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Feasibility of body roundness index for identifying a clustering of cardiometabolic abnormalities compared to BMI, waist circumference and other anthropometric indices: the China Health and Nutrition Survey, 2008 to 2009

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Abstract

The body mass index (BMI) and waist circumference (WC) are commonly used anthropometric measures for predicting cardiovascular diseases risk factors, but it is uncertain which specific measure might be the most appropriate predictor of a cluster of cardiometabolic abnormalities (CMA) in Chinese adults. A body shape index (ABSI) and body roundness index (BRI) have been recently developed as alternative anthropometric indices that may better reflect health status. The main aims of this study were to investigate the predictive capacity of ABSI and BRI in identifying various CMA compared to BMI, WC, waist-to-hip ratio (WHpR), and waist-to-height ratio (WHtR), and to determine whether there exists a best single predictor of all CMA.

We used data from the 2009 wave of the China Health and Nutrition Survey, and the final analysis included 8126 adults aged 18 to 85 years with available fasting blood samples and anthropometric measurements. Receiver-operating characteristic (ROC) analyses were conducted to assess the best anthropometric indices to predict the risk of hypertension, diabetes, dyslipidemia, hyperuricemia, and metabolic syndrome (MetS). Logistic regression models were fit to evaluate the OR of each CMA according to anthropometric indices.

In women, the ROC analysis showed that BRI and WHtR had the best predictive capability in identifying all of CMA (area under the curves [AUCs] ranged from 0.658 to 0.721). In men, BRI and WHtR were better predictor of hypertension, diabetes, and at least 1 CMA (AUC: 0.668, 0.708, and 0.698, respectively), whereas BMI and WC were more sensitive predictor of dyslipidemia, hyperuricemia, and MetS. Furthermore, the ABSI showed the lowest AUCs for each CMA. According to the multivariate logistic regression analysis, BRI and WHtR were superior in discriminating hyperuricemia and at least 1 CMA while BMI performed better in predicting hypertension, diabetes, and MetS in women. In men, WC and BRI were the 2 best predictor of all CMA except MetS, and the ABSI was the worst.

Our results showed the novel index BRI could be used as a single suitable anthropometric measure in simultaneously identifying a cluster of CMA compared to BMI and WHtR, especially in Chinese women, whereas the ABSI showed the weakest discriminative power.

Abbreviations: ABSI = a body shape index, AUROC = area under the ROC curve, BMI = body mass index, BRI = body roundness index, CHNS= China Health and Nutrition Survey, CI = confidence interval, CMA = cardiometabolic abnormalities, CVD = cardiovascular diseases, HDL = high density lipoprotein, MetS = metabolic syndrome, OR = odds ratio, ROC= receiver-operating characteristic, WC = waist circumference, WHpR = waist-to-hip ratio, WHtR = waist-to-height ratio.

Keywords: anthropometric indices, body roundness index, cardiometabolic abnormalities, discriminative ability, the China Health and Nutrition Survey

1. Introduction

Obesity is increasing worldwide and becomes one of the most prevalent conditions with significant impact on public health.[1,2] Recent global report estimated that the number of overweight and obesity has risen up to 2.1 billion adults in 2013, and within the adult group approximately 36.9% were classified as overweight or obese.[3] Nowadays obesity is recognized as the main cause of a great number of diseases including hypertension,[4] type 2 diabetes,[5] metabolic syndrome (MetS),[6,7] and cardiovascular diseases (CVDs),[2,8,9] and it also plays an important indirect role in some cancers.[10,11] Accordingly, precise criteria and early diagnosis of obesity are of special importance in medical practice for preventing health risk.

Body mass index (BMI) is the most commonly recommended and used anthropometric measure to classify general obesity in clinical and epidemiological studies.[12] Indeed, the strong association of an increase in BMI with CVD and MetS has been well documented; therefore, the BMI is shown to be a risk factor

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for various cardiovascular and metabolic disorders.[13] However, the discriminative capacity of BMI has been criticized because it cannot distinguish muscle mass from fat mass, or reflect fat distribution.[14] Alternatively, abdominal obesity indices, such as waist circumference (WC) and waist-to-height ratio (WHtR), have been suggested to be better predictor of cardiometabolic abnormalities (CMA) because they modulate the limitation of BMI. A significant number of published studies have emphasized the superiority of abdominal obesity indices over BMI in identifying cardiometabolic disturbances, especially in Asians.[15–18] Still, controversy remains over which anthropometric indices convey the highest risk of different CVD risk factors, such as hypertension or diabetes, and MetS. Some have found that BMI was more strongly associated with hypertension than WC or WHtR in Asian,[19,20] and this finding is recently confirmed by longitudinal study in Japan.[21] However, other meta-analysis have found that WHtR exhibited a better predictive power than BMI in detecting several cardiometabolic risk factors.[22,23] The conflicting data have led to explore novel anthropometric indices by combining traditional measures.

In 2012, Krakauer and Krakauer[24] developed a body shape index (ABSI) that standardized WC for BMI and height. The authors have claimed that an increase in ABSI is associated with a greater fraction of abdominal adipose tissue, and that the ABSI appears to be a significant risk factor over WC or BMI for predicting premature death. Furthermore, subsequent cohort studies have also showed that the ABSI was a relevant predictor of onset of diabetes[25] or mortality.[26] In 2013, Thomas et al[27] developed the body roundness index (BRI), which combines height and WC to predict percentage of body fat and to evaluate health status. Up to date, only a few studies investigated whether ABSI and BRI could be suitable predictor for identifying CVD risk factors or MetS. Maessen et al[28] were the 1st to assess predictive capability of ABSI and BRI for both CVD and CVD risk factors, and the BRI was not superior to BMI or WC in this regard. A very recent population-based study with northern Chinese respectively demonstrated a relevant predictive ability of the BRI and poor predictive ability of the ABSI for predicting diabetes when compared with BMI, WC, or WHtR.[29] However, it is unclear whether the ABSI and BRI are better predictors than BMI, WC, or WHtR in identifying other CMA, such as hypertension, dyslipidemia, hyperuricemia, or MetS in the Chinese population, and within the studied population whether there exists one particular anthropometric index could simultaneously provide appropriate predictive capabilities for a cluster of CMA.

Thus, this study was undertaken and aimed at investigating the predictive capacity of these 2 new anthropometric indices to discriminate individuals at a higher risk of hypertension, diabetes, dyslipidemia, hyperuricemia, and MetS from a nationally representative Chinese sample. We also attempted to determine whether there exists a best single predictor of all CMA by comparing the ability of the ABSI and BRI and various other anthropometric indices (BMI, WC, WHtR, and waist-to-hip ratio [WHpR]).

2. Methods

2.1. Study population

All the data analyzed in the present study were obtained from the 2009 wave of the China Health and Nutrition Survey (CHNS). The CHNS is a large-scale longitudinal, household-based ongoing survey designed to represent a set of large provinces with a range of socio-economic variation and to examine the effects of the health nutrition. The comprehensive description and the sampling procedures regarding the survey have been published elsewhere.[30] In brief, starting in 1989, this survey used a multistage, random cluster process to select households from 9 of the 31 mainland provinces, the original and new household members have been longitudinally assessed. The fasting blood, glycated hemoglobin, and other biomakers from participants aged ≥7 years were collected for the 1st time in 2009. Survey protocols, instruments, and the process for obtaining informed consent for this study were approved by the institutional review committees of the University of North Carolina at Chapel Hill, the National Institute of Nutrition and Food Safety, Chinese Center for Disease Control and Prevention, and the China-Japan Friendship Hospital, Ministry of Health. Among the 11,929 participants in the 2009 wave of the CHNS, 3776 men and 4350 women aged 18 to 85 years with available anthropometric measures and fasting blood sample information were included in the present study (as shown in Fig. 1).

2.2. Anthropometric measurements

Anthropometric indices were measured by well-trained examiners using standardized procedures. Body weight and height were taken with participants in barefoot and light clothing, and measured to the nearest 0.1 kg and 0.1 cm, respectively. Waist circumference was measured midway between the lowest rib and the iliac crest with a flexible anthropometric tape on the horizontal plane with the participant in standing position. Hip circumference was measured over thin clothing at the point of maximum circumference of the buttocks. Both circumferences were measured to the nearest 0.1 cm. BMI was calculated as

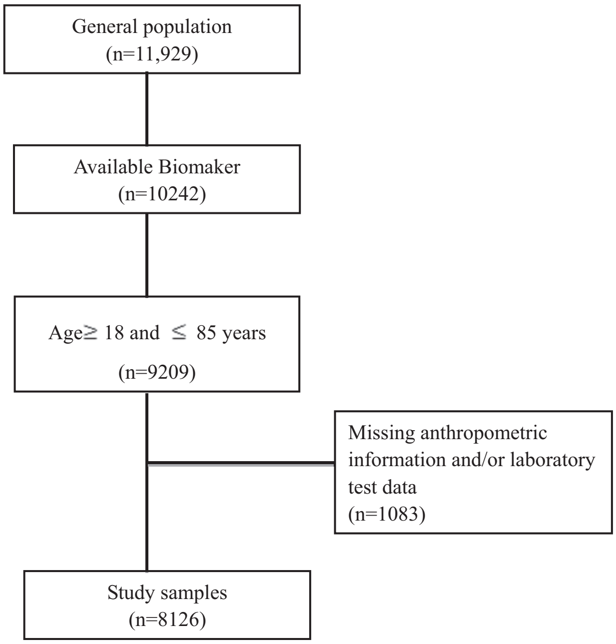

Figure 1. Flow chart of the participant selection process. A total of 11,929 individuals were recruited from the 2009 wave of the China Health and Nutrition Survey (CHNS). Of the 10,242 individuals participating laboratory test, 9209 adults aged ≥18 and ≤85 years, 1083 adults had missing data on laboratory test and/or anthropometric information, and as result was excluded. The final sample size was 8126 adults, which consisted of 3776 men and 4350 women.

weight (kg) divided by the square of the height (m). WHtR was calculated as WC (cm) divided by the height (cm), WHpR was calculated as WC (cm) divided by hip circumference (cm). ABSI was calculated using the following formula[24]:

$$\mathrm{ABSI} = \frac{\mathrm{WC}}{\mathrm{BMI}^2\ \mathrm{height}^{1/2}}$$

BRI was calculated using the formula[27]:

$$\mathrm{BRI} = 364.2 - 365.5 \times \sqrt{1 - \left(\frac{(\mathrm{WC}/(2\pi))^2}{(0.5\ \mathrm{height})^2}\right)}.$$

Systolic and diastolic blood pressures were measured on the right arm, using mercury sphygmomanometers. Measures were collected in triplicate after a 10 minute seated rest and the mean of the 3 measurements was used in analyses.

2.3. Serum analysis

A fasting blood sample was collected for each participant by following a standardized process, and then was analyzed in a national central clinical laboratory in Beijing. Serum levels of fasting plasma glucose, total cholesterol and high-density lipoprotein (HDL)-cholesterol concentrations, triglyceride, and uric acid were measured by a biochemical autoanalyzer. Details of laboratory analysis were reported in "CHNS, Manual for Specimen Collection and Processing" (http://www.cpc.unc.edu/projects/china/data/datasets/Blood%20Collection%20Protocol_English.pdf) and "A list of biomarkers and methods used to measure them" (http://www.cpc.unc.edu/projects/china/data/datasets/Biomarker_Methods.pdf).

2.4. Definition of cardiometabolic abnormalities

CMA in the present study included hypertension, diabetes, MetS, dyslipidemia, and hyperuricemia. According to the criteria recommended by the Working Group on Obesity in China,[31] hypertension was defined as a systolic blood pressure of ≥140 mm Hg, or a diastolic blood pressure of ≥90 mm Hg, or self-reported use of antihypertensive medication. Diabetes was defined as fasting plasma glucose of ≥7.0 mmol/L, or treatment for diabetes. Based on National Cholesterol Education Project guidelines,[32] dyslipidemia was defined as low-density lipoprotein cholesterol ≥4.14 mmol/L, HDL-cholesterol ≤1.036 mmol/L, and triglycerides ≥2.26 mmol/L. Hyperuricemia was defined when uric acid (UA) ≥420 for males and ≥350 for females.

The present study followed the harmonized criteria,[33,34] subjects were diagnosed as having MetS if they had at least 3 of the following factors: WC ≥102 cm in men or ≥88 cm in women; triglycerides >1.7 mmol/L; reduced HDL-cholesterol <1.0 mmol/L in men or <1.3 mmol/L in women; blood pressure ≥130/85 mm Hg; and fasting plasma glucose ≥5.6 mmol/L.

2.5. Statistical analyses

The analysis for male and female groups was considered separately because human body shape differs according to gender. The characteristics of the study population were presented as means ± standard deviations for continuous variables or percentages for categorical variables. Comparisons between men and women groups were conducted using Students *t* test for continuous variables and the χ^2 test for categorical variables. Receiver-operating characteristic (ROC) analyses were performed to examine diagnostic ability of obesity indices for various CMA risk. The area under the ROC curve (AUROC) and the 95% confidence intervals (CIs) were computed to compare the discriminative power of each anthropometric index. The AUROC is a measure of accuracy to evaluate discriminative power between subjects with or without CMA. For the correlation analysis between anthropometric indices and CVD risk factors, partial correlation coefficient was used by adjusting age and gender.[35] The odds ratios (ORs) and their 95% CIs for the presence of CMA were compared using the highest to the lowest quartile of each anthropometric index and were calculated by logistic regression models by controlling age, smoking, and alcohol status. All statistical analyses involved were conducted with R version 3.1.1 software (R Foundation for Statistical Computing, Vienna, Austria),[36] and *P*-value < 0.05 was considered statistically significant.

3. Results

The characteristics of study population according to gender are summarized in Table 1. Men and women had similar BMI, WHtR, WHpR, and ABSI values. Men tended to have higher WC, while women had higher BRI value. In addition, men were more likely to have higher fasting glucose concentrations, higher

Table 1

Characteristics of the adult study population.

	Men n = 3776	Women n = 4350
Age, year	50.69 ± 14.9	50.51 ± 14.74
Alcohol drinker, n, %	2266 (60.0%)	377 (8.8%)
Smokers, n, %	2332 (61.8%)	174 (4.0%)
Anthropometric measures		
Height, cm	167.96 ± 6.67	156.87 ± 6.39
Weight, kg	65.19 ± 11.26	56.90 ± 9.61
BMI, kg/m^2	23.32 ± 3.39	23.38 ± 3.49
WC, cm	84.31 ± 10.16	81.2 ± 10.18
Hip circumference, cm	94.7 ± 7.65	94.26 ± 7.98
WHpR	0.89 ± 0.07	0.86 ± 0.08
WHtR	0.51 ± 0.06	0.52 ± 0.07
BRI	3.52 ± 1.13	3.86 ± 1.36
ABSI, $m^{11/6}kg^{-2/3}$	0.0801 ± 0.0057	0.0798 ± 0.0066
Biochemical indicators		
HDL-C, mmol/L	1.39 ± 0.51	1.48 ± 0.44
LDL-C, mmol/L	2.92 ± 0.96	3.03 ± 0.99
DBP, mm Hg	82.06 ± 11.08	79.1 ± 11.41
SBP, mm Hg	125.98 ± 17.55	123.55 ± 20.17
FPG, mmol/L	5.47 ± 1.62	5.33 ± 1.3
TC, mmol/L	4.81 ± 0.97	4.9 ± 1.03
Triglycerides, mmol/L	1.79 ± 1.68	1.56 ± 1.23
Uric acid, mmol/L	354.72 ± 111.73	266.21 ± 79.69
CMA		
Hypertension, n, %	1218 (32.3%)*	1207 (27.7%)
Diabetes, n, %	338 (9%)*	285 (6.6%)
MetS, n, %	1391 (36.8%)	1547 (35.6%)
Dyslipidemia, n, %	1397 (37%)*	1361 (31.3%)
Hyperuricemia, n, %	755 (20%)*	560 (12.9%)
At least 1 CMA, n, %	2303 (61%)*	2187 (50.3%)

Proportion value of each CMA of men was significantly different from that of women. *$P < 0.05$.
ABSI = a body shape index, BMI = body mass index, BRI = body roundness index, CMA = cardiometabolic abnormalities, DBP = diastolic blood pressure, FPG = fasting plasma glucose, HDL-C = high-density lipoprotein cholesterol, LDL-C = low-density lipoprotein cholesterol, MetS = metabolic syndrome, SBP = systolic blood pressure, TC = total cholesterol, WC = waist circumference, WHpR = waist-to-hip ratio, WHtR = waist-to-height ratio.

Table 2

The AUCs of each anthropometric index for the presence of CMA in both genders.

	Hypertension	Diabetes	MetS	Dyslipidemia	Hyperuricemia	At least 1 CMA
Men						
BMI	0.639 (0.62,0.658)	0.663 (0.633,0.693)	**0.717 (0.7,0.734)**	**0.69 (0.673,0.708)**	**0.648 (0.626,0.669)**	0.688 (0.671,0.705)
WC	0.662 (0.643,0.68)	0.697 (0.669,0.726)	0.712 (0.695,0.729)	0.683 (0.665,0.7)	0.64 (0.619,0.662)	0.697 (0.68,0.714)
WHpR	0.638 (0.619,0.657)	0.685 (0.657,0.713)	0.672 (0.654,0.689)	0.654 (0.636,0.672)	0.617 (0.596,0.638)	0.673 (0.656,0.691)
WHtR	**0.668 (0.65,0.687)**	**0.708 (0.679,0.736)**	0.71 (0.693,0.727)	0.674 (0.656,0.691)	0.637 (0.616,0.658)	**0.698 (0.681,0.715)**
ABSI	0.597 (0.578,0.616)	0.635 (0.605,0.666)	0.572 (0.553,0.591)	0.551 (0.532,0.57)	0.541 (0.518,0.563)	0.59 (0.571,0.609)
BRI	**0.668 (0.65,0.687)**	**0.708 (0.679,0.736)**	0.71 (0.693,0.727)	0.674 (0.656,0.691)	0.637 (0.616,0.658)	**0.698 (0.681,0.715)**
Women						
BMI	0.667 (0.649,0.686)	0.661 (0.629,0.694)	0.692 (0.675,0.708)	0.66 (0.643,0.678)	0.633 (0.607,0.658)	0.675 (0.659,0.691)
WC	0.698 (0.681,0.715)	0.697 (0.665,0.728)	0.699 (0.683,0.715)	0.671 (0.654,0.688)	0.643 (0.619,0.667)	0.705 (0.69,0.721)
WHpR	0.656 (0.639,0.674)	0.677 (0.646,0.707)	0.657 (0.641,0.674)	0.649 (0.632,0.666)	0.626 (0.602,0.65)	0.678 (0.662,0.694)
WHtR	**0.714 (0.698,0.73)**	**0.702 (0.671,0.733)**	**0.703 (0.687,0.719)**	**0.676 (0.659,0.692)**	**0.658 (0.635,0.682)**	**0.721 (0.707,0.736)**
ABSI	0.628 (0.61,0.646)	0.631 (0.599,0.664)	0.586 (0.569,0.604)	0.584 (0.566,0.602)	0.58 (0.556,0.605)	0.63 (0.613,0.646)
BRI	**0.714 (0.698,0.73)**	**0.702 (0.671,0.733)**	**0.703 (0.687,0.719)**	**0.676 (0.659,0.692)**	**0.658 (0.635,0.682)**	**0.721 (0.707,0.736)**

Values are AUC (95% CI). The bold indicates the highest value of AUC value among the anthropometric indices. ABSI = a body shape index, AUC = area under the curve, BMI = body mass index, BRI = body roundness index, CI = confidence interval, CMA = cardiometabolic abnormalities, MetS = metabolic syndrome, WC = waist circumference, WHpR = waist-to-hip ratio, WHtR = waist-to-height ratio.

blood pressure values, and more adverse lipid profiles when compared with women. Men had significantly higher prevalence of hypertension (32.3% vs 27.7%), diabetes (9.0% vs 6.6%), dyslipidemia (37.0% vs 31.3%), hyperuricemia (20.0% vs 12.9%), and at least 1 CMA (61.0% vs 50.3%) than women (all $P < 0.05$), except MetS (37.9% vs 33.6%).

ROC curves are shown in Figs. 2 and 3, and the corresponding AUROC for anthropometric indices related to CMA are given in Table 2. The AUROC for BMI ranged between 0.639 and 0.717 kg/m^2 for men and between 0.633 and 0.692 kg/m^2 for women. The AUROC for WC ranged between 0.640 and 0.712 cm for men and between 0.643 and 0.705 cm for women. The AUROC for WHpR ranged between 0.617 and 0.685 for men and between 0.626 and 0.678 for women. The AUROC for WHtR and BRI ranged between 0.637 and 0.710 for men and between 0.658 and 0.721 for women. The AUROC for ABSI ranged between 0.541 and 0.635 m$^{11/6}$kg$^{-2/3}$ for men and between 0.580 and 0.631 m$^{11/6}$kg$^{-2/3}$ for women. Overall in women, BRI and WHtR had the highest AUROC values; thus, these 2 indices were the best predictor of all CMA, followed by WC, BMI, and WHpR. In men, no single index had a consistently higher AUROC value than the others. However, BRI and WHtR demonstrated better predictive abilities in identifying hypertension (0.668), diabetes (0.708), and at least 1 CMA (0.698), whereas BMI and WC were the 2 best predictor of MetS (0.717 vs 0.712), dyslipidemia (0.690 vs 0.683), and hyperuricemia (0.648 vs 0.640). For these 3 CMA, BRI exhibited a competitive discriminative power compared with BMI and WC. Additionally, the ABSI had substantially lower AUROC values than other indices regardless of genders, demonstrating the weakest predictive ability for CVD risk factors and MetS (Table 2). The optimal cut-off value, sensitivity, specificity, positive, and negative predictive values for each anthropometric index in ROC analysis for predicting those health outcomes was shown in Supplemental Table S1 and Table S2, http://links.lww.com/MD/B219.

Table 3 shows the results of Spearman rank test of anthropometric indices and CMA after adjusting gender and age. Overall BMI, WC, WHtR, and BRI consistently showed highest Spearman partial correlation coefficient for all risks (r = 0.23, 0.15, 0.33, 0.28, 0.17, and 0.3 for hypertension, diabetes, MetS, dyslipidemia, hyperuricemia, and at least 1 CMA, respectively, $P < 0.001$), whereas the ABSI showed the lowest for each risk.

We classified the subjects into quartiles according to each anthropometric index. The category boundaries were shown in Table S3, http://links.lww.com/MD/B219. Multivariate-adjusted ORs for CMA in the highest (vs the lowest) quartile of each anthropometric index are shown in Table 4. In women, BRI and WHtR were the best predictor of hyperuricemia and at least 1 CMA with the corresponding ORs of 3.37 (95% CI 2.44–4.65) for hyperuricemia and 4.92 (95% CI 4.00–6.05) for at least 1 CMA, respectively, whereas BMI demonstrated highest OR value for hypertension (OR 5.02, 95% CI 3.97–6.34), diabetes (OR 4.40, 95% CI 2.89–6.71), and MetS (OR 5.70, 95% CI 4.64–7.01). WC showed the highest OR value for dyslipidemia and the corresponding OR in the highest (vs lowest) quartile of WC were 4.65 (95% CI 3.73–5.80). In men, WC was the best

Table 3

Partial correlation coefficients (adjusted for age and gender) between anthropometric indices and CMA.

	Hypertension	Diabetes	MetS	Dyslipidemia	Hyperuricemia	At least 1 CMA
BMI	0.23	0.14	0.33	0.28	0.17	0.3
WC	0.23	0.15	0.31	0.28	0.17	0.3
WHpR	0.15	0.13	0.22	0.23	0.14	0.24
WHtR	0.21	0.15	0.3	0.27	0.17	0.3
ABSI	0.06	0.07	0.06	0.09	0.05	0.1
BRI	0.21	0.15	0.3	0.27	0.17	0.3

All correlation coefficients had P-value < 0.001. ABSI = a body shape index, BMI = body mass index, BRI = body roundness index, CMA = cardiometabolic abnormalities, MetS = metabolic syndrome, WC = waist circumference, WHpR = waist-to-hip ratio, WHtR = waist-to-height ratio.

Table 4

OR (95% CI) of the presence of CMA for the highest quartile versus the lowest quartile of anthropometric index.

	Hypertension	Diabetes	MetS	Dyslipidemia	Hyperuricemia	At least 1 CMA
Men						
BMI	4.53 (3.62,5.65)	4.79 (3.29,6.98)	**9.22 (7.35,11.56)**	6.48 (5.24,8.02)	3.78 (2.94,4.85)	6.58 (5.32,8.14)
WC	**4.67 (3.74,5.83)**	**6.48 (4.26,9.86)**	8.06 (6.46,10.05)	**6.71 (5.4,8.33)**	**4.5 (3.44,5.88)**	**7.08 (5.73,8.75)**
WHpR	2.94 (2.38,3.64)	4.8 (3.23,7.13)	5.11 (4.15,6.3)	4.84 (3.93,5.96)	3.34 (2.57,4.32)	4.56 (3.72,5.6)
WHtR	3.87 (3.11,4.82)	6.28 (4.15,9.5)	7.53 (6.03,9.39)	6.47 (5.2,8.04)	4.05 (3.12,5.26)	6.19 (5,7.65)
ABSI	1.48 (1.19,1.83)	2.67 (1.86,3.83)	1.63 (1.33,1.99)	1.82 (1.49,2.22)	1.48 (1.17,1.89)	1.76 (1.45,2.14)
BRI	3.87 (3.11,4.82)	6.28 (4.15,9.5)	7.53 (6.03,9.39)	6.47 (5.2,8.04)	4.05 (3.12,5.26)	6.19 (5,7.65)
Women						
BMI	**5.02 (3.97,6.34)**	**4.4 (2.89,6.71)**	**5.7 (4.64,7.01)**	4.33 (3.53,5.32)	3 (2.28,3.95)	4.74 (3.89,5.78)
WC	4.32 (3.38,5.52)	3.5 (2.28,5.37)	4.79 (3.88,5.91)	**4.65 (3.73,5.8)**	2.49 (1.86,3.32)	4.83 (3.94,5.91)
WHpR	2.24 (1.78,2.82)	3.48 (2.2,5.5)	3.4 (2.77,4.19)	3.52 (2.85,4.35)	2.28 (1.7,3.06)	3.33 (2.74,4.06)
WHtR	4 (3.11,5.15)	3.09 (1.99,4.79)	4.74 (3.82,5.88)	4.39 (3.52,5.48)	**3.37 (2.44,4.65)**	**4.92 (4,6.05)**
ABSI	1.42 (1.13,1.79)	1.71 (1.14,2.57)	1.3 (1.06,1.6)	1.62 (1.32,1.99)	1.27 (0.95,1.69)	1.71 (1.4,2.08)
BRI	4 (3.11,5.15)	3.09 (1.99,4.79)	4.74 (3.82,5.88)	4.39 (3.52,5.48)	**3.37 (2.44,4.65)**	**4.92 (4,6.05)**

The bold indicates the highest value of OR value among the anthropometric indices. ABSI = a body shape index, BMI = body mass index, BRI = body roundness index, CI = confidence interval, CMA = cardiometabolic abnormalities, MetS = metabolic syndrome, OR = odds ratio, WC = waist circumference, WHpR = waist-to-hip ratio, WHtR = waist-to-height ratio.

predictor of all of the studied endpoints except MetS. The corresponding ORs of the best predictors were 4.67 (95% CI 3.74–5.83) for hypertension, 6.48 (95% CI 4.26–9.86) for diabetes, 6.71 (95% CI 5.40–8.33) for dyslipidemia, 4.50 (95% CI 3.44–5.88) for hyperuricemia, and 7.08 (95% CI 5.73–8.75) for at least 1 CMA. For most of CMA, the BRI was the 2nd-best predictor and showed the competitive discriminative power compared with WC. Nevertheless, the ABSI consistently showed the weakest association with all of the CMA; thus, it was the worst predictor (Table 4).

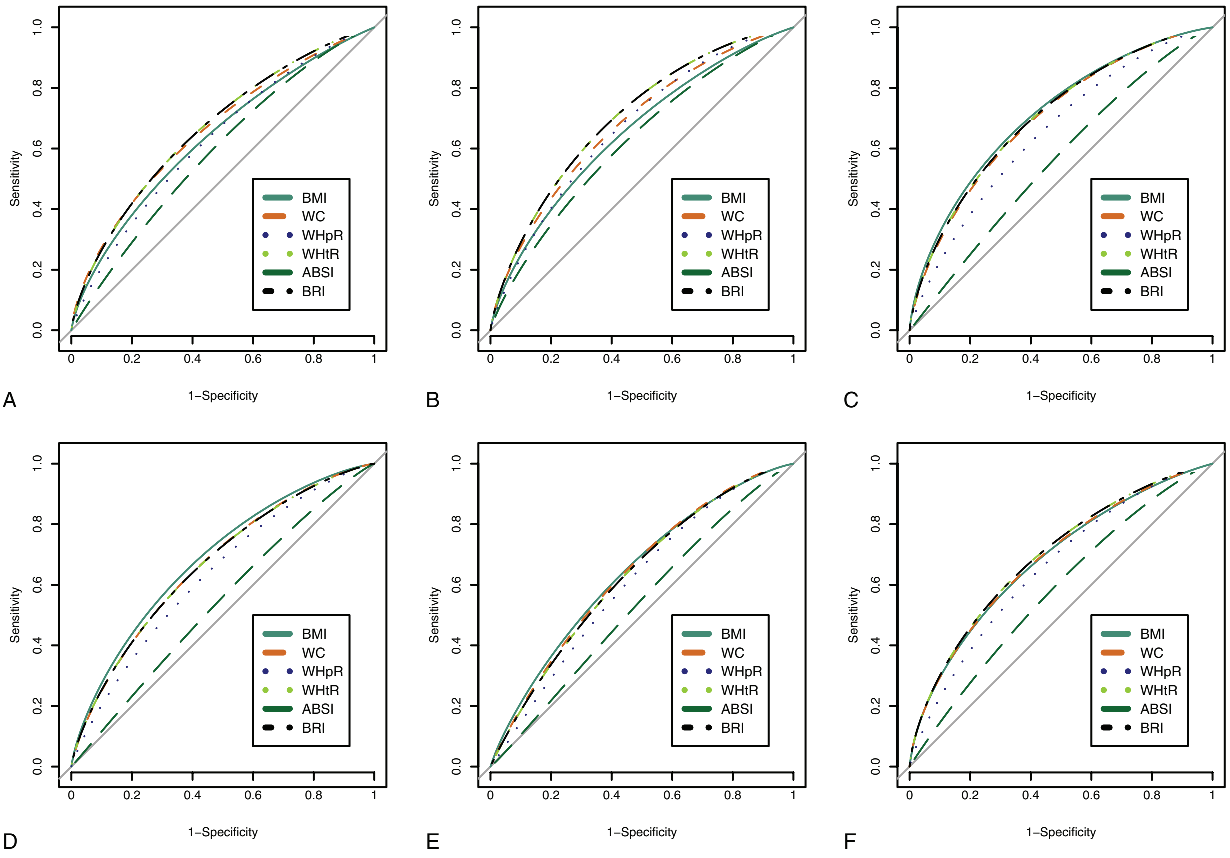

Figure 2. Receiver operating characteristic curves of BMI, WC, WHpR, WHtR, ABSI, and BRI to identify subjects with (A) hypertension, (B) diabetes, (C) metabolic syndrome, (D) dyslipidaemia, (E) hyperuricemia, and (F) at least 1 cardiometabolic abnormalities in men. Areas for the curves in men are summarized in Table 2. ABSI = a body shape index, BMI = body mass index, BRI = body roundness index, WC = waist circumference, WHpR = waist-to-hip ratio, WHtR = waist-to-height ratio.

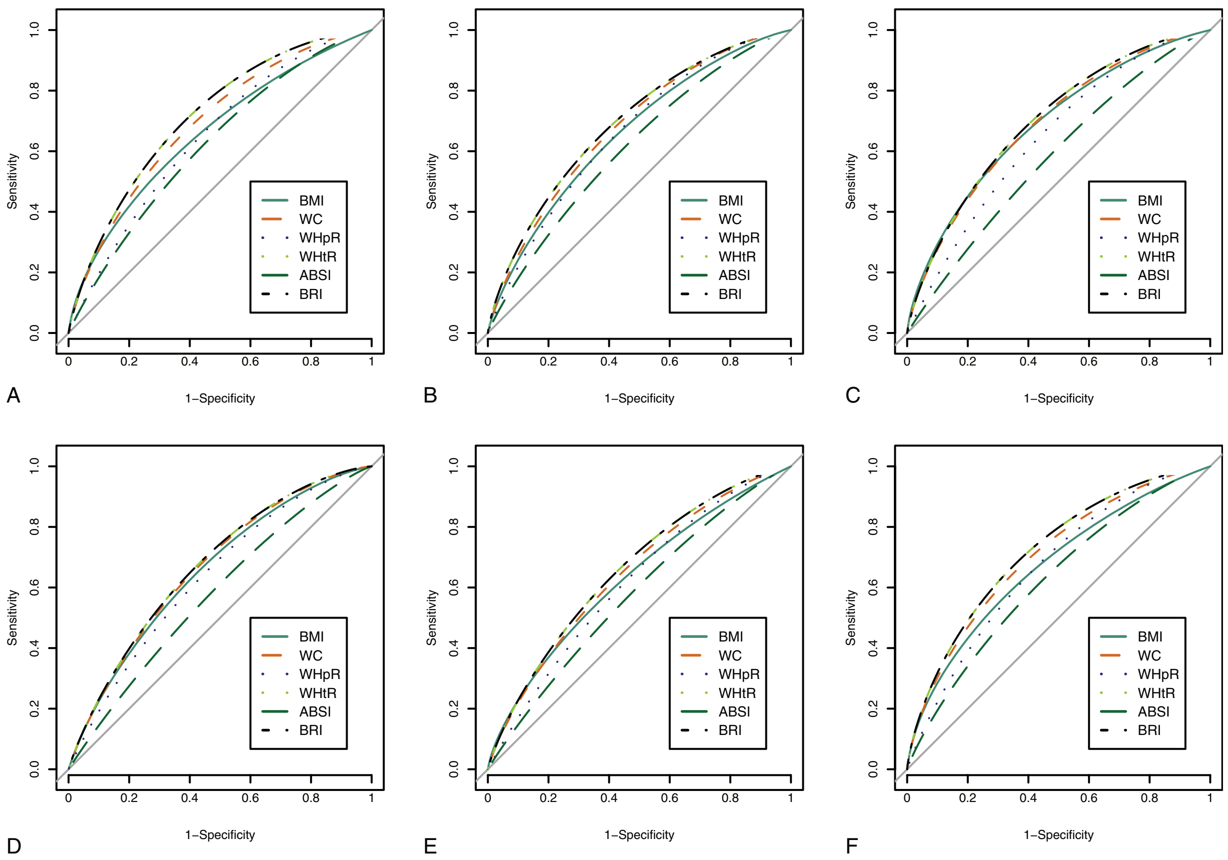

Figure 3. Receiver-operating characteristic curves of BMI, WC, WHpR, WHtR, ABSI, and BRI to identify subjects with (A) hypertension, (B) diabetes, (C) metabolic syndrome, (D) dyslipidaemia, (E) hyperuricemia, and (F) at least 1 cardiometabolic abnormalities in women. Areas for the curves in women are summarized in Table 2. ABSI = a body shape index, BMI = body mass index, BRI = body roundness index, WC = waist circumference, WHpR = waist-to-hip ratio, WHtR = waist-to-height ratio.

4. Discussion

4.1. Overall results

The present study, conducted from a nationally representative Chinese sample, showed that BRI and WHtR had the best predictive abilities for discriminating each of the CMA in women, and hypertension and diabetes in men. Our findings highlight that the novel index BRI could be used as a single suitable anthropometric measure in simultaneously identifying a cluster of CMA, including hypertension, diabetes, dyslipidemia, hyperuricemia, and MetS when compared with BMI and WC.

4.2. Body roundness index

The BRI was 1st developed by Thomas et al[27] to predict the percentage of body fat and visceral adipose tissue. This index relies on waist and height eccentricity and was derived from American cohorts and validated against a German cohort, more importantly, Thomas et al[27] showed the capabilities of BRI for health status evaluations. The present study investigated the feasibilities of BRI to identify a cluster of CMA in a nationally representative cohort in China, and demonstrated that the BRI is the best predictor of various cardiometabolic disturbances for women. It also showed the competitive predictive capabilities for men compared with other anthropometric indices. Up to now, only 2 studies have investigated the predictive abilities of BRI for CVD and its risk factors, and the investigators have found that the BRI has a good discriminative power for either diabetes[37] or CVD and its risk factors,[28] having a larger area under the curve (AUC) value than BMI, WC, and other indices. In regard to adjusted ORs, our findings were consistent with Chang et al study,[29] which showed that the adjusted OR for predicting diabetes increased with increasing quintiles of BRI, after adjustment for age, smoking, alcohol status, and other confounders. However, contrary to Maessen et al study,[28] the present study showed that despite the favorable discriminative capabilities of BRI, its adjusted ORs for health outcomes were not superior to those of BMI or WC in men and women, except for hyperuricemia and at least 1 CMA in women. Furthermore, consistent with both previous studies,[28,29] the present study emphasized a coincident predictive ability between BRI and WHtR with respect to AUROCs and partial correlation coefficients for CMA. Indeed, as properly discussed in Maessen et al and Chang et al, the Spearman rank test revealed a perfect nonlinear relationship between those 2 indices ($r = 1$; $P < 0.001$); besides, from BRI definition, it is easy to verify the one-to-one nonlinear transformation of WHtR to BRI. Despite some limitations of the BRI construction indicated by Thomas et al,[27] the advantage of the BRI over the WHtR consists of enabling an accurate estimation of the percentage of body fat and visceral adipose tissue; therefore, it could provide a better impression of physical health status. Furthermore, it is noteworthy mentioning another study that has investigated the important discriminative power of BRI for other diseases.[37] Based on a cross-sectional study of 10,907 Chinese rural people, Chang et al[37] addressed the capacity of BRI to identify the left ventricular hypertrophy, and they found that BRI showed superior predictive capacity to ABSI, BMI, WC, and WHtR, with the highest AUROCs being 0.74 and 0.67 and the highest OR being 5.11 and 2.48 for eccentric and concentric left ventricular hypertrophy, respectively. This compelling result emphasizes the clinical application of BRI for identifying other diseases. Moreover, in our data, the BRI could be used as a single suitable anthropometric measure in simultaneously identifying a cluster of CMA compared to BMI and WHtR, especially in Chinese women. The reason for this sex difference is unclear, although differences in anatomy, physiology, metabolism, and sex hormones may offer a partial explanation. Cross-sectional studies in the Asian and American populations[38,39] have shown that associations of metabolic risk factors, such as systolic and diastolic blood pressure, fasting glucose, and total cholesterol, with increasing volumes of both subcutaneous and visceral fat, were stronger in women than in men. Our observation of a sex difference in BRI could be the same phenomenon. Additionally, in our study, the mean/variance of BRI was significantly higher in women than in men ($P < 0.001$, not shown), and this might also be a possible reason for the seeming sex difference in its discriminative ability. In conclusion, all this evidence suggests that the BRI could serve as a complementary tool compared to the well-established indices, such as BMI or WC. This requires further research on detecting and identifying other diseases.

4.3. A body shape index

The ABSI was 1st proposed by Krakauer and Krakauer[24] for estimating the health of body shape independently of height, weight, and BMI. The authors also demonstrated that the ABSI was more predictive for premature mortality than either BMI or WC in the general American population.[24] As indicated in their subsequent study using a relatively large British follow-up cohort,[26] the ABSI was a readily computed dynamic indicator of health outcomes, especially mortality risk, across BMI categories and had potential uses for making clinical decisions. Since then, identification on whether ABSI was a better predictor than BMI or WC for identifying diseases appeared recently. Based on a cross-sectional study of 445 Portuguese adolescents aged 10 to 17 years, Duncan et al[40] showed a superior utility of ABSI over BMI or WC in predicting resting blood pressure in a pediatric population. Similarly, in a cohort of 4813 Korean gastric cancer patients aged 58 years on average, Eom et al[41] found a significant association between ABSI, as independent risk factor and overall surgical complications, while BMI did not. This was the 1st study to investigate the association between ABSI and surgical complications as claimed by the authors, and they also demonstrated that for each 0.01 increase in ABSI, the odds of the occurrence of surgical complication increased by 22%.

However, there was also controversy that ABSI did not show a superior predictive ability for identifying CVD risk factors,[42] new onset of diabetes mellitus or stroke, and mortality[43] compared to BMI or WC. Based on a prospective cohort study in China that included 687 people after a follow up of 15 years, He and Chen[25] found that ABSI had similar predictive abilities for new onset diabetes to that of BMI and WC, indicating that ABSI in this respect was not better than BMI or WC. Similarly, in a cross-sectional study including 4627 Dutch subjects, the investigators showed that ABSI is not suitable for identifying CVD (myocardial infarction and stroke) or CVD risk factors (hypertension and hypercholesterolemia).[28] Consistent with that, Abete et al[42] in one 13-year follow-up cohort study with 41,020 Spanish adults also highlighted that ABSI was not a better predictor of stroke incidence compared to WC or WHpR. This kind of finding was confirmed in another retrospective cohort of 48,953 Japanese adults during a follow-up of 4 years, Fujita et al[21] found that compared with BMI or WC, ABSI was not a favorable predictor of hypertension, diabetes, and dyslipidimia in Japanese adults, despite conducting a logistic regression and propensity score matching method. Finally, a very recent cross-sectional study of 11,345 people aged ≥35 years, conducted in Northern rural China by Chang et al,[29] confirmed that when compared with BMI, WC, or WHtR, ABSI had the lowest AUROCs for diabetes (AUROC 0.61 for both men and women). Moreover, ABSI exhibited the weakest association with diabetes (OR 1.51 and 1.55 in men and women, respectively) after adjusting for age and other potential confounders. These findings are in contrast with those of Haghighatdoost et al.[44] From a population-based cohort of 9555 Iranian adults aged ≥19 years, they showed that in spite of the lowest AUROCs by ABSI for CVD risk factors and MetS, ABSI revealed the highest OR for MetS compared to BMI, WC, or WHtR in different age and sex categories, suggesting that ABSI could be a good predictor for CVD per se. Our findings were consistent with those of previous studies that when compared with BMI, WC, and especially another novel index BRI, ABSI is not suitable for identifying various CMA like hypertension, diabetes, MetS, and others. Even though the precise reasons for the discrepancy were unable to be ascertained, some investigators speculate that some possible explanations are based on the endpoint variable chosen,[28] or the weak correlation between ABSI and height.[44]

Furthermore, as reported in Krakauer and Krakauer study,[24] ABSI was strongly correlated with age and sex, which was further confirmed by subsequent studies. Based on a cohort of 562 adolescents aged 10 to 17 years, Xu et al[45] suggested appropriate scaling exponents values of 0.45 and 0.55 for standardizing the WC for BMI and height in Chinese adolescents; moreover, the ABSI-adolescents have been shown to be a superior predictor than BMI for prehypertension and prediabetes. Another Indonesian cohort of 8014 adults aged 40 to 85 years[46] found that the regression coefficients in men were roughly similar to those reported in Krakauer and Krakauer study,[24] but those in women were more discrepant, which highlights that a gender-specific scaling exponent should be taken into account.

Despite the conflicting findings on whether ABSI is a suitable predictor of diseases, ABSI offered one means of separating the impact on health of body shape from that of body size; thus, ABSI could be an important complementary index when identifying subjects at risk of some diseases or disease incidence.

4.4. BMI and abdominal obesity index (waist circumference, waist-to-height ratio, and waist-to-hip ratio)

As recommended by the Working Group on Obesity in China,[47] BMI is a better predictor of hypertension in men and women, while waist-related indices like WHtR and WC are more sensitive indicator of diabetes and dyslipidemia. Based on a cohort study that included 8940 Chinese adults, Feng et al[19] reported that BMI was strongly associated with hypertension in Chinese men and women, with a higher AUROC and prevalence ratio, while WC was associated with diabetes and dyslipidemia. Consistent results were found in another previous study conducted in Chinese cohort,[48] highlighting the significant association of BMI with hypertension in this Chinese population. Similarly, Zhang et al[49] in a large cohort of middle-aged Chinese adults reported that WHtR proved to be the best predictor of diabetes, dyslipidemia, hyperuricemia, and MetS, while BMI was the best screening tool for hypertension in both genders. Furthermore, a recent study based on a population-based cohort of 244,266 Chinese adults[50] confirmed that according to well-established cut-off values, BMI was found to be a more sensitive indicator of hypertension in both men and women, while WC and WHtR were found to be better indicators of diabetes and dyslipidemia. The respective role player by BMI and WHtR on hypertension and diabetes is also justified in a longitudinal study, conducted by Kabat et al[51] in the Women's Health Initiative Study. Based on this prospective cohort study, including 2672 postmenopausal women after a follow-up of 13 years, the investigators found that WHtR was statistically a superior predictor of glucose, triglycerides, and HDL, and that these risks were nearly 1.5-fold increased for each 1 SD-unit increase in WHtR, whereas change in BMI showed the strongest association with both change in systolic and diastolic blood pressure, adding again to the evidence that WHtR is more suitable for diabetes, dyslipidemia or hyperuricemia, and BMI for hypertension. This is in partial agreement with our findings of the OR analyses according to the quartiles of each anthropometric index. Indeed, the present study showed that BMI was superior to WC or WHtR for predicting hypertension in Chinese women, and for MetS in both genders, whereas WC was a favorable predictor of dyslipidemia in Chinese men and women. Moreover, Kabat et al[51] also demonstrated that WHpR was a weaker predictor of all cardometabolic risk factors compared with BMI, WHtR, or WC, in spite of comparable predictive abilities reported from several other cross-sectional studies.[52–54] In agreement with these findings, our results indicate that WHpR was not favorable predictor of various CVD risk factors and MetS in regardless of AUROC or OR values.

In addition, several studies reported the superior predictive capabilities of the waist-related index, especially WHtR, in identifying multiple CVD risk factors from different ethnic populations.[55–57] Borné et al[58] in a prospective study with 26,604 Swedish adults aged 45 to 73 years found that the adjusted hazard ratio of incident diabetes was higher for WHtR than WC and BMI in both men and women after a 14-years follow-up. Their finding is in line with those of other meta-analysis studies,[22,23] especially, the suggested cut-off value of WHtR for diabetes based on various cross-sectional prospective studies was 0.52 and 0.53 in men and women, respectively.[22] This led to the following advice "keep your WC to less than half your height."[59] Likewise, it is noteworthy that WHtR is a better predictor of cardiometabolic risks in overweight/obese children and adolescents.[60–62] In a recent cohort of 110 Mexican obese adolescents aged 8 to 16 years, Rodea-Montero et al[63] concluded that WHtR exhibited a better discriminative power than WC or BMI for identifying MetS, and suggested a value of 0.6 as an appropriate WHtR cut-off in obese adolescents. The results of the present study support previous conclusions that WHtR shows superiority over WC and BMI for detecting hypertension, diabetes, and other CVD risk factors, particularly in Chinese women. This emphasizes the importance of WHtR as a rapid and effective global indicator of health risks.

4.5. Limitations and strengths

Several limitations of the present study should be considered. First, the ABSI was initially build to predict mortality hazard in a follow-up study, and we applied it as predictor of CVD risk factors and MetS in a cross-sectional study, which may explain its deficiency of discriminative power in the present study. Furthermore, the findings of this cross-sectional study do not explicitly imply a causal relation of BRI, WHtR, and others with the studied health outcomes. Thus, we must be cautious in interpreting the present results, and further cohort studies are needed to clarify our findings. Second, China is a vast country with diverse living mode, and some factors including lifestyles and heredity of different regions may have effect on the body shape and metabolic indices. The studied population was from 9 of China's 31 provinces in its sampling frame, thus generalizing the results and conclusion to the whole of China should be interpreted cautiously. However, the CHNS is a well-established cohort of Chinese population, a vigorous quality assurance program and the same strict methodology used to ensure the quality of the data collection over the entire study period. In the present study, only measurements and biomarker data in 2009 wave of CHNS were available, and since then obesity indices and cardiometabolic disorders may have change due to lifestyle modification; therefore, the findings should be carefully extrapolated to current situation. However, a future round of data collection is anticipated. In addition, the 2 new anthropometric indices were 1st developed in Western countries, and should be readjusted by taking into account different ethnic characteristics to make them suitable for Chinese population. Another limitation of the study was that only age, smoking, and alcohol status were considered in the logistic regression model to assess the strength of association between various anthropometric indices and CMA. Since cardiometabolic diseases such as hypertension and diabetes are heterogeneous and multifactorial, some other potential confounders such as socio-demographic variables, dietary intake, and physical activity were not controlled, which could affect the strength of association; therefore, those factors must be considered during the statistical analysis in future researches. Furthermore, it is noteworthy stressing that the predictive power of anthropometric indices was assessed by ROC analysis in our study, the lack of other important predictors in the logistic model may overestimate the association of presence of CMA with anthropometric indices. However, this study does not concern the use of the model for predictive accuracy. It concerns the anthropometric indices and their relative performance in terms of association with risk factors. Since the analyses of the indices were equally influenced by the same set of confounders, the comparison was fair.

However, these deficiencies will not reduce our contribution, because the present study had several strengths. First of all, although the cross-sectional nature of our study is not optimal in design, we demonstrated that the BRI was a suitable predictor in identifying a cluster of cardiometabolic disturbances. This compelling result validates a close association of BRI with risk factors; therefore, the further longitudinal relation between BRI and disease incidence should be investigated. Second, with the strength of the large sample size, the present study could have a reasonable statistical power to reflect the real associations. In addition, the study sample comes from a partly nationally representative survey, which could minimize the possibility of sample selection bias. Third, anthropometric measurements and serum analysis were obtained by trained study personnel following a standard protocol, which could rule out the effect of measurement bias. Finally, as the anthropometric cut-off points might be different between men and women, we did all analysis separately for each gender.

5. Conclusions

In the present study, we demonstrated that BRI was a superior predictor compared with BMI, WC, or WHtR for identifying a cluster of CMA including hypertension, diabetes, dyslipidemia, hyperuricemia, and MetS, especially in Chinese women. In contrast, the ABSI showed the weakest discriminative power. Under the advantage of giving a better impression of physical and health cardiovascular status, the BRI may be used as an alternative obesity measure for assessing Chinese people suffering from various health risks. Further prospective studies are needed before definite conclusions can be made regarding the best predictor of future cardiometabolic risk events.

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