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

Simiao Tian, PhD\textsuperscript{a,}\textsuperscript{*,} Xiuzhi Zhang, MD\textsuperscript{b}, Yang Xu, MM\textsuperscript{a}, Huimin Dong, MM\textsuperscript{b}

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 (WHtR), 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, WHtR = 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.\textsuperscript{[11,2]} 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.\textsuperscript{[13]} Nowadays obesity is recognized as the main cause of a great number of diseases including hypertension,\textsuperscript{[4]} type 2 diabetes,\textsuperscript{[5]} metabolic syndrome (MetS),\textsuperscript{[6,7]} and cardiovascular diseases (CVDs).\textsuperscript{[2,3,9]} and it also plays an important indirect role in some cancers.\textsuperscript{[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.\textsuperscript{[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...
for various cardiovascular and metabolic disorders. However, the discriminative capacity of BMI has been criticized because it cannot distinguish muscle mass from fat mass, or reflect fat distribution. 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.

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, and finding is recently confirmed by longitudinal study in Japan. However, other meta-analysis have found that WHtR exhibited a better predictive power than BMI in detecting several cardiometabolic risk factors. The conflicting data have led to explore novel anthropometric indices by combining traditional measures.

In 2012, Krakauer and Krakauer 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 or mortality. In 2013, Thomas et al 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 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. 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. 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 biomarkers 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

\[
\text{BMI} = \frac{\text{weight (kg)}}{\text{height (m)}^2}\nonumber
\]

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\(^{[24]}\):

\[
\text{ABSI} = \frac{\text{WC}}{\text{BMI}^{0.4} \text{ height}^{1.2}}
\]

BRI was calculated using the formula\(^{[27]}\):

\[
\text{BRI} = 364.2 - 365.5 \times \left(1 - \frac{\left(\frac{\text{WC}}{2 \pi}\right)^2}{(0.5 \text{ height})^2}\right)
\]

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 \(\geq 140\) mmHg, or a diastolic blood pressure of \(\geq 90\) mmHg, or self-reported use of antihypertensive medication. Diabetes was defined as fasting plasma glucose of \(\geq 7.0\) mmol/L, or treatment for diabetes. Based on National Cholesterol Education Project guidelines,\(^{[32]}\) dyslipidemia was defined as low-density lipoprotein cholesterol \(\geq 4.14\) mmol/L, HDL-cholesterol \(\leq 1.036\) mmol/L, and triglycerides \(\geq 2.26\) mmol/L. Hyperuricemia was defined when uric acid (UA) \(\geq 420\) mmol/L for males and \(\geq 350\) mmol/L 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 \(\geq 102\) cm in men or \(\geq 88\) cm in women; triglycerides \(\geq 1.7\) mmol/L; reduced HDL-cholesterol \(< 1.0\) mmol/L in men or \(< 1.3\) mmol/L in women; blood pressure \(\geq 130/85\) mm Hg; and fasting plasma glucose \(\geq 5.6\) 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 \(\chi^2\) 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    | Women  |
| Age, year | n = 3776 | n = 4350 |
| 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/m² | 23.32 ± 3.39 | 23.38 ± 3.49 |
| WC, cm | 84.31 ± 10.16 | 81.20 ± 10.18 |
| Hip circumference, cm | 94.7 ± 7.65 | 94.26 ± 7.98 |
| WHtR | 0.89 ± 0.07 | 0.86 ± 0.08 |
| WHpR | 0.51 ± 0.06 | 0.52 ± 0.07 |
| BRI | 3.52 ± 0.13 | 3.86 ± 1.38 |
| ABSI, m¹²/kg⁻¹ | 0.9891 ± 0.0057 | 0.9796 ± 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, mmHg | 82.06 ± 11.08 | 79.1 ± 11.41 |
| SBP, mmHg | 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%) | 265 (6.6%) |
| MetS, n, % | 1391 (36.8%) | 1547 (35.6%) |
| Dyslipidemia, n, % | 1397 (37.0%) | 1361 (31.3%) |
| Hyperuricemia, n, % | 755 (20%) | 560 (12.9%) |
| At least 1 CMA, n, % | 2303 (61%) | 2187 (50.3%) |
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 for men and between 0.633 and 0.693 for women. The AUROC for WHtR ranged between 0.698 and 0.718 and between 0.697 and 0.718 for men and women. The AUROC for WHR ranged between 0.674 and 0.704 and between 0.658 and 0.696 for men and women. The AUROC for WC ranged between 0.667 and 0.712 and between 0.643 and 0.675 for men and women. The AUROC for WHpR ranged between 0.597 and 0.638 and between 0.572 and 0.604 for men and women. The AUROC for ABSI ranged between 0.597 and 0.668 and between 0.551 and 0.601 for men and women. The AUROC for BRI ranged between 0.656 and 0.696 and between 0.637 and 0.672 for men and women. The AUROC for WHtR had the highest AUROC values; thus, these 2 indices were demonstrated better predictive abilities in identifying hypertension, diabetes, MetS, dyslipidemia, hyperuricemia, and at least 1 CMA, respectively, \( P < 0.001 \), whereas BMI 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, BMI and WHR 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 predictor of MetS (OR 4.65, 95% CI 3.73–5.80), diabetes (OR 4.70, 95% CI 3.77–5.71), and at least 1 CMA (OR 4.64, 95% CI 3.73–5.80).

### Table 2

| Area Under the Curve (AUROC) | Hypertension | Diabetes | MetS | Dyslipidemia | Hyperuricemia | At least 1 CMA |
|-----------------------------|-------------|---------|------|--------------|---------------|---------------|
| **Men**                     |             |         |      |              |               |               |
| BMI                         | 0.639       | 0.663   | 0.717| 0.690 (0.673, 0.723) | 0.648 (0.626, 0.669) | 0.688 (0.671, 0.705) |
| WC                          | 0.662       | 0.697   | 0.712| 0.683 (0.665, 0.7)  | 0.64 (0.619, 0.662)  | 0.697 (0.680, 0.714) |
| WHtR                        | 0.638       | 0.685   | 0.672| 0.654 (0.636, 0.672) | 0.617 (0.596, 0.638) | 0.673 (0.656, 0.691) |
| WHR                         | 0.666       | 0.708   | 0.712| 0.674 (0.658, 0.691) | 0.637 (0.616, 0.658) | 0.698 (0.681, 0.715) |
| ABSI                        | 0.597       | 0.635   | 0.572| 0.551 (0.532, 0.57)  | 0.541 (0.518, 0.563) | 0.59 (0.571, 0.609) |
| BRI                         | 0.665       | 0.708   | 0.712| 0.674 (0.658, 0.691) | 0.637 (0.616, 0.658) | 0.698 (0.681, 0.715) |
| **Women**                   |             |         |      |              |               |               |
| BMI                         | 0.667       | 0.661   | 0.692| 0.663 (0.643, 0.686) | 0.633 (0.607, 0.658) | 0.675 (0.659, 0.691) |
| WC                          | 0.698       | 0.697   | 0.699| 0.671 (0.654, 0.688) | 0.643 (0.619, 0.667) | 0.705 (0.690, 0.721) |
| WHtR                        | 0.656       | 0.677   | 0.657| 0.649 (0.632, 0.666) | 0.626 (0.602, 0.65)  | 0.678 (0.662, 0.694) |
| WHR                         | 0.714       | 0.702   | 0.703| 0.676 (0.659, 0.692) | 0.658 (0.635, 0.682) | 0.721 (0.707, 0.736) |
| ABSI                        | 0.626       | 0.631   | 0.586| 0.584 (0.566, 0.602) | 0.58 (0.556, 0.605)  | 0.63 (0.613, 0.646) |
| BRI                         | 0.714       | 0.702   | 0.703| 0.676 (0.659, 0.692) | 0.658 (0.635, 0.682) | 0.721 (0.707, 0.736) |

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

### 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  | 0.26 | 0.17   | 0.3 |
| **WHtR**                                            | 0.21 | 0.15 | 0.22  | 0.23 | 0.14   | 0.24|
| **WHR**                                             | 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, WHtR = waist-to-hip ratio, WHR = 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).

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.

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.
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

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) dyslipidemia, (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.
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[13,18,39] 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 pediatric population, 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.[43] 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 index for identifying other diseases. 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 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.[43] 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 WHtR.

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 dyslipidemia 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 Haghhighatoost et al.[46] 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.[43] 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\(^\text{19}\) 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,\(^\text{48}\) highlighting the significant association of BMI with hypertension in this Chinese population. Similarly, Zhang et al\(^\text{12}\) 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\(^\text{50}\) 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\(^\text{51}\) 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\(^\text{51}\) also demonstrated that WHpR was a weaker predictor of all cardiometabolic risk factors compared with BMI, WHtR, or WC, in spite of comparable predictive abilities reported from several other cross-sectional studies.\(^\text{12,52–54}\) 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.\(^\text{51}\) 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.\(^\text{55–57}\) Born et al\(^\text{58}\) 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 findings is in line with those of other meta-analysis studies,\(^\text{22,23}\) 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.\(^\text{22}\) This led to the following advice “keep your WC to less than half your height.”\(^\text{15}\) Likewise, it is noteworthy that WHtR is a better predictor of cardiometabolic risks in overweight/obese children and adolescents.\(^\text{60–62}\) In a recent cohort of 110 Mexican obese adolescents aged 8 to 16 years, Rodea-Montero et al\(^\text{63}\) 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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References
[1] Hossain P, Kawar B, El Nahas M. Obesity and diabetes in the developing world – a growing challenge. N En 1994;107(6):213–5.
[2] Zalesin KC, Franklin BA, Miller WM, et al. Impact of obesity on cardiovascular disease. Med Clin North Am 2011;95:919–37.
[3] Ng M, Fleming T, Robinson M, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet 2014;384:766–81.
[4] Girotto E, Andrade SM, Cabrera MA. Prevalence of abdominal obesity in hypertensive patients registered in a Family Health Unit. Arq Bras Cardiol 2010;94:754–62.
[5] Lorenzo C, Okoloue M, Williams K, et al. The metabolic syndrome as predicator of type 2 diabetes: the San Antonio heart study. Diabetes Care 2003;26:3153–9.
[6] Janssen I, Katzmarzyk PT, Ross R. Waist circumference and not body mass index explains obesity-related health risk. Am J Clin Nutr 2004;79:379–84.
[7] Pajunen P, Jousilahti P, Borodulin K, et al. Body fat measured by a near-infrared interactance device as a predictor of cardiovascular events: the FINRISK 92 cohort. Obesity (Silver Spring) 2011;19:848–52.
[8] Song ZZ, Wang J, Zhang J. Body mass index, central obesity, and mortality among coronary disease subjects. J Am Coll Cardiol 2013;62:85.
[9] Lu Y, Hajifathalian K, Ezzati M, et al. Metabolic predictors of the effects of body-mass index, overweight, and obesity on coronary heart disease and stroke: a pooled analysis of 97 prospective cohorts with 1.8 million participants. Lancet 2014;383:970–83.
[10] Renahan AG, Tyson M, Egger M, et al. Body-mass index and incidence of cancer: a systematic review and meta-analysis of prospective observational studies. Lancet 2008;371:169–78.
[11] Arnold M, Pandeya N, Byrnes G, et al. Global burden of cancer attributable to high body-mass index in 2012: a population-based study. Lancet Oncol 2015;16:36–46.
[12] World Health Organization. Physical Status: The Use and Interpretation of Anthropometry. Report of a WHO Expert Committee. WHO Tech Rep Ser. 1995; no. 854. Geneva: WHO.
[13] WHO. Obesity: preventing and managing the global epidemic. Report of a World Health Organization consultation. WHO Tech Rep Ser. 2000;894:i–iv, 1–253.
[14] Gomez-Ambrosi J, Silva C, Galofre JC, et al. Body mass index classification misses subjects with increased cardiometabolic risk factors related to elevated adiposity. Int J Obes (Lond) 2012;36:286–94.
[15] Hsieh SD, Yoshinaga H, Muto T. Waist-to-height ratio, a simple and practical index for assessing central fat distribution and metabolic risk in Japanese men and women. Int J Obes Relat Metab Disord 2003;27:610–6.
[16] Panagia L, Lohsoonthorn Y, Lertmaharit S, et al. Comparison of waist circumference, body mass index, percent body fat and other measure of adiposity in identifying cardiovascular disease risks among Thai adults. Obes Res Clin Pract 2008;2:215–23.
[17] Ouyang X, Lou Q, Gu L, et al. Anthropometric parameters and their associations with cardiometabolic risk in Chinese working population. Diabetol Metab Syndr 2015;7:37.
[18] Ren Q, Su C, Wang H, et al. Prospective study of optimal obesity index cut-off values for predicting incidence of hypertension in 15-65 years old Chinese adults. PLoS One 2016;11:e0148140.
[19] Feng RN, Zhao C, Wang C, et al. BMI is strongly associated with hypertension, and waist circumference is strongly associated with type 2 diabetes and dyslipidemia, in northern Chinese adults. J Epidemiol 2012;22:317–23.
[20] Oda E, Kawai R. Body mass index is more strongly associated with hypertension than waist circumference in apparently healthy Japanese men and women. Acta Diabetol 2010;47:309–13.
[21] Fujita M, Sato Y, Nagashima K, et al. 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.
[22] Ashwell M, Gunn P, Gibson S. Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factor: systenx analysis. Obes Rev 2012;13:275–86.
[23] Savva SC, Lamnious D, Kaftos AG. Predicting cardiometabolic risk: waist-to-height ratio or BMI. A meta-analysis. Diabetes Metab Syndr Obes 2013;6:403–19.
[24] Krakauer NY, Krakauer JC. A new body shape index predicts mortality hazard independently of body mass index. PLoS One 2012;7:e93904.
[25] 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.
[26] Krakauer NY, Krakauer JC. Dynamic association of mortality hazard with body shape. PLoS One 2014;9:e85793.
[27] Thomas DM, Bredlass C, Bassy-Westphal A, et al. Relationships between body roundness with body fat and visceral adipose tissue emerging from a new geometrical model. Obesity (Silver Spring) 2013;21:2264–71.
[28] Maessen MF, Eijpveges TM, Verhogen RJ, et al. 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.
[29] Chang Y, Guo X, Chen Y, et al. A body shape index and body roundness index: two new body indices to identify diabetes mellitus among rural population in northeast China. BMC Public Health 2015;15:794.
[30] Yan S, Li J, Li S, et al. The expanded burden of cardiometabolic risk in China: the China Health and Nutrition Survey. Obes Rev 2012;13:810–21.
[31] 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.
[32] National Cholesterol Education Program Expert Panel Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) final report. Circulation 2002;106:3143.
[33] Alberti K, Eckel RH, Grundy SM, et al. Harmonizing the Metabolic Syndrome A Joint Interim Statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. Circulation 2009;120:1640–5.
[34] Latinen TT, Pahkala K, Magnussen CG, et al. Ideal cardiovascular health in childhood and cardiometabolic outcomes in adulthood the cardiovascular risk in Young Finns study. Circulation 2012;125:1971–8.
[35] Baba K, Shibata R, Sibuya M. Partial correlation and conditional correlation as measures of conditional independence. Aust New Zealand J Stat 2004;46:657–64.
[36] R Core Team. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. 2015; Vienna, Austria.
A body shape index and body roundness index: two new body indices to identify left ventricular hypertrophy among rural populations in northeast China. Heart Lung Circ 2016;25:358–64.

Oka R, Miura K, Sakurai M, et al. Impacts of visceral adipose tissue and subcutaneous adipose tissue on metabolic risk factors in middle-aged Japanese. Obesity 2010;18:153–60.

Fox CS, Massaro JM, Hoffmann U, et al. Abdominal visceral and subcutaneous adipose tissue compartments: association with metabolic risk factors in the Framingham Heart Study. Circulation 2007;116:39–48.

Duncan MJ, Mota J, Vale S, et al. 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.

Eom BW, Joo J, Yoon HM, et al. A body shape index has a good correlation with postoperative complications in gastric cancer surgery. Ann Surg Oncol 2014;21:1115–22.

Abete I, Arriola L, Etxezarreta N, et al. Association between different obesity measures and the risk of stroke in the EPIC Spanish cohort. Eur J Nutr 2015;54:365–76.

Kabat GC, Heo M, Van Horn LV, et al. Longitudinal association of anthropometric measures of adiposity with cardiometabolic risk factors in postmenopausal women. Ann Epidemiol 2014;24:896–902.

Orsatti FL, Nahas EAP, Nahas-Neto J, et al. Association between anthropometric indicators of body fat and metabolic risk markers in post-menopausal women. Gynecol Endocrinol 2010;26:16–22.

Melmer A, Lamina C, Tschanter A, et al. Body adiposity index and other indices of body composition in the SAPPHIR study: association with cardiovascular risk factors. Obesity 2013;21:775–81.

Liu P, Ma F, Lou H, et al. Utility of obesity indices in screening Chinese postmenopausal women. Menopause 2014;21:509–14.

Barzi F, Woodward M, Czernichow S, et al. The discrimination of dyslipidaemia using anthropometric measures in ethnically diverse populations of the Asia-Pacific Region: the Obesity in Asia Collaboration. Obes Rev 2010;11:127–36.

Dong X, Liu Y, Yang J, et al. Efficiency of anthropometric obesity measures and their association with cardiovascular disease risk factors: a meta-analysis. Neth Heart J 2012;20:208–18.

Kodama S, Horikawa C, Fujihara K, et al. Comparisons of the strength of associations with future type 2 diabetes risk among anthropometric obesity indicators, including waist-to-height ratio: a meta-analysis. Am J Epidemiol 2012;176:959–69.

Borne Y, Nilsson PM, Melander O, et al. Multiple anthropometric measures in relation to incidence of diabetes: a Swedish population-based cohort study. Eur J Public Health 2015;25:1100–5.

Ashwell M, Hsieh SD. Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. Int J Food Sci Nutr 2005;56:303–8.

Khoury M, Manhioht C, Dobbin S, et al. Role of waist measures in characterizing the lipid and blood pressure assessment of adolescents classified by body mass index. Arch Pediatr Adolesc Med 2012;166:719–24.

Maffes C, Banzato C, Talamini G. Waist-to-height ratio, a useful index to identify high metabolic risk in overweight children. J Pediatr 2008;152:207–13.

Mokha JS, Srinivasan SR, DasMahapatra P, et al. Utility of waist-to-height ratio in assessing the status of central obesity and related cardiometabolic risk profile among normal weight and overweight/obese children: the Bogalusa Heart Study. BMC Pediatr 2010;10:73.

Rodea-Montero ER, Evia-Viscarsa ML, Apolinar-Jiménez E. Waist-to-height ratio is a better anthropometric index than waist circumference and BMI in predicting metabolic syndrome among obese Mexican adolescents. Int J Endocrinol 2014;2014:195407.