furthermore, the correlation between anthropometric indices and inflammatory factors was assessed.

Results: Multivariate regression analysis depicting BRI and waist circumference (WC) were associated significantly with MetS and IR. BRI had the highest odds ratios (ORs) for IR and WC had the highest ORs for MetS in all anthropometric indices. However, ABSI did not exhibit any association between the MetS and IR. The ABSI adjusted regression coefficients (β values) were 0.403 for high-sensitivity C reactive protein, 0.077 for tumor necrosis factor-α, and 0.022 for interleukin-6. BRI and WC were also significantly associated with three inflammatory factors. Comparing the lowest with the highest quintile, BRI had the largest ORs for MetS (OR, 5.778; 95% confidence interval [CI], 2.954–11.303; $P < 0.01$) and IR (OR, 6.212; 95% CI, 2.912–13.250; $P < 0.01$).

Conclusion: Only BRI and WC, not ABSI, can significantly determine the presence of MetS and IR. BRI showed the optimal capability to identify IR in obese and overweight population.

Introduction

Overweight and obesity are well-known risk factors for all-cause mortality and cardiovascular disease (CVD), and they are closely related to non-communicable diseases, such as diabetes, hypertension, and dyslipidemia [1–3]. Although body mass index (BMI) is the most commonly used anthropometric measure for defining obesity, as recommended by the World Health Organization, the BMI has potential weaknesses. Specifically, the BMI does

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not distinguish between weight due to fat accumulation and muscle weight [4,5], nor does the BMI distinguish peripheral fat from abdominal fat [6], the latter being more strongly associated with CVD risk. To overcome these shortcomings, the waist circumference (WC) and waist-to-hip ratio (WHR) have been suggested as indicators of central adiposity due to their relevance with fat distribution [7,8]. A number of studies have shown that WC and WHR are more accurate than BMI in predicting all-cause mortality and CVD [9,10]; however, WC reflects not only abdominal fat accumulation, but also overall body size, such as height and weight. In fact, WC is strongly correlated with both weight and BMI.

Figure 1.

Recently, two new anthropometric indices have been introduced. In 2012, Krakauer et al. [11] developed a body shape index (ABSI), which is based on WC, BMI, and height. Krakauer et al. [12] claim that ABSI is more closely associated with visceral adipose tissue (VAT) than BMI and WC, and it is a significant risk factor for premature death. Other studies have suggested that ABSI can

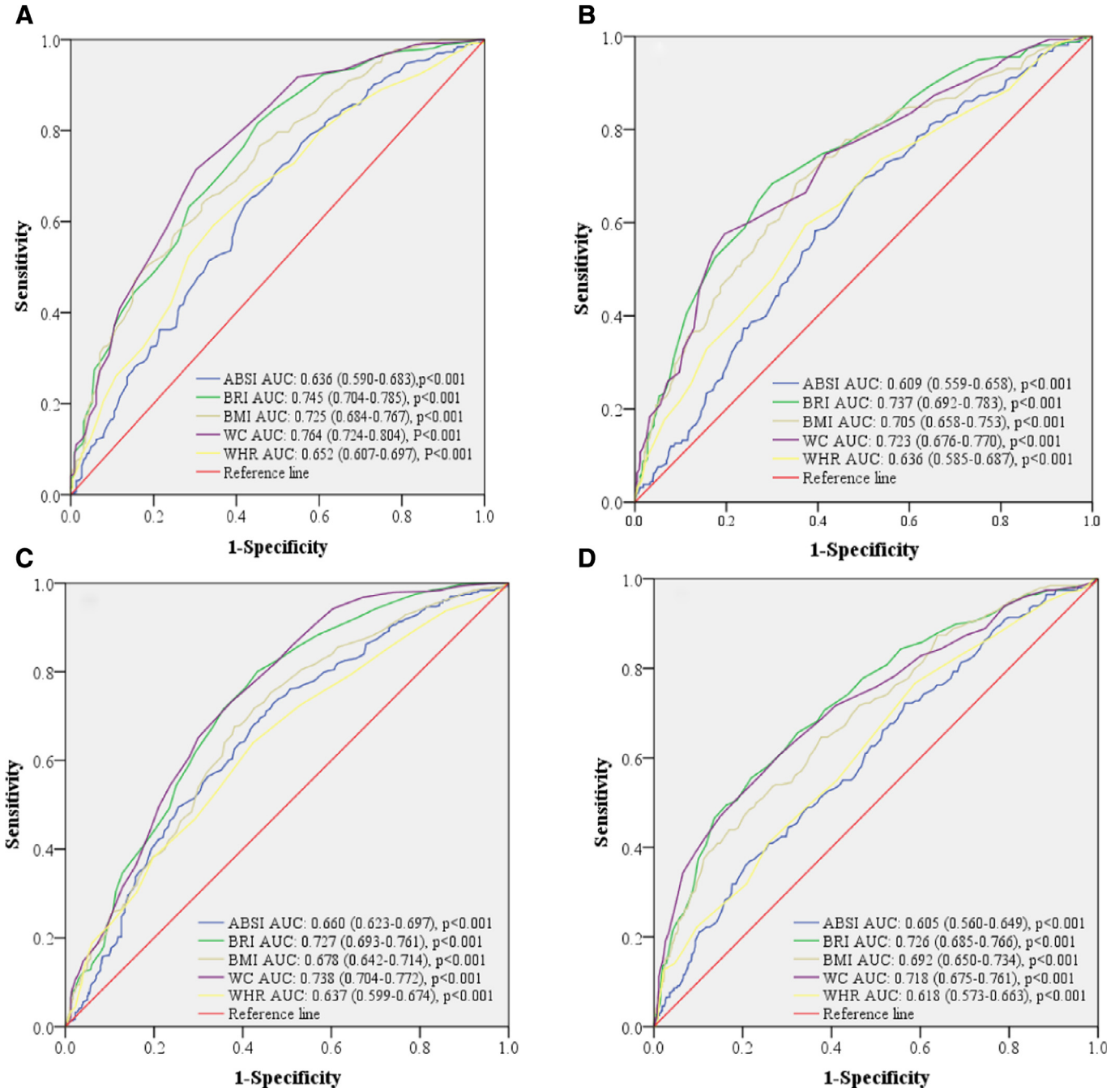

Fig. 1. The discriminatory power of anthropometric indexes between individuals with or without MetS or IR. (**A**) Area under the ROC curve of anthropometric indexes to identify men with MetS. (**B**) Area under the ROC curve of anthropometric indexes to identify male subjects with IR. (**C**) Area under the ROC curve of anthropometric indexes to identify female subjects with MetS. (**D**) Area under the ROC curve of anthropometric indexes to identify female subjects with IR. ABSI, ABSI, a body shape index; AUC, area under the curve; BMI, body mass index; BRI, body roundness index; IR, insulin resistance; MetS, metabolic syndrome; ROC, receiver operating characteristic; WC, waist circumference; WHR, waist-to-hip ratio.

predict the onset of diabetes and can be used to assess the physical health status of adolescents [13,14]. However, the predictive power of ABSI in different populations is contradictory. In Japanese adults, ABSI is not superior to BMI or WC in the prediction of diabetes, hypertension, and dyslipidemia [15]. In 2013, Thomas et al. [16] developed the body roundness index (BRI), which is a geometric index that combines height and WC to predict the percentage of body fat and to evaluate health status. Although BRI can predict CVD and CVD risk factors, it is not superior to BMI and WC [17].

Overall, the new anthropometric indices exhibited some feasibility to identify CVD and metabolic risk in general population. Overweight and obese individuals often have higher metabolic risk and chronic inflammation [18–20]. However, the association between the new anthropometric indices and metabolic risk has not been evaluated separately in these populations. The goal of this study was to determine the predictive power of ABSI and BRI for metabolic risk and inflammatory levels in overweight and obese populations, and to determine if the ABSI and BRI are superior to conventional markers.

Materials and methods

Participants

This study was conducted in Hubei Province, which is located in Central China. Between January 2015 and August 2016, a representative sample of overweight and obese individuals ≥35 y of age was selected to participate in an assessment of the associations between two new body indices (ABSI and BRI) and MetS, IR, and inflammatory factors in an urban population. Overweight and obesity were defined as a participant with a BMI ≥24 and <28 kg/m^2, and ≥28 kg/m^2, respectively, according to the cutoff point for Chinese adults [21]. My colleagues and I initially recruited 1921 participants—973 overweight and 948 obese. Of the eligible participants, 1442 (75.1%) had complete data on the entire examination and were for further analysis. The study was approved by the Human Research Ethics Committee of Hubei Provincial Hospital of Traditional Chinese Medicine (Wuhan, China). Written informed consent was obtained from each participant. We had signed consent from every participant to participate in the study. The results are all anonymous. No individual result is presented and only group statistics were provided.

Lifestyle factors

The survey was performed by physicians and trained nurses. Information on covariates, such as age, sex, and lifestyle, was collected using a standard questionnaire by face-to-face interviews. Before conducting the survey, all eligible investigators were invited to attend a training session. The training session covered various topics, including how to administer the questionnaire; the standard method of measurement; the importance of standardization, and study procedures. In the present study, family income was classified as <30 000, 30000 to 100 000, and >100 000 CNY/y. Educational level was categorized as low (no schooling, incomplete primary education, and primary education), middle (3 or 4 y of secondary education), and high (college and university education). Physical activity was classified into three groups using methods presented elsewhere [22].

Anthropometric measurements

Anthropometric measurements were obtained using standard protocols and techniques. Weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively, with the participant in lightweight clothing and without shoes. The WC was measured at the midpoint between the inferior costal margin and the superior border of the iliac crest on the midaxillary line. The BMI, a measure of general obesity, was calculated as the weight in kilograms divided by the height squared in meters. The WHR was calculated by dividing WC by the hip circumference. ABSI was calculated using the following formula: $\text{ABSI} = \frac{\text{WC}}{\text{BMI}^{2/3}\,\text{height}^{1/2}}$ [11]. The BRI was calculated using the following formula: $\text{BRI} = 364.2 - 365.5 \times \sqrt{1 - \left(\frac{(\text{WC}/(2\pi))^2}{(0.5\ \text{height})^2}\right)}$ [16].

Blood pressure measurements and definition of MetS and IR

Arterial blood pressure was measured with a mercury sphygmomanometer after sitting for at least 15 min. Three readings were taken at 5-min intervals. The mean of the three measurements was recorded.

According to the International Diabetes Federation definitions [23], for a person to be defined as having MetS, they must have the following:

- Central obesity, which is ethnically defined as WC ≥90 cm for Chinese men and ≥80 cm for Chinese women (all of the participants met this criterion)
- Raised blood pressure, meaning patients had systolic blood pressure (SBP) ≥130 or diastolic blood pressure (DBP) ≥85 mm Hg or treatment of previously diagnosed hypertension
- Raised fasting plasma glucose (FPG) ≥5.6 mmol/L or previously diagnosed type 2 diabetes
- Raised triacylglycerol (TG) levels: ≥1.7 mmol/L or specific treatment for this lipid abnormality
- Reduced high-density lipoprotein cholesterol (HDL-C) <1.03 mmol/L in men and <1.29 mmol/L in women or specific treatment for this lipid abnormality.

IR was calculated using homeostasis model assessment of IR (HOMA-IR): fasting glucose (mmol/L) × fasting insulin (μU/mL)/22.5, and participants in the top quartile of HOMA-IR were defined as IR [24].

Biochemical measurements

A fasting blood sample was collected from each participant in the morning after at least 12 h of fasting. Blood samples were obtained from an antecubital vein and collected in Vacutainer tubes containing EDTA. Plasma glucose, liver enzyme levels, and serum lipid profiles, including TG, total cholesterol (TC), and HDL-C were determined on a HITACHI 7450 analyzer (HITACHI, Tokyo, Japan). Low-density lipoprotein cholesterol (LDL-C) was calculated by Friedewald's formula. Fasting FPG was measured by the hexokinase method. Serum fasting insulzn concentration was measured by electrochemiluminiscence immunoassay (Roche Elecsys Insulin Test, Roche Diagnostics, Mannheim, Germany). The enzyme-linked immunosorbent assay (ELISA) technique was used to measure levels of high-sensitivity C reactive protein (hs-CRP; Immunodiagnostik Ag). The sensitivity of the assay was 0.05 ± 0.007. The cytokines interleukin (IL)-6 and tumor necrosis factor (TNF)-α (R & D Systems Ltd.) were measured by ELISA in duplicates. The TNF-α and IL-6 assays detected concentrations down to 0.32 and 0.11 pg/mL, respectively. Intra-assay variability was <9% for the three assays.

Statistical analysis

SPSS version 18 (SPSS, Inc., Chicago, IL, USA) was used for statistical analysis. Continuous variables in a normal distribution were compared using Student's t test. Categorical variables were analyzed using the χ^2 test. Participants were divided into two groups according to sex, and then subdivided into overweight and obese groups within each sex. Partial Spearman correlation coefficients were used to clarify the association between anthropometric measures (ABSI, BRI, BMI, WC, and WHR) with biochemical measurements and inflammatory markers, after adjustment for age and sex. For standardization, Z scores for ABSI and WHR were calculated. As reported by Krakauer et al. [12], Z scores were calculated from measurement values, predicted means, and SDs as follows: (measurement value − predicted mean)/predicted SD. We conducted logistic regression analysis to examine the associations between BRI, BMI, WC, WHR, and ABSI (Z scores) with incidences of MetS and IR in both sexes. Logistic regression analyses were adjusted for abdominal circumference, age, family income, educational level, smoking, alcohol consumption physical activity, SBP, DBP, UA, TG, TC, HDL, LDL, fasting glucose, and fasting insulin. To assess the association between anthropometric measures and inflammatory factors, we used two model types of multivariate linear regression analysis. Further analyses were performed to determine multivariable-adjusted ORs (95% CIs) of MetS and IR for the highest quartile versus the lowest quartile of each anthropometric index after adjustment for covariates. To determine the discriminative power of the anthropometric indices for MetS and IR in different sexes, the area under the receiver operating characteristic (AROC) curves were calculated. Statistical significance was assumed at $P < 0.05$.

Results

A total of 1442 individuals ≥35 y of age participated in the study. Table 1 shows the clinical and demographic characteristics of the study population according to sex and body shape. Obese men and women were more likely to consume alcohol and smoke cigarettes ($P < 0.05$). Obese participants had a higher prevalence of hypertension, diabetes, MetS, and IR compared with overweight participants in both sexes. Overall, obese participants had higher blood pressure; higher liver enzyme levels; higher TG, UA, FBG, and insulin levels; and a higher HOMA-IR than overweight

Table 1
Demographic, lifestyle, and clinical characteristics of population by sex

Variables	Men			Women		
	Overweight n=290	Obesity n=305	*P*-value	Overweight n=466	Obesity n=381	*P*-value
Age (y)	40.88 ± 10.03	39.50 ± 9.89	0.092	44.91 ± 9.20	44.45 ± 9.30	0.478
Education (y)			0.975			0.382
Low (<9 y)	69 (23.8%)	72 (23.6%)		121 (26%)	113(29.7%)	
Middle (9–12 y)	86 (29.7%)	93 (30.5%)		208 (44.6%)	154 (40.4%)	
High (>12 y)	135 (46.5%)	140 (45.9%)		137 (29.4%)	114 (29.9%)	
Family income (CNY/y)			0.474			0.223
<30 000	33 (11.4%)	36 (11.9%)		62 (13.3%)	62 (16.3%)	
30 000–100 000	179 (61.7%)	174 (57%)		310 (66.5%)	256 (67.4%)	
>100 000	78 (26.9%)	95 (31.1%)		94 (20.2%)	62 (16.3%)	
Physical activity			0.337			0.002
Low	163 (56.2%)	189 (62%)		203 (43.5%)	197 (51.7%)	
Intermediate	96 (33.1%)	90 (29.5%)		175 (37.6%)	143 (37.5%)	
High	31 (10.7%)	26 (8.5%)		88 (18.9%)	41 (10.8%)	
Smoking (%)	140 (48.3%)	143 (46.9%)	0.734	24 (5.2%)	33(8.7%)	0.042
Drinking (%)	118 (40.7%)	100 (32.8%)	0.046	32 (6.9%)	20 (5.2%)	0.329
Hypertension (%)	97 (33.4%)	152 (49.8%)	<0.001	129 (27.7%)	195 (51.3%)	<0.001
Diabetes (%)	53 (18.3%)	101 (33.1%)	<0.001	61 (13.1%)	125 (32.8%)	<0.001
MetS (%)	133 (45.9%)	232 (76.1%)	<0.001	188 (40.3%)	251 (65.9%)	<0.001
SBP (mm Hg)	129.00 ± 15.81	136.52 ± 18.22	<0.001	127.04 ± 15.89	135.23 ± 18.34	<0.001
DBP (mm Hg)	85.27 ± 10.92	90.80 ± 13.05	<0.001	82.97 ± 10.07	87.99 ± 11.57	<0.001
HR (bpm)	68.06 ± 9.94	70.01 ± 10.43	0.021	68.83 ± 9.30	69.58 ± 9.41	0.251
TC (mmol/L)	4.63 ± 0.91	4.81 ± 0.99	0.021	4.78 ± 0.96	4.83 ± 0.91	0.443
TG (mmol/L)	1.70 ± 1.12	2.33 ± 2.06	<0.001	1.52 ± 1.33	1.72 ± 1.20	0.024
LDL-C (mmol/L)	2.98 ± 0.79	3.07 ± 0.85	0.157	3.01 ± 0.79	3.08 ± 0.81	0.182
HDL-C (mmol/L)	1.18 ± 0.27	1.05 ± 0.25	<0.001	1.36 ± 0.33	1.26 ± 0.28	<0.001
ALT (U/L)	30.08 ± 21.40	46.99 ± 39.35	<0.001	20.32 ± 17.98	27.55 ± 20.82	<0.001
AST (U/L)	22.96 ± 9.49	28.68 ± 17.88	<0.001	19.87 ± 10.46	23.23 ± 14.10	<0.001
GGT (U/L)	44.20 ± 43.18	53.74 ± 46.73	0.01	23.72 ± 22.50	29.89 ± 23.70	<0.001
BUN (mmol/L)	5.51 ± 1.17	5.42 ± 1.28	0.376	5.02 ± 1.26	5.00 ± 1.33	0.847
Cr (ummol/L)	78.14 ± 11.88	76.76 ± 12.04	0.194	57.15 ± 9.19	57.03 ± 13.06	0.875
UA (ummol/L)	396.83 ± 90.13	434.74 ± 98.30	<0.001	299.77 ± 70.88	330.91 ± 75.32	<0.001
FPG (mmol/L)	5.62 ± 1.60	5.93 ± 1.76	0.026	5.62 ± 1.52	5.93 ± 1.70	0.005
Insulin (μU/mL)	12.04 ± 2.50	14.02 ± 3.24	<0.001	12.14 ± 2.76	13.51 ± 3.07	<0.001
HOMA-IR	3.02 ± 1.16	3.69 ± 1.42	<0.001	3.03 ± 1.08	3.58 ± 1.39	<0.001
IR (n, %)	41(14.1%)	117(38.4%)	<0.001	71(15.2%)	129(33.9%)	<0.001
BMI (kg/m^2)	26.22 ± 1.02	30.91 ± 2.76	<0.001	26.02 ± 1.20	30.71 ± 2.56	<0.001
WC(cm)	90.41 ± 5.02	100.00 ± 8.28	<0.001	86.84 ± 5.87	96.13 ± 7.65	<0.001
WHR	0.937 ± 0.050	0.973 ± 0.056	<0.001	0.916 ± 0.039	0.952 ± 0.051	<0.001
Abdominal circumference (cm)	92.90 ± 5.27	104.80 ± 8.90	<0.001	88.12 ± 4.37	98.40 ± 7.22	<0.001
BRI	4.04 ± 0.59	5.28 ± 1.07	<0.001	4.39 ± 0.76	5.75 ± 1.11	<0.001
ABSI	0.0786 ± 0.0043	0.0783 ± 0.0040	0.311	0.0783 ± 0.0046	0.0784 ± 0.0047	0.971
Height (m)	168.7 ± 6.7	168.5 ± 6.6	0.754	156.9 ± 5.8	156.6 ± 5.7	0.494
hs-CRP (mg/L)	4.67 ± 1.13	5.58 ± 1.26	0.002	4.15 ± 1.18	5.09 ± 1.25	0.01
TNF-α (pg/mL)	2.87 ± 0.87	3.11 ± 0.82	0.001	2.98 ± 0.91	2.99 ± 0.85	0.945
IL-6 (pg/mL)	2.54 ± 1.15	2.79 ± 1.17	0.025	2.59 ± 1.23	2.70 ± 1.37	0.092

ABSI, a body shape index; ALT, alanine aminotransferase; AST, aspartate aminotransferase; BMI, body mass index; BRI, body roundness index; BUN, blood urea nitrogen; Cr, creatinine; DBP, diastolic blood pressure; FPG, fasting plasma glucose; GGT, gamma-glutamyltransferase; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; HR, heart rate; hs-CRP, high-sensitivity C reactive protein; IL, interleukin; IR, insulin resistance; LDL-C, low-density lipoprotein cholesterol; MetS, metabolic syndrome; SBP, systolic blood pressure; TNF, tumor necrosis factor; TC, total cholesterol; TG, triacylglycerol; UA, uric acid; WC, waist circumference; WHR, waist-to-hip ratio

participants. However, the LDL-C level in both sexes and the TC level in women did not differ between overweight and obese participants. With respect to anthropometric measures, the mean levels of BMI, BRI, WC, and WHR were significantly higher among obese participants, unlike the ABSI. Notably, the inflammatory factor levels in obese men were significantly higher than overweight men, but not women (Table 1).

Table 2 shows the results of partial Spearman correlation coefficients of anthropometric measures (ABSI, BRI, BMI, WC, and WHR) with metabolic features, and inflammatory factors. After adjustment for age and sex, the new anthropometric indices (ABSI and BRI) had a moderate correlation ($r = 0.537$, $P < 0.001$). The BRI had a strong correlation with BMI ($r = 0.772$, $P < 0.001$) and WC ($r = 0.911$, $P < 0.001$) but a weak relationship with WHR ($r = 0.375$, $P < 0.001$). However, in the overweight and obese populations, the ABSI only exhibited a moderate correlation with WC ($r = 0.568$, $P < 0.001$). The BRI had a slight but significant correlation with both blood pressure and TG, HDL, and FBG levels, whereas ABSI was not associated with blood pressure, FBG level, or any lipid parameters. The relationship between BRI and insulin, HOMA-IR, and inflammatory factors was superior to ABSI.

Multivariate regression analysis depicted the association between anthropometric measures with MetS and IR (Table 3). After adjustment for abdominal circumference, age, income, educational level, smoking, alcohol consumption, physical activity, SBP, DBP, UA, TG, TC, HDL, LDL, and FBG levels, the OR of MetS was still significant for BRI in both men and women (men: OR, 1.986 [1.175–3.356]; women: OR,1.679 [1.283–2.197]). WC had the highest ORs for MetS in all five anthropometric indices in men and women (men: OR, 3.276 [1.706–6.293]; women: OR, 2.908

Table 2
Partial Spearman correlation coefficients of anthropometric measures (ABSI, BRI, BMI, WC, and WHR) with biochemical measurements, and inflammatory markers*

All (N = 1442)	ABSI, r (*P*-value)	BRI, r (*P*-value)	BMI, r (*P*-value)	WC, r (*P*-value)	WHR, r (*P*-value)
ABSI	1	0.537 (<0.001)	−0.022 (0.403)	0.568 (<0.001)	0.065 (0.013)
BRI	0.537 (<0.001)	1	0.772 (<0.001)	0.911 (<0.001)	0.375 (<0.001)
BMI (kg/m^2)	−0.022 (0.403)	0.772 (<0.001)	1	0.754 (<0.001)	0.476 (<0.001)
WC (cm)	0.568 (<0.001)	0.911 (<0.001)	0.754 (<0.001)	1	0.473 (<0.001)
WHR	0.065 (0.013)	0.375 (<0.001)	0.476 (<0.001)	0.473 (<0.001)	1
Height (m)	0.089 (<0.001)	−0.127 (<0.001)	0.020 (0.456)	0.278 (<0.001)	0.257 (<0.001)
SBP (mm Hg)	0.029 (0.279)	0.223 (<0.001)	0.293 (<0.001)	0.269 (<0.001)	0.210 (<0.001)
DBP (mm Hg)	0.006 (0.833)	0.214 (<0.001)	0.309 (<0.001)	0.264 (<0.001)	0.211 (<0.001)
TG (mmol/L)	0.048 (0.0690)	0.134 (<0.001)	0.141 (<0.001)	0.139 (<0.001)	0.098 (<0.001)
TC (mmol/L)	−0.016 (0.620)	0.044 (0.097)	0.028 (0.387)	0.012 (0.705)	0.075 (0.022)
LDL-C (mmol/L)	−0.011 (0.737)	0.037 (0.158)	0.034 (0.295)	0.028 (0.383)	0.086 (0.009)
HDL-C (mmol/L)	−0.027 (0.301)	−0.184 (<0.001)	−0.214 (<0.001)	−0.210 (<0.001)	−0.140 (<0.001)
FPG (mmol/L)	0.029 (0.278)	0.123 (<0.001)	0.125 (<0.001)	0.118 (<0.001)	0.072 (0.007)
Insulin (μU/mL)	0.097 (<0.001)	0.322 (<0.001)	0.330 (<0.001)	0.339 (<0.001)	0.211 (<0.001)
HOMA-IR	0.074 (0.005)	0.283 (<0.001)	0.292 (<0.001)	0.287 (<0.001)	0.174 (<0.001)
hs-CRP (mg/L)	0.208 (<0.001)	0.125 (<0.001)	0.109 (<0.001)	0.164 (<0.001)	0.031 (0.048)
IL-6 (pg/mL)	0.031 (0.044)	0.078 (0.003)	0.090 (<0.001)	0.086 (0.001)	0.053 (0.045)
TNF-α (pg/mL)	0.055 (0.038)	0.087 (0.001)	0.061 (0.021)	0.078 (0.003)	0.010 (0.707)
UA (ummol/L)	0.052 (0.111)	0.180 (<0.001)	0.226 (<0.001)	0.208 (<0.001)	0.152 (<0.001)

ABSI, a body shape index; BRI, body roundness index; BMI, body mass index; BUN, blood urea nitrogen; DBP, diastolic blood pressure; FPG, fasting plasma glucose; GGT, gamma-glutamyltransferase; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; HR, heart rate; hs-CRP, high-sensitivity C reactive protein; IL, interleukin; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; TC, total cholesterol; TG, triacylglycerol; TNF, tumor necrosis factor; TC, total cholesterol; UA, uric acid; WC, waist circumference; WHR, waist-to-hip ratio

* All correlation coefficients were calculated after adjustment for age and sex.

[2.000–4.288]). After adjustment for these covariates and the addition of the fasting insulin level, the BRI (men: OR, 3.370 [1.818–6.246]; women: OR, 3.043 [2.027–4.569]) and WC (men: OR, 1.255 [1.127–1.398]; women: OR, 1.247 [1.158–1.343]) also showed significant ORs for IR in both sexes. In this case, the BRI had the highest ORs for IR in all anthropometric indices. The ORs of WHR for MetS and IR were significant in women only. ABSI did not exhibit any association between the MetS and IR in men or women.

The association between anthropometric indices and inflammatory factors were analyzed after adjustment for covariates using multiple regression models. As shown in Table 4, ABSI was most closely associated with the hs-CRP level, even after multivariate adjustment. The ABSI adjusted regression coefficients (β values) were 0.403 for hs-CRP, 0.077 for TNF-α, and 0.022 for IL-6. BRI and WC were also significantly associated with three inflammatory factors. In addition to the hs-CRP level, the BRI had a strong correlation with TNF-α ($\beta = 0.104$, $P < 0.001$) in these five anthropometric indices. The BMI only had a significant association with the hs-CRP level ($\beta = 0.151$, $P = 0.037$); however, the WHR was not associated with these three inflammatory factors in the multiple regression models.

Further analyses were performed to examine multivariable-adjusted ORs (95% CIs) of the presence of MetS and IR for the highest quartile versus the lowest quartile of each anthropometric index after adjustment for age, sex, income, education, physical activity, smoking, alcohol consumption, blood pressure, inflammatory factors, serum lipid, FBG, and fast insulin levels. Participants were grouped based on the quartiles of the five anthropometric indices. The BRI had the largest ORs (95% CI) for MetS (OR, 5.778; 95% CI, 2.954–11.303; $P < 0.01$) and IR (OR, 6.212; 95% CI, 2.912–13.250; $P < 0.01$) compared with the first quartile. The WC was the only anthropometric index for which the ORs of the second, third, and fourth quartiles were significantly increased compared with the first quartile for both MetS and IR. There was no difference in ORs between each quartile of ABSI for both MetS and IR (Table 5).

ROC results demonstrated the power of all anthropometric indices to discriminate participants with or without MetS and IR in the overweight and obese populations. ROC curves showed that WC had the optimal power to discriminate MetS individuals in both men (area under curve [AUC], 0.764; 95% CI, 0.724–0.804; $P < 0.001$) and women (AUC, 0.738; 95% CI, 0.704–0.772; $P < 0.001$). Moreover, BRI had the optimal power to discriminate IR in both sexes (men: AUC, 0.737; 95% CI, 0.692–0.783; $P < 0.001$; women: AUC, 0.726; 95% CI, 0.685–0.766; $P < 0.001$).

Discussion

In this cross-sectional study we compared the associations between five anthropometric indices (ABSI, BMI, BRI, WC, and WHR) and MetS, IR, and inflammatory factors in an overweight and obese populations from a central city in China. The BRI, as a new anthropometric index, had a significant association with MetS and IR in overweight and obese individuals. BRI had the optimal potential to determine the presence of IR in both sexes compared with WC and WHR. Participants with a higher BRI had a higher risk for MetS and IR. Although ABSI had a limited association with inflammatory factors, ABSI was not suitable for determining the prevalence of MetS and IR. Overall, BRI can be used to identify MetS and IR risk, especially IR, and it is significantly associated with inflammatory factors.

In 2012, Krakauer et al. developed ABSI to quantitatively measure the health of body shape, which is based on WC, BMI, and height [11]. Krakauer et al. [11] standardized the WC for BMI and height with the scaling exponents, 2/3 and 1/2, in the denominator, which rendered the ABSI non-correlated with the BMI. Krakauer et al. [11] suggested that ABSI is closely related with VAT and more associated with mortality risk than BMI and WC. The BRI was developed in 2013. Thomas et al. [16] demonstrated that BRI improved the prediction of body fat and VAT compared with traditional indicators, such as BMI or WC. In agreement with previous studies [17,25], ABSI was not correlated with BMI, but it was moderately related to WC in our overweight and obese participants. BRI was strongly correlated with WC and was highly correlated with BMI, even after adjusting for age and sex. Although there were some limitations, it is widely accepted that BMI and WC can predict cardiovascular and metabolic risk in obese populations. The

Table 3
Adjusted ORs with associated 95% CI of anthropometric measures (ABSI, BRI, BMI, WC, and WHR) for incidences of MetS and IR

MetS	Men			Women		
Model 1*	OR	95% CI	*P*-value	OR	95% CI	*P*-value
ABSI *Z* score	1.446	1.103–1.896	0.008	1.724	1.425–2.087	<0.001
BRI	1.993	1.335–2.976	0.001	1.594	1.301–1.953	<0.001
BMI	1.641	1.006–2.678	0.047	1.309	0.933–1.836	0.119
WC	2.898	1.801–4.663	<0.001	2.262	1.724–2.967	<0.001
WHR *Z* score	0.596	0.354–1.001	0.05	0.603	0.427–0.852	0.004
Model 2†						
ABSI *Z* score	1.450	1.111–1.892	0.006	1.754	1.442–2.133	<0.001
BRI	2.102	1.395–3.168	<0.001	1.591	1.294–1.957	<0.001
BMI	1.692	1.032–2.774	0.037	1.298	0.923–1.825	0.134
WC	2.869	1.769–4.655	<0.001	2.271	1.722–2.995	<0.001
WHR *Z* score	0.599	0.349–1.029	0.063	0.611	0.430–0.869	0.006
Model 3‡						
ABSI *Z* score	1.686	0.958–2.381	0.233	2.206	0.976–2.897	0.347
BRI	1.986	1.175–3.356	0.01	1.679	1.283–2.197	<0.001
BMI	1.239	0.674–2.276	0.491	1.008	0.654–1.556	0.970
WC	3.276	1.706–6.293	<0.001	2.908	2.000–4.228	<0.001
WHR *Z* score	0.797	0.403–1.577	0.514	0.604	0.381–0.957	0.032
IR	Men			Women		
Model 1*	OR	95% CI	*P*-value	OR	95% CI	*P*-value
ABSI *Z* score	1.617	1.205–2.168	0.001	2.396	1.859–3.087	<0.001
BRI	2.793	1.826–4.273	<0.001	2.801	2.144–3.659	<0.001
BMI	1.182	1.000–1.396	0.05	1.400	1.217–1.609	<0.001
WC	1.204	1.121–1.293	<0.001	1.224	1.166–1.286	<0.001
WHR *Z* score	0.498	0.279–0.888	0.018	0.328	0.209–0.514	<0.001
Model 2†						
ABSI *Z* score	1.676	1.239–2.265	0.01	2.435	1.876–3.161	<0.001
BRI	3.105	1.984–4.861	<0.001	2.841	2.166–3.728	<0.001
BMI	1.205	1.016–1.430	0.032	1.409	1.224–1.623	<0.001
WC	1.214	1.128–1.307	<0.001	1.227	1.167–1.289	<0.001
WHR *Z* score	0.475	0.261–0.863	0.015	0.323	0.205–0.510	<0.001
Model 4§						
ABSI *Z* score	1.571	0.896–2.255	0.147	1.855	0.890–3.312	0.155
BRI	3.370	1.818–6.246	<0.001	3.043	2.027–4.569	<0.001
BMI	1.225	0.974–1.541	0.083	1.482	1.191–1.845	<0.001
WC	1.255	1.127–1.398	<0.001	1.247	1.158–1.343	<0.001
WHR *Z* score	0.449	0.197–1.022	0.056	0.275	0.138–0.546	<0.001

ABSI, a body shape index; BMI, body mass index; BRI, body roundness index; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HDL-C, high-density lipoprotein cholesterol; IR, insulin resistance; LDL-C, low-density lipoprotein cholesterol; MetS, metabolic syndrome; SBP, systolic blood pressure; TG, triacylglycerol; TC, total cholesterol; UA, uric acid; WC, waist circumference; WHR, waist-to-hip ratio

* Model 1 was adjusted for abdominal circumference and age.

† Model 2 was further adjusted for family income, educational level, smoking, drinking and physical activity.

‡ Model 3 was further adjusted for SBP, DBP, UA, TG, TC, HDL-C, LDL-C, FPG.

§ Model 4 was Model 3 added fasting insulin.

Table 4
Multivariable linear regression of inflammatory factors with anthropometric indices

hs-CRP	*β*	95% CI	*P*-value
ABSI *Z* score*	0.403	0.176–0.630	0.001
BRI*	0.373	0.046–0.700	0.025
BMI*	0.151	0.009–0.293	0.037
WC*	0.101	0.059–0.146	<0.001
WHR *Z* score*	0.056	0.021–0.171	0.007
TNF-α	*β*	95%CI	*P* Value
ABSI *Z* score*	0.077	0.018–0.135	0.01
BRI*	0.104	0.020–0.187	<0.001
BMI†	0.035	−0.002 to 0.071	0.061
WC*	0.015	0.004–0.027	0.009
WHR *Z* score*	−0.099	−0.284 to 0.085	0.291
IL-6	*β*	95% CI	*P*-value
ABSI *Z* score*	0.022	0.009–0.047	0.001
BRI*	0.042	0.006–0.072	0.015
BMI†	0.029	0.008–0.051	0.256
WC*	0.019	0.010–0.033	0.05
WHR *Z* score*	0.141	0.111–0.392	0.272

ABSI, a body shape index; BMI, body mass index; BRI, body roundness index; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HDL-C, high-density lipoprotein cholesterol; hs-CRP, high-sensitivity C reactive protein; IL, interleukin; SBP, systolic blood pressure; TG, triacylglycerol; TNF, tumor necrosis factor; UA, uric acid; WC, waist circumference; WHR, waist-to-hip ratio

* Adjusted for sex, age, UA, FPG, fasting insulin, smoking, drinking, TG, HDL-C, SBP, DBP, BMI, and abdominal circumference.

† Adjusted for sex, age, UA, FPG, fasting insulin, smoking, drinking, TG, HDL-C, SBP, DBP, and abdominal circumference.

new anthropometric index is completely independent of BMI or WC, and it may be affected by the ability to predict risk.

In the US population, ABSI is able to predict all-cause mortality independent of BMI. The predictive power of ABSI for all-cause mortality differs among ethnicities, with less predictive power in Latinos than whites and blacks [11]. Other studies have shown that ABSI is associated with the progression of diabetes and hypertension; however, the predictive power is not superior to WC and BMI [26]. Compared with BMI or WC, the ABSI is not a better predictor of diabetes, hypertension, and dyslipidemia in Japanese adults [15]. A small prospective study of Chinese adults showed that ABSI is not superior to WC or BMI in predicting diabetes as a primary endpoint [25]. In the present study, after adjusted for anthropometric indices, socioeconomic status, and lifestyle, ABSI is significantly associated with MetS and IR. However, clinical characteristic and biochemical measurements as confusing factors were adjusted in the logistic regression model, ABSI didn't show any association with MetS and IR in the overweight and obese populations.

Table 5
MetS and IR incidence and ORs according to the quintiles of ABSI, BRI, BMI, WC, and WHR

MetS Quintile	ABSI *Z* score OR (95% CI)	BRI OR (95% CI)	BMI OR (95% CI)	WC OR (95% CI)	WHR *Z* score OR (95% CI)
1	1	1	1	1	1
2	1.220 (0.776–2.727)*	4.244 (2.351–7.662)†	1.442 (0.669–3.107)*	2.788 (1.231–6.315)‡	0.679 (0.396–1.163)*
3	1.355 (0.698–.3032) §	5.430 (3.037–9.706)†	1.748 (1.032–2.962)‡	3.269 (1.620–6.598)‡	0.843 (0.450–1.579)*
4	1.990 (0.835–4.260)*	5.778 (2.954–11.303)†	2.382 (1.340–4.236)‡	3.335 (1.049–10.602)‡	0.446 (0.195–1.021)*
IR Quintile	ABSI *Z* scoRE OR (95% CI)	BRI OR (95% CI)	BMI OR (95% CI)	WC OR (95% CI)	WHR *Z* score OR (95% CI)
1	1	1	1	1	1
2	1.042 (0.667–2.699)*	1.754 (0.824–3.735)*	1.919 (0.943–3.902)*	1.986 (1.060–3.720)‡	0.792 (0.438–1.432)*
3	1.427 (0.828–3.109)*	2.481 (1.236–4.981)‡	2.197 (1.107–4.362)‡	2.250 (1.217–4.162)‡	0.301 (0.131–0.693)†
4	1.506 (0.895–3.521)*	6.212 (2.912–13.250)†	4.119 (1.784–9.512)†	5.201 (2.553–10.596)†	0.285 (0.142–0.572)‡

ABSI, a body shape index; BMI, body mass index; BRI, body roundness index; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HDL-C, high-density lipoprotein cholesterol; MetS, metabolic syndrome; SBP, systolic blood pressure; TG, triacylglycerol; UA, uric acid; WC, waist circumference; WHR, waits-to-hit ratio

Adjusted for sex, age, UA, FPG, fasting insulin, smoking, drinking, TG, HDL-C, SBP, DBP, and abdominal circumference

* $P > 0.05$.

† $P < 0.01$.

‡ $P < 0.05$.

Morphometric measures and physiologic racial differences may be major factors influencing the ABSI predictive power. The obesity type of Asians is different from Europeans and Americans, thus there is a difference with the WC, even when the BMI is equal. Moreover, the average height of the Asian population is significantly lower than Americans and Europeans, and this may also confuse the predictive power of the ABSI. Meanwhile, according to the partial Spearman correlation analysis, ABSI didn't show a significant correlation with blood pressure and blood lipids. Additionally, although BMI was included in the ABSI computational formula, there was no significant correlation between ABSI and BMI. BMI and lipids were widely accepted as markers to assess the risk for CVD and MetS. ABSI was not correlated with them in overweight and obese populations. This also may affect its predictive power.

The BRI was developed to predict both body fat and the percentage of VAT by using the WC in relation to height, which estimates the shape of the human figure as an ellipse or oval [16]. As Thomas et al. [16] pointed out, the advantage of BRI exceed WRH because BRI can improve the predictive power of body fat and VAT, thus better reflecting health status as a function of the body. The association between VAT, MetS, and IR is well known [27]. BRI was strongly correlated with WC in our participants. BRI was negatively related to height after adjusting for sex and age. Thus, when WC is fixed, the height is shorter, and the BRI is greater, body shape is more like an ellipse. An ellipse or centrally obese body shape significantly increased metabolic and CVD risk. After adjusted the effects of age and sex, BRI had a significant correlation with TG, HDL-C, LDL-C, blood pressure, FPG, and inflammatory factors. Moreover, after adjusted for socioeconomic status, lifestyle, anthropometric indices, clinical characteristics, and biochemical measurements, BRI still showed an association with MetS and IR. Although BMI was not included in the BRI computational formula, BRI was strongly correlated with BMI. BRI is superior to BMI predicting the risk for MetS and IR in overweight and obese populations. It may be due to BRI improved the prediction of VAT.

Obesity is a mild inflammatory state. A number of studies have suggested that chronic inflammation is part of the IR syndrome [18]. Excessive IL-6 and TNF-α are secreted by adipocytes and then promote CRP synthesis in the liver [28]. CRP can be considered as a remarkable inflammatory factor of MetS and IR [18]. In previous studies, some anthropometric indices also indicated an association with inflammatory factors [28]. Although the ABSI is not significantly associated with MetS and IR, the ABSI can be used to measure the levels of inflammation in obese and overweight people, especially the CRP level. BRI and WC have this predictive ability, also.

Limitations

One might argue that the cross-sectional nature of this study was suboptimal to study the predictive capacity of anthropometric characteristics; however, in our study design we demonstrated that BRI and WC were able to identify the presence of MetS and IR. Our findings represent the first step in validating the BRI in relation to metabolic risk, and therefore we believe that the method is appropriate. One shortcoming of this cross-sectional study is without having a control group of normal body weight. Additionally, our study was conducted on urban populations in central China, whose unique lifestyle influences both body shape and metabolic indices. In future studies, the longitudinal relationship between these two new anthropometric indices and metabolic disease should be studied.

Conclusion

Only BRI and WC, not ABSI, can significantly determine the presence of MetS and IR in overweight and obese populations. BRI showed the optimal capability to identify IR in both sexes compared with WC and WHR. Although the ABSI had a limited association with inflammatory factors, ABSI is not suitable for determining the prevalence of MetS and IR.

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References

[1] Flegal KM, Kit BK, Orpana H, Graubard BI. Association of all-cause mortality with overweight and obesity using standard body mass index categories: a systematic review and meta-analysis. JAMA 2013;30:71–82.
[2] Flegal KM, Graubard BI, Williamson DF, Gail MH. Excess deaths associated with underweight, overweight, and obesity. JAMA 2005;29:1861–7.
[3] Allison DB, Fontaine KR, Manson JE, Stevens J, Vanltallie TB. Annual deaths attributable to obesity in the United States. JAMA 1999;28:1530–8.
[4] Nevill AM, Stewart AD, Olds T, Holder R. Relationship between adiposity and body size reveals limitations of BMI. Am J Phys Anthropol 2006;129:151–6.
[5] Gómez-Ambrosi J, Silva C, Galofré JC, Escalada J, Santos S, Millán D, et al. Body mass index classification misses subjects with increased cardiometabolic risk factors related to elevated adiposity. Int J Obes 2012;36:286.
[6] Ruhl CE, Everhart JE. Trunk fat is associated with increased serum levels of alanine aminotransferase in the United States. Gastroenterology 2010;138:1346–56. e3.
[7] Taylor RW, Jones IE, Williams SM, Goulding A. Evaluation of waist circumference, waist-to-hip ratio, and the conicity index as screening tools for high trunk fat mass, as measured by dual-energy X-ray absorptiometry, in children aged 3–19 y. Am J Clin Nutr 2000;72:490–5.
[8] Klein S, Allison DB, Heymsfield SB, Kelley DE, Leibel RL, Nonas C, et al. Waist circumference and cardiometabolic risk: a consensus statement from shaping America's health: Association for Weight Management and Obesity Prevention; NAASO, the Obesity Society; the American Society for Nutrition; and the American Diabetes Association. Obesity 2007;15:1061–7.
[9] Jacobs EJ, Newton CC, Wang Y, Patel AV, McCullough ML, Campbell PT, et al. Waist circumference and all-cause mortality in a large US cohort. Arch Intern Med 2010;170:1293–301.
[10] Czernichow S, Kengne AP, Stamatakis E, Hamer M, Batty GD. Body mass index, waist circumference and waist–hip ratio: which is the better discriminator of cardiovascular disease mortality risk? Evidence from an individual–participant meta–analysis of 82 864 participants from nine cohort studies. Obes Rev 2011;12:680–7.
[11] Krakauer NY, Krakauer JC. A new body shape index predicts mortality hazard independently of body mass index. PLoS One 2012;7:E39504.
[12] Krakauer NY, Krakauer JC. Dynamic association of mortality hazard with body shape. PLoS One 2014;9:E88793.
[13] He S, Chen X. Could the new body shape index predict the new onset of diabetes mellitus in the Chinese population? PLoS One 2013;8:E50573.
[14] Duncan MJ, Mota J, Vale S, Santos MP, Ribeiro JC. Associations between body mass index, waist circumference and body shape index with resting blood pressure in Portuguese adolescents. Ann Hum Biol 2013;40:163–7.
[15] Fujita M, Sato Y, Nagashima K, Takahashi S, Hata A. Predictive power of a body shape index for development of diabetes, hypertension, and dyslipidemia in Japanese adults: a retrospective cohort study. PLoS One 2015;10: E0128972.
[16] Thomas DM, Bredlau C, Bosy–Westphal A, Mueller M, Shen W, Gallagher D, et al. Relationships between body roundness with body fat and visceral adipose tissue emerging from a new geometrical model. Obesity 2013;21:2264–71.
[17] Maessen MFH, Eijsvogels TMH, Verheggen RJHM, Hopman MTE, Verbeek ALM, de Vegt F. Entering a new era of body indices: the feasibility of a body shape index and body roundness index to identify cardiovascular health status. PLoS One 2014;9:E107212.
[18] Xu H, Barnes GT, Yang Q, Tan G, Yang D, Chou CJ, et al. Chronic inflammation in fat plays a crucial role in the development of obesity-related insulin resistance. J Clin Invest 2003;112:1821.
[19] Dandona P, Aljada A, Bandyopadhyay A. Inflammation: the link between insulin resistance, obesity and diabetes. Trends Immunol 2004;25:4–7.
[20] Bastard J P, Maachi M, Lagathu C, Kim MJ, Caron M, Vidal H, et al. Recent advances in the relationship between obesity, inflammation, and insulin resistance. Eur Cytokine Netw 2006;17:4–12.

[21] Zhou BF. Predictive values of body mass index and waist circumference for risk factors of certain related diseases in Chinese adults—study on optimal cut-off points of body mass index and waist circumference in Chinese adults. Biomed Environ Sci 2002;15:83–96.
[22] Ng SW, Norton EC, Popkin BM. Why have physical activity levels declined among Chinese adults? Findings from the 1991–2006 China Health and Nutrition Surveys. Soc Sci Med 2009;68:1305–14.
[23] Alberti KGMM, Zimmet P, Shaw J. Metabolic syndrome—a new world-wide definition. A consensus statement from the international diabetes federation. Diabet Med 2006;23:469–80.
[24] Bonora E, Targher G, Alberiche M, Bonadonna RC, Saggiana F, Zenere MB, et al. Homeostasis model assessment closely mirrors the glucose clamp technique in the assessment of insulin sensitivity: studies in subjects with various degrees of glucose tolerance and insulin sensitivity. Diabetes care 2000;23:57–63.
[25] Dhana K, Kavousi M, Ikram MA, Tiemeier HW, Hofman A, Franco OH. Body shape index in comparison with other anthropometric measures in prediction of total and cause-specific mortality. J Epidemiol Community Health 2016;70:90–6.
[26] Cheung YB. "A Body Shape Index" in middle-age and older Indonesian population: scaling exponents and association with incident hypertension. PLoS One 2014;9:E85421.
[27] Wajchenberg BL. Subcutaneous and visceral adipose tissue: their relation to the metabolic syndrome. Endocr Rev 2000;21:697–738.
[28] Park HS, Park JY, Yu R. Relationship of obesity and visceral adiposity with serum concentrations of CRP, TNF-α and IL-6. Diabetes Res Clin Pract 2005;69:29–35.