ISSN: 0975-3583,0976-2833 VOL14, ISSUE 01, 2023

Anthropometric cut-offs for screening metabolic syndrome in a Nigerian population in southeast Nigeria

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ABSTRACT

Background: The use of anthropometric measures for assessment of metabolic syndrome (MetS) could provide a safe, rapid, effective and inexpensive method to screen MetS, but there has not been consensus on the best anthropometric indicators and cut-off points. *Objective.* The goal of this study is to determine the ability of 11 anthropometric indicators to predict MetS in a Nigerian population. **Methods:** A total of 4,168 subjects aged 20 to 50 years were recruited from southeast Nigeria between September 2017 and August 2018 for a cross-sectional study. MetS was defined based on the International Diabetes Federation (IDF) criteria. We used the receiver operating characteristic (ROC) curves to evaluate balance between sensitivity and specificity to predict MetS and its factors. **Results:** Abdominal volume index (AVI) had significantly higher areas under the curves (AUCs) for predicting MetS (AUC = 0.90) and central obesity (AUC = 0.93). Lipid accumulation product (LAP) showed the best prediction for hyperglycaemia (AUC = 0.59), body mass index (BMI) is the best diagnostic index for abnormal blood pressure (BP) (AUC = 0.57). Compared to other anthropometric measures, waist circumference (WC) triglyceride index (WTI) had significantly higher AUCs for high triglyceride (TG) (AUC = 0.99)/low high-density lipoprotein cholesterol (HDL-C) (AUC = 0.68). **Conclusion:** Our study suggests that AVI is the best surrogate for both MetS and central obesity and should be used as preliminary screening tool. LAP showed best prediction for hyperglycaemia, BMI had a better diagnostic ability to predict high BP, while WTI had a better prediction for high TG/low HDL cholesterol.

Key words: Anthropometry, metabolic syndrome, abdominal volume index, obesity, predictors

INTRODUCTION

Metabolic syndrome (MetS) is a constellation of several cardiometabolic risk factors including central adiposity, hyperglycaemia, hypertension, hypertriglyceridemia/low HDL-C levels. Studies of pathophysiological condition has shown that the prevalence of MetS especially among adult population is on the increase globally[1,2]. The National Health and Nutrition Examination Survey has reported that more than one third of adults have been

ISSN: 0975-3583,0976-2833 VOL14, ISSUE 01, 2023

diagnosed of MetS[3]. Central obesity and hyperglycaemia are generally recognized as fundamental underlying components necessary for developing MetS[4]. Of the two risk conditions, it has been hypothesized that central obesity is precursor to the emergence of other risk conditions of MetS[5]. Hence, it is reasonable that the IDF made high WC mandatory criterion for diagnosing MetS. Although diagnostic procedures such as magnetic resonance imaging and computed tomography are procedures for accurately determining body fat distribution, its major drawbacks include cost, time to get the image ready, not suitable in field settings and technical knowhow especially in third world nations. However, an inexpensive, noninvasive anthropometric measurements will serve as a handy alternative indicator for adiposity.

For many years, Quetelet index otherwise known as BMI is the classical and most commonly used index for classifying individuals into underweight, overweight and obesity. Unfortunately, the operational disadvantages of BMI include its inability to differentiate muscle mass from fat mass and the idea that it is sex- and correct age-dependent[6]. This has led to the proposal of alternative anthropometric measures for routine obesity assessment such as WC, hip circumference (HC), waist-to-height ratio (WHtR), conicity index (CI), body adiposity index (BAI), AVI, a body shape index (ABSI) and body roundness index (BRI)[7-10]. The use of AVI was based on its ability to estimate obesity[10], its association with MetS in adolescents[11] and adults[12,13], hyperglycaemia[14] and other cardiovascular disease (CVD) risk factors[15,16]. WC has also been reported to be linked to near-term cardiovascular mortality[17,18]. The WHtR (index of central obesity) is defined as the quotient between the WC and the height. Because both measures are in the same unit, WHtR is dimensionless. WHtR has been used as predictor of metabolic risk and has been reported as having superior performance in predicting MetS than WC or BMI alone[7,19]. Moreover, WHtR has been reported of being a screening tool for cardiometabolic risks (MetS, hyperglycaemia, hypertension, CVD)[7,16,20]. The CI is an index of body fat distribution especially central obesity[21]. It has also been demonstrated as being a screening tool for MetS[21,22], hypertension[23,24], hyperglycaemia[14,23] and CVD risk[15]. Ten years ago, Krakauer and Krakauer[25] proposed an index known as ABSI that describes the body's shape and volume concentration. Since its proposal in 2012, various researchers have verified the association between ABSI and parameters of MetS[26], cardiometabolic risk[16], carotid atherosclerosis[27] and near-term mortality from CVD[28]. Another newly developed anthropometric is the BRI by Thomas *et al*.[29]. BRI has shown to have both heuristic significance and discriminatory power. It has been reported to be associated with MetS[30], insulin resistance[30], hyperglycaemia[31] and CVD risk factors[16,32]. More recently, Nevil and colleagues proposed the use of BMI multiplied by the square root of WC (BMI$\sqrt{WC}$) to estimate body fat distribution in children using allometric modelling[33]. BMI$\sqrt{WC}$ has been shown to be associated with components of MetS[33]. The discovery of a routinely applicable MetS indicator with higher sensitivity and specificity than traditional parameters (such as BMI, WC and lipid profiles), could be useful for MetS risk assessment. Hence the main goal of this paper was to extrapolate a surrogate marker of MetS and its factors and to compare their predictive abilities of these markers with those of other anthropometric measures in identifying MetS from a group of adults in southeast Nigeria.

MATERIALS AND METHODS

ISSN: 0975-3583,0976-2833 VOL14, ISSUE 01, 2023

This study was based on cross-sectional data collected between September 2017 and August 2018 at the general outpatient department of Enugu State University Teaching Hospital, southeast Nigeria. Convenient random sampling technique was used to recruit participants. A total of 4,168 (2,748 males, 1,420 females) age ≥18 years were included. The study was reviewed and necessary authorization was given by the Enugu State Ministry of Health Research Ethics Committee and only participants who signed informed written consent were enrolled. The study obeyed the principles of Helsinki Declaration. Only participants aged ≥ 18 years, with no missing anthropometric data, physiological or biochemical measurements have been included in this study. Other data collected included lifestyle (cigarette smoking, alcohol consumption, exercise and educational attainment) and health-related information.

Anthropometric Measurements

Details of how anthropometric measurements, physiological and biochemical parameters were taken have been described elsewhere[34,35]. On both sexes, the following anthropometric measurements were taken: height, weight, hip and waist circumferences following procedures described in *Anthropometric Standardization Reference Manual*[36].

Calculating Anthropometric Indices

ABSI, AVI, CI, BRI, LAP, WTI, BMI, BAI, WHtR and BMI x $\sqrt{WC}$ were calculated using the following formulas:

- ABSI = $\frac{WC}{BMI^{2/3} \times Height^{1/2}}$
- AVI = $\frac{2\,(WC)^2 + 0.7\,(WC-HC)^2}{1000}$
- CI = $\frac{wc\,(m)}{0.109\sqrt{\frac{Weight\,(kg)}{Height\,(m)}}}$
- BRI = 364.2 – 365.5 × Eccentricity
- Eccentricity = $\sqrt{1 - \frac{1}{\pi^2}\left(\frac{WC\,(m)}{Height\,(m)}\right)^2}$
- LAP_{males} = [WC (cm) – 65] x [TG ($mmolL^{-1}$)]
- $LAP_{females}$ = [WC (cm) – 58] x [TG ($mmolL^{-1}$)]
- WTI = WC (cm) x TG ($mmolL^{-1}$)
- BMI = $\frac{Body\ mass\,(kg)}{Height^2\,(m^2)}$
- BAI[8] = $\frac{HC\,(m)}{Height\,(m)^{1.5}} - 18$
- WHtR = $\frac{WC}{Height}$
- BMI x $\sqrt{WC\,(m)}$

Definition of MetS

The IDF criteria for classification of individuals as having MetS was used to classify the sample population. In 2005, the components of MetS were proposed by the IDF and recommends diagnosing MetS when individuals had central obesity defined as 1) WC ≥ 94 cm in men or ≥ 80 cm in women plus any two or more of the following four (4) conditions: 2) fasting blood glucose ≥ 5.60 mmol/L or previously diagnosed of type 2 diabetes mellitus, 3) systolic BP ≥ 130 mmHg and/or diastolic BP ≥ 85 mmHg or reported being on therapy of hypertension, 4) HDL-C < 1.03 mmol/L for men, HDL-C < 1.29 mmol/L for women or report being on any therapy for low HDL-C and 5) having serum TG ≥ 1.70 mmol/L or reported being on any regimen for hypertriglyceridemia. The choice of IDF in which central obesity was prerequisite was due to the evolving incidence of double burden of malnutrition in Nigeria; obesity (due to overnutrition) among the affluent and thinness (due to undernutrition) among the lower class.

Data Analysis

For each sex, subjects were classified into two bands; for simplicity, subjects were classified as those with MetS (MetS+) and those without MetS (MetS−). The descriptive summary of continuous variables was presented as means ± SDs. Prior to data analysis, quality controls were conducted to check for outliers. Histogram and boxplots were used for data visualization while to verify normality of data distribution, Kolmogorov-Smirnov tests were performed for the measurements considered herein. Sex and group differences (MetS− vs. MetS+) were tested separately using unpaired sample *t*-test. Correlation matrix was used to compute the strength of association between pairs of anthropometric variables included. ROC curves were used to determine the association between anthropometric measures and MetS using the AUC with its corresponding 95% CI and to establish the cut-off point of anthropometric measurements as screening tools for predicting MetS. The optimal cut-off points for each anthropometric index and for each sex in detecting MetS was determined using the optimal cut-off point that is, the Youden index J [37], (J = sensitivity + specificity −1). YI can take the value between 0 to 1. A test with perfect accuracy has $J = 1$, whereas, for a test with no diagnostic accuracy, $J = 0$. Further, the ROC curves were used to determine the cut-off points that delineates presence or absence of the five risk conditions of MetS. Predictive accuracy of anthropometric indices was assessed using Sn, Sp, positive predictive value (PPV) and negative predictive value (NPV) and were calculated using the proportion of true negatives (TN), false negatives (FN), false positives (FP) and true positives (TP). Sn measures the probability of an anthropometric indices to accurately diagnose MetS individuals (true positive rate). Sp measures the probability of an anthropometric indices to accurately diagnose individuals without MetS (true negative rate). PPV is the probability that an individual has MetS if the test is positive. NPV is the probability that an individual has no MetS if the test is negative. All statistical analyses were conducted with MedCalc Statistical Software version 18.11.6 (MedCalc Software bvba, Ostend, Belgium; https://www.medcalc.org; 2019), and the significance level was set at two-tailed $P < 0.05$.

RESULTS

Descriptive Summary of Study Population

The sample size includes 1,420 females and 2,748 males between the ages of 20 and 50 years. Results of the *t*-test for each of the anthropometric measures are provided in Table 1. Significant differences ($P < 0.001$) between the MetS+ and MetS− groups were noted for all the variables within sexes. Still within sexes, the most consistently obvious differences revealed that the MetS+ group has higher anthropometric measures than the MetS− group. We found significant sex differences were observed in MetS− and MetS− groups in all anthropometric variables except BMI and BMI$\sqrt{WC}$ ($P > 0.05$). Also, we found that females have higher mean anthropometrics than their male counterparts. Sexual dimorphism was also apparent between male MetS+ and female MetS+ groups in all anthropometric variables but LAP and WTI. In contrast to MetS−, all the anthropometric measures showing statistical significance between male and female in the MetS+ group, revealed that males consistently have higher mean values than females. Table 1 shows also the comparison of anthropometric measures for the overall population between males and females. The results revealed that

ISSN: 0975-3583,0976-2833 VOL14, ISSUE 01, 2023

females have significantly higher anthropometric measures than their male counterparts. However, no significant differences were found for WTI and BMI.

Intercorrelation of Anthropometric Variables

The correlation between anthropometric measures are reported in Table 2. The crude correlations in anthropometric measures were predominantly linear and generally strong. We found no significant correlation between WTI and BAI in both males and females. On like in females, WTI had no significant association with BMI in males (r = 0.03, P = NS). Significant inverse correlations were found between ABSI and BMI in both sexes. Significant inverse correlations were found between BMI and CI in both sexes.

Comparison of Ability to Detect MetS

Table 3 summarizes the balances between Sn and Sp to detect MetS by various anthropometric measurements and their thresholds for both sexes. In males, the attained AUC ranged from 0.62 to 0.99 (P <0.001), indicating good/excellent predictive power of the anthropometric measurements. On the other hand, attained AUC ranged between 0.65 to 0.85 (P <0.001) in females also indicating good/excellent predictive capacity of the anthropometrics. A comparative analysis showed that AVI performed significantly better in predicting MetS in both males (AUC = 0.99) and females (AUC = 0.83) than did their attained anthropometric counterparts. The discriminatory ability of anthropometric measures to detect MetS is generally higher in males than it is in females. The optimal AVI cut-off to detect MetS in males and females are respectively 17.70 (Sn = 100%, Sp = 97%) and 12.86 (Sn = 98%, Sp = 62%). In males, WTI has the least predictive ability to detect MetS with an AUC of 0.62. Its cut-off point is 131.76 (Sn = 50%, Sp = 74%). On the other hand, ABSI has the lowest predictive potential in females with a cut-off of 0.07 (Sn = 79%, Sp = 46%). A comparative analysis of YI still supports the hypothesis that AVI performed significantly better in predicting MetS than any other anthropometric variables. The NPV of all anthropometric measures was much higher than the PPV, indicating that the cut-offs of anthropometric measurements were able to accurately exclude MetS− group. In addition to AUC, other parameter (including YI, cut-off points, Sn, Sp, NPV and PPV, LR (+) and LR (−)) values extended the analysis we conducted on the ROC curve.

Comparison of Ability of Anthropometric Dimensions to Detect Risk Conditions of MetS

Table 4 shows the AUCs (95 CIs), balances between sensitivity and specificity, YI and optimal cut-off points of anthropometric measurements to predict MetS and its components for both sexes. AVI is likely the best predictor of MetS (AUC = 0.90, Sn = 87%, Sp = 73%) and central obesity (AUC = 0.93, Sn = 94%, Sp = 74%) and LAP for hyperglycaemia (AUC = 0.59, Sn = 66%, Sp = 50%). However, BMI performed significantly better in predicting impaired BP (AUC = 0.57, Sn = 75%, Sp = 37%) than did its attained counterparts. WTI appears to be the best predictor of high TG level (AUC = 0.99, Sn = 98%, Sp = 94%, cut-off point = 128)/low HDL-C (AUC = 0.68, Sn = 82%, Sp = 49%, cut-off point = 98.4).

Table 5 provides results of comparison of predictive ability of anthropometrics of interest to detect individual components of MetS stratified by sex. The AUC values for all anthropometric measures to detect central obesity were highly significant, suggesting high accuracy of the measures to detect central obesity. AVI is likely the best predictor of central obesity for both males (AUC = 1.00, Sn = 100%, Sp = 100%, cut-off point = 17.50) and

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females (AUC = 1.00, Sn = 100%, Sp = 100%, cut-off point = 12.76) respectively. For males, WHtR is perhaps the best predictor for impaired FG (AUC = 0.59, Sn = 66%, Sp = 50%, cut-off point = 0.52). All other anthropometric dimensions that attained significance have approximately similar AUC values. In females, CI is likely the best predictor of impaired FG (AUC = 0.61, Sn = 47%, Sp = 72%, cut-off point = 1.19).

For males, BAI and HC showed superiority in diagnosing abnormal BP. Both measures have the same AUC values. ABSI and CI showed no statistically significant differences in diagnosing abnormal BP. For females, ABSI, BMI and CI have approximately the same AUC. AVI, BRI, LAP, WTI, WHtR and HC are not statistically significantly different in diagnosing abnormal BP ($P > 0.05$). Not surprising, WTI is the most superior in diagnosing abnormal TG level (AUC = 0.99, Sn = 99%, Sp = 94%, cut-off point = 128) followed by LAP (AUC = 0.78, Sn = 70%, Sp = 80%, cut-off point = 21.39). All the other anthropometric dimensions, could not attain statistically significant difference in detecting abnormal TG level ($P > 0.05$). In females, WTI and LAP are the two most superior indicators of abnormal TG level with AUC ≥ 0.90. Whereas, BMI and BMI$\sqrt{WC}$ had the same AUC (0.54). For males, LAP and WTI are likely the best predictors of abnormal HDL-C level (AUC = 0.71, Sn = 68%, Sp = 65%, cut-off point = 9.92) and (AUC = 0.71, Sn = 85%, Sp = 49%, cut-off point = 98.4) respectively. In females, BMI and BAI showed lowest AUCs to detect abnormal HDL-C ($P > 0.05$). The capacity of all the other anthropometric dimensions to predict abnormal HDL-C level ranged from 0.55 to 0.63, indicating good predictive capacity for low HDL-C level.

DISCUSSION

This study showed that anthropometric measures can be useful in identifying MetS and its components among adults in southeast Nigeria. The constellation of high fasting glucose, central obesity, hypertension, low HDL-C and hypertriglyceridemia known as MetS has been reported in a number of ethnic groups worldwide[38-41]. Previous studies across global population demonstrated that MetS plays a pivotal role in the aetiology of CVD risk factors. As a result, early diagnosis of the phenotypic components of MetS and how its phenotypic appearance differs across ethnic groups, would enhance understanding the causes of chronic diseases which are inherent in metabolic abnormalities[42]. Anthropometric measures offer a rapid, inexpensive, safe and effective method to screen for central obesity. Although the use of MRI is the most reliable, safety concerns, cost and expertise are considerable drawbacks for its use to assess abdominal obesity. Unpaired sample *t*-test revealed significant group differences in anthropometric measurements between the MetS + and MetS – groups. Comparing these groups showed that the MetS + group had higher mean values than the MetS – group, confirming that anthropometric measures could be used as surrogate markers of MetS and its components especially adiposity dysfunction. The significantly higher anthropometric values in the MetS + group is consistent with the studies of Wang and colleagues[13]. We found evidence of significant correlation among anthropometric measurements associated with MetS and its components.

Comparing the MetS-predictive abilities of the 11 anthropometric measurements with the help of ROC curves, AVI is the best predictor of MetS in both males and females. Other excellent performing variables in males are WHtR, BRI, HC and CI. In females, HC is another excellent performing variable. Noteworthy, the strong associations indicated in this

ISSN: 0975-3583,0976-2833 VOL14, ISSUE 01, 2023

study between adiposity-related parameters and MetS were consistent with earlier studies[43-47]. Our results provide evidence that AVI could be useful and important predictor of MetS compared to other anthropometric parameters. Our study results are comparable with previous study that have found that AVI can be an efficient and useful index for the screening of MetS[12-14]. Previous studies have warranted that WC performed best in both sexes with the help of ROC curves[47].

Concerning central obesity, our results also indicate that AVI could be the best surrogate index in both males and females. Previous study had suggested that AVI is a better predictor of obesity[49]. This finding may be explained by the fact that both WC and HC used for calculating AVI, are able to evaluate visceral fat, free fat and subcutaneous fat. Although, they cannot distinguish between visceral and subcutaneous fat mass. Additionally, AVI accounted for the entire volume of the free fat and adipose tissue of the abdominal region, using the pubic symphysis and xiphoid process of the sternum as landmarks, thereby including visceral fat volume at the abdominal region. Unlike the classical anthropometric index for estimating the overall body adiposity, the BMI, that is more reliable at older age due to fat redistribution to the abdominal region at an older age. WC on the other hand has the potential of properly classifying individuals at such age. However, we found WHtR may be the best useful proxy for impaired fasting glucose in males than BMI and WC. It has been widely reported by scholars as an indirect parameter for evaluation of diabetes and other cardiometabolic risk factors (hypertension, dyslipidemia, MetS and CVD)[7,16,21]. Nevertheless, a meta-analysis comparing the predictive abilities of WHtR, BMI and WC as screening tools for cardiometabolic risk factors reported WHtR as not being superior screening tool for MetS and cardiometabolic events[50]. This finding might be explained by the fact that WHtR takes both WC (index for visceral fat) and height (index to muscle mass distribution and a factor in body shape). Perhaps this makes it a better index of central obesity than BMI. However, CI is a better predictor of impaired fasting glucose than BMI and WC in females. Previous studies have also found that CI is a good indicator of diabetes than other new anthropometric parameters[21,29] and classical indicators[51] and was the strongest predictor of diabetes[14,24,25] which was similar to the findings of this study.

However, we found that BAI and HC had similar ability to screen for abnormal BP. BAI is regarded as a useful index for percentage body fat whereas, HC has also been reported to be strongly associated with percentage body fat which has been shown to be closely associated to high BP[52]. Noteworthy, only WTI and LAP were able to reliably forecast high TG level in both males and females, which is consistent with previous finding[47]. In females however, in addition to LAP and WTI, BMI and BMI$\sqrt{WC}$ showed weak predictive ability. One plausible explanation is that probably only a few individuals developed high TG level leading to misclassification by the other indices whereas WTI and LAP takes TG into account unlike the other indices. Regarding low HDL-C, LAP and WTI could be best predictors in both males and females. These findings are consistent with previous findings[48]. An explanation to the strong association between HDL-C, LAP and WTI could be due to the fact that both indices accounted for TG and WC which are strongly correlated to visceral fat.

CONCLUSIONS

In conclusion, our study provides evidence that anthropometric parameters could be useful and as important as a screening tool for identifying MetS and its risk conditions. AVI was better able to predict MetS and central obesity than other new and more traditionally used anthropometric measurements. BRI, WHtR and HC are other superior predictors of MetS.

ISSN: 0975-3583,0976-2833 VOL14, ISSUE 01, 2023

LAP could be used more to identify risk of hyperglycaemia while BMI could be used as a more superior predictor of hypertension. However, WTI has the best predictive ability to detect high TG/low HDL-C dyslipidaemia. Although AVI is not a diagnostic tool for MetS event, it is a useful assessment tool for MetS, and the simplicity of measuring WC and BMI extends its practical use.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported by any of the authors.

ABBREVIATIONS USED

ABSI: A body shape index; **AUC:** Area under curve; **AVI:** Abdominal volume index; **BAI:** Body adiposity index; **BMI:** Body mass index; **BP:** Blood pressure; **BRI:** Body roundness index; **CI:** Conicity index; **CVD:** Cardiovascular disease; **FG:** Fasting glucose; **FN:** False negative; **FP:** False positive; **HC:** Hip circumference; **HDL-C:** High-density lipoprotein cholesterol; **IDF:** International Diabetes Federation; **LAP:** lipid accumulation; **LR:** Likelihood ratio; **MetS:** Metabolic syndrome; **MetS-:** Metabolic syndrome absent; **MetS+:** Metabolic syndrome present; **NPV:** Negative predictive value; **PPV:** Positive predictive value; **ROC:** Receiver operating characteristic curve; **SN:** Sensitivity; **SP:** Specificity; **TG:** Triglyceride; **TN:** True negative; **TP:** True positive; **WC:** Waist circumference; **WHtR:** Waist-to-height ratio; **WTI:** Waist circumference-triglyceride index; **YI:** Youden index.

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Table 1: Mean of anthropometric measurements according to MetS category and sex

	Combined	MetS−	MetS+	
	Mean ± SD	Mean ± SD	Mean ± SD	*P*-value*
Males				
ABSI	0.07 ± 0.01	0.07 ± 0.01	0.08 ± 0.01	<0.001
AVI	13.31 ± 3.31	12.69 ± 2.57	20.51 ± 2.37	<0.001
CI	1.13 ± 0.10	1.12 ± 0.10	1.29 ± 0.07	<0.001
BRI	3.44 ± 1.22	3.24 ± 1.00	5.79 ± 1.06	<0.001
LAP	20.42 ± 2.21	17.81 ± 17.71	50.75 ± 18.90	<0.001
WTI	106.47 ± 7.86	103.40 ± 7.52	142.19 ± 10.41	<0.001
BMI	26.65 ± 4.60	26.22 ± 4.34	31.70 ± 4.58	<0.001
BAI	27.17 ± 7.35	26.41 ± 6.97	35.97 ± 5.82	<0.001
WHtR	0.50 ± 0.06	0.49 ± 0.05	0.61 ± 0.05	<0.001
HC	92.55 ± 12.16	90.76 ± 10.61	113.35 ± 9.34	<0.001
BMI$\sqrt{WC}$	24.00 ± 5.06	23.33 ± 4.47	31.84 ± 4.99	<0.001
Females				
ABSI	0.07 ± 0.01§	0.07 ± 0.01†	0.08 ± 0.01‡	<0.001
AVI	14.49 ± 3.88§	13.13 ± 3.40†	17.19 ± 3.34‡	<0.001
CI	1.17 ± 0.12§	1.14 ± 0.12†	1.23 ± 0.09‡	<0.001
BRI	3.80 ± 1.35§	3.37 ± 1.15†	4.65 ± 1.31‡	<0.001
LAP	32.98 ± 3.01§	23.64 ± 8.52†	51.49 ± 8.77	<0.001
WTI	106.19 ± 7.93	89.20 ± 6.14†	139.89 ± 9.79	<0.001
BMI	26.93 ± 4.78	25.91 ± 4.34	28.95 ± 4.97‡	<0.001
BAI	28.73 ± 6.94§	27.10 ± 5.93†	31.95 ± 7.65‡	<0.001
WHtR	0.50 ± 0.06§	0.50 ± 0.06†	0.56 ± 0.06‡	<0.001
HC	96.39 ± 12.87§	91.94 ± 11.63†	105.22 ± 10.42‡	<0.001
BMI$\sqrt{WC}$	24.75 ± 5.38§	23.20 ± 4.59	27.82 ± 5.53‡	<0.001

ABSI = a body shape index, AVI = abdominal volume index, CI = conicity index, BRI = body roundness index, LAP = lipid accumulation product, WTI = waist circumference-triglyceride index, BMI = body mass index, BAI = body adiposity index, WHtR = waist circumference-height ratio, HP = hip circumference,
**P* <0.001 as compared between MetS− and MetS+ groups.
§*P* <0.001 as compared between male and female subjects
†*P* <0.001 as compared between male MetS− and female MetS− groups.
‡*P* <0.001 as compared between male MetS+ and female MetS+ groups.

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Table 2: Intercorrelation matrix in anthropometric measures (n = 4,168)

	ABSI	AVI	CI	BRI	LAP	WTI	BMI	BAI	WHtR	HC	BMI$\sqrt{WC}$
Males											
ABSI	1	0.56[a]	0.96[a]	0.32[a]	0.37[a]	0.12[a]	−0.40[a]	0.04[b]	0.32[a]	0.43[a]	−0.16[a]
AVI		1	0.76[a]	0.87[a]	0.61[a]	0.15[a]	0.48[a]	0.57[a]	0.87[a]	0.86[a]	0.70[a]
CI			1	0.57[a]	0.49[a]	0.14[a]	−0.14[a]	0.26[a]	0.57[a]	0.61[a]	0.12[a]
BRI				1	0.52[a]	0.12[a]	0.71[a]	0.77[a]	1.00[a]	0.74[a]	0.85[a]
LAP					1	0.78[a]	0.26[a]	0.25[a]	0.52[a]	0.49[a]	0.40[a]
WTI						1	0.03	−0.01	0.12[a]	0.11[a]	0.07[a]
BMI							1	0.67[a]	0.71[a]	0.46[a]	0.97[a]
BAI								1	0.78[a]	0.70[a]	0.71[a]
WHtR									1	0.74[a]	0.84[a]
HC										1	0.63[a]
BMI$\sqrt{WC}$											1
Females											
ABSI	1	0.60[a]	0.97[a]	0.36[a]	0.29[a]	0.10[a]	−0.40[a]	0.09[a]	0.37[a]	0.51[a]	−0.13[a]
AVI		1	0.78[a]	0.88[a]	0.52[a]	0.21[a]	0.45[a]	0.59[a]	0.88[a]	0.87[a]	0.68[a]
CI			1	0.58[a]	0.38[a]	0.14[a]	−0.15[a]	0.29[a]	0.59[a]	0.67[a]	0.13[a]
BRI				1	0.45[a]	0.18[a]	0.68[a]	0.80[a]	1.00[a]	0.73[a]	0.84[a]
LAP					1	0.91[a]	0.26[a]	0.23[a]	0.45[a]	0.43[a]	0.38[a]
WTI						1	0.11[a]	0.03	0.17[a]	0.16[a]	0.16[a]
BMI							1	0.67[a]	0.68[a]	0.40[a]	0.96[a]
BAI								1	0.81[a]	0.70[a]	0.73[a]
WHtR									1	0.74[a]	0.83[a]
HC										1	0.60[a]
BMI$\sqrt{WC}$											1

ABSI = a body shape index, AVI = abdominal volume index, CI = conicity index, BRI = body roundness index, LAP = lipid accumulation product, WTI = waist circumference-triglyceride index, BMI = body mass index, BAI = body adiposity index, WHtR = waist circumference-height ratio, HP = hip circumference

a: indicates significant difference at P <0.01

b: indicates significant difference at P <0.05

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Table 3: Performance of various anthropometric parameters as predictors of MetS

	AUC (95% CI)	YI	Cutoff	Sn (%)	Sp (%)	LR (+)	LR (−)	NPV (%)	PPV (%)
Males									
ABSI	**0.82 (0.80, 0.83)**	0.51	0.08	73 (67, 79)	77 (76, 79)	3.21	0.34	97 (96, 98)	22 (20, 24)
AVI	**0.99 (0.98, 0.99)**	0.97	17.70	100 (98, 100)	97 (96, 97)	31.23	0.00	100 (99, 100)	73 (69, 77)
CI	**0.92 (0.91, 0.93)**	0.71	1.18	97 (94, 99)	74 (72, 75)	3.68	0.04	100 (99, 100)	24 (23, 25)
BRI	**0.96 (0.95, 0.97)**	0.81	4.15	98 (95, 100)	83 (81, 84)	5.64	0.02	100 (99, 100)	33 (31, 35)
LAP	**0.82 (0.80, 0.83)**	0.53	27	73 (67, 79)	79 (78, 81)	3.56	0.34	97 (97, 98)	24 (22, 26)
WTI	**0.62 (0.60, 0.64)**	0.24	131.76	50 (43, 56)	74 (73, 76)	1.94	0.68	95 (94, 95)	14 (13, 16)
BMI	**0.81 (0.80, 0.82)**	0.52	28.72	78 (72, 83)	74 (73, 76)	3.04	0.30	98 (97, 98)	21 (19, 22)
BAI	**0.87 (0.86, 0.88)**	0.67	30.24	92 (88, 95)	75 (73, 77)	3.66	0.10	99 (98, 99)	24 (23, 25)
WHtR	**0.96 (0.95, 0.97)**	0.80	0.53	100 (98, 100)	80 (79, 82)	5.08	0.00	100 (99, 100)	30 (29, 32)
HC	**0.94 (0.93, 0.95)**	0.79	99	96 (92, 98)	83 (82, 85)	5.80	0.05	100 (99, 100)	33 (31, 35)
BMI$\sqrt{WC}$	**0.90 (0.89, 0.91)**	0.68	27.62	84 (79, 89)	83 (82, 85)	5.05	0.19	98 (98, 99)	30 (28, 33)
Females									
ABSI	**0.65 (0.63, 0.68)**	0.25	0.07	79 (76, 83)	46 (43, 49)	1.47	0.45	82 (79, 84)	43 (41, 44)
AVI	**0.83 (0.81, 0.85)**	0.61	12.86	98 (97, 99)	62 (59, 65)	2.61	0.03	99 (97, 99)	57 (55, 59)
CI	**0.72 (0.69, 0.74)**	0.38	1.12	88 (85, 91)	50 (47, 53)	1.76	0.23	90 (87, 92)	47 (45, 49)
BRI	**0.78 (0.76, 0.80)**	0.46	3.70	75 (71, 79)	71 (68, 73)	2.56	0.35	85 (83, 87)	56 (54, 59)
LAP	**0.76 (0.73, 0.78)**	0.41	38	57 (53, 62)	84 (82, 86)	3.57	0.51	80 (78, 81)	64 (60, 68)
WTI	**0.67 (0.64, 0.69)**	0.29	115.5	56 (51, 60)	74 (71, 77)	2.12	0.60	77 (75, 79)	52 (48, 55)
BMI	**0.68 (0.65, 0.70)**	0.26	28.67	50 (46, 55)	75 (73, 78)	2.04	0.66	75 (73, 77)	51 (47, 54)
BAI	**0.73 (0.70, 0.75)**	0.39	29.14	71 (66, 75)	68 (65, 71)	2.23	0.43	82 (80, 84)	53 (50. 56)
WHtR	**0.79 (0.76, 0.81)**	0.45	0.51	76 (72, 80)	68 (65, 71)	2.41	0.35	85 (83, 87)	55 (52, 57)
HC	**0.80 (0.78, 0.82)**	0.49	91	91 (89, 94)	57 (54, 600	2.14	0.15	93 (91, 95)	52 (50, 54)
BMI$\sqrt{WC}$	**0.75 (0.72, 0.77)**	0.37	23.49	79 (75, 82)	59 (56, 62)	1.90	0.37	85 (82, 87)	49 (47, 51)

ABSI = a body shape index, AVI = abdominal volume index, CI = conicity index, BRI = body roundness index, LAP = lipid accumulation product, WTI = waist circumference-triglyceride index, BMI = body mass index, BAI = body adiposity index, WHtR = waist circumference-height ratio, HP = hip circumference

Boldface indicates statistical significance at P <0.05

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Table 4: Performance of various anthropometric parameters as predictors of components of MetS

MetS	AUC (95%)	YI	CP	SN	SP
ABSI	**0.73 (0.72, 0.75)**	0.36	0.08	63	72
AVI	**0.90 (0.89, 0.90)**	0.61	14.55	87	73
CI	**0.81 (0.80, 0.83)**	0.48	1.18	77	71
BRI	**0.85 (0.84, 0.86)**	0.56	3.95	79	77
LAP	**0.80 (0.79, 0.82)**	0.47	24.2	75	72
WTI	**0.63 (0.62, 0.65)**	0.25	115.5	56	69
BMI	**0.71 (0.70, 0.72)**	0.33	28.67	59	74
BAI	**0.78 (0.77, 0.79)**	0.47	29.18	78	69
WHtR	**0.85 (0.84, 0.86)**	0.55	0.53	76	79
HC	**0.86 (0.85, 0.87)**	0.61	99	80	81
BMI$\sqrt{WC}$	**0.79 (0.78, 0.80)**	0.43	27.37	61	82
Central obesity					
ABSI	**0.80 (0.79, 0.81)**	0.45	0.07	74	71
AVI	**0.93 (0.92, 0.94)**	0.68	13.24	94	74
CI	**0.87 (0.86, 0.88)**	0.57	1.18	79	78
BRI	**0.87 (0.86, 0.88)**	0.58	3.96	74	84
LAP	**0.79 (0.78, 0.80)**	0.45	24.2	68	77
WTI	**0.57 (0.55, 0.58)**	0.13	114.76	45	68
BMI	**0.67 (0.65, 0.68)**	0.26	27.47	58	68
BAI	**0.78 (0.76, 0.79)**	0.43	29.9	66	77
WHtR	**0.87 (0.86, 0.88)**	0.57	0.53	72	86
HC	**0.88 (0.87, 0.89)**	0.61	99	73	69
BMI$\sqrt{WC}$	**0.77 (0.75, 0.78)**	0.41	23.57	78	62
High FG					
ABSI	0.52 (0.51, 0.54)	0.08	0.07	80	28
AVI	**0.57 (0.55, 0.58)**	0.13	12.55	55	58
CI	**0.54 (0.53, 0.56)**	0.11	1.08	70	41
BRI	**0.56 (0.55, 0.58)**	0.15	3.75	38	77
LAP	**0.59 (0.57, 0.60)**	0.16	12.19	66	50
WTI	**0.58 (0.57, 0.60)**	0.15	51.68	78	38
BMI	**0.55 (0.54, 0.57)**	0.11	26.45	49	62
BAI	**0.55 (0.53, 0.56)**	0.14	29.93	36	77
WHtR	**0.56 (0.55, 0.58)**	0.15	0.52	37	78
HC	**0.55 (0.54, 0.57)**	0.13	98	38	75
BMI$\sqrt{WC}$	**0.56 (0.55, 0.58)**	0.11	28.19	23	88

ABSI = a body shape index, AVI = abdominal volume index, CI = conicity index, BRI = body roundness index, LAP = lipid accumulation product, WTI = waist circumference-triglyceride index, BMI = body mass index,
BAI = body adiposity index, WHtR = waist circumference-height ratio, HP = hip circumference
Boldface indicates statistical significance at $P < 0.05$

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Table 4: (Continued)

High BP	AUC (95%)	YI	CP	SN	SP
ABSI	**0.54 (0.52, 0.55)**	0.07	0.07	62	45
AVI	**0.52 (0.51, 0.54)**	0.10	15.54	32	78
CI	**0.52 (0.51, 0.54)**	0.06	1.16	61	45
BRI	**0.53 (0.52, 0.55)**	0.08	4.33	29	79
LAP	0.52 (0.50, 0.53)	0.06	29.92	32	75
WTI	**0.53 (0.51, 0.54)**	0.07	154.5	23	84
BMI	**0.57 (0.55, 0.58)**	0.12	24.14	75	37
BAI	**0.56 (0.54, 0.57)**	0.12	28.8	47	65
WHtR	**0.53 (0.52, 0.55)**	0.08	0.49	54	52
HC	**0.55 (0.53, 0.56)**	0.09	107	18	91
BMI$\sqrt{WC}$	**0.56 (0.54, 0.57)**	0.12	26.32	26	85
High TG					
ABSI	0.51 (0.49, 0.52)	0.04	0.06	15	89
AVI	0.51 (0.49, 0.52)	0.08	9.59	15	92
CI	0.51 (0.50, 0.53)	0.06	1.08	33	73
BRI	0.51 (0.49, 0.53)	0.06	2.65	31	76
LAP	**0.80 (0.79, 0.81)**	0.50	21.42	78	71
WTI	**0.99 (0.98, 0.99)**	0.92	128	98	94
BMI	0.50 (0.49, 0.52)	0.05	27.41	43	62
BAI	0.50 (0.49, 0.52)	0.03	31.5	76	27
WHtR	0.51 (0.49, 0.53)	0.05	0.46	32	73
HC	0.51 (0.49, 0.52)	0.05	78	16	89
BMI$\sqrt{WC}$	0.50 (0.49, 0.52)	0.06	23.24	56	50
Low HDL-C		YI	CP	SN	SP
ABSI	**0.55 (0.54, 0.57)**	0.12	0.07	28	84
AVI	**0.56 (0.54, 0.57)**	0.13	10.68	32	82
CI	**0.55 (0.54, 0.57)**	0.12	1.06	33	79
BRI	**0.53 (0.52, 0.55)**	0.08	3.82	72	35
LAP	**0.65 (0.63, 0.66)**	0.24	10.01	53	71
WTI	**0.68 (0.66, 0.69)**	0.31	98.4	82	49
BMI	0.50 (0.49, 0.52)	0.07	26.58	48	45
BAI	0.51 (0.50, 0.53)	0.06	33.76	24	82
WHtR	**0.53 (0.52, 0.55)**	0.08	0.52	72	35
HC	0.52 (0.51, 0.54)	0.05	83	26	79
BMI$\sqrt{WC}$	0.53 (0.51, 0.54)	0.09	23.79	61	48

ABSI = a body shape index, AVI = abdominal volume index, CI = conicity index, BRI = body roundness index, LAP = lipid accumulation product, WTI = waist circumference-triglyceride index, BMI = body mass index, BAI = body adiposity index, WHtR = waist circumference-height ratio, HP = hip circumference, Boldface indicates statistical significance at P <0.05

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Table 5: Comparison of diagnostic test accuracy of anthropometric measures in predicting risk conditions of MetS

	Males					Females				
Central obesity	AUC (95% CI)	YI	CP	SN	SP		YI	CP	SN	SP
ABSI	**0.84 (0.82, 0.85)**	0.52	0.07	80	71	**0.84 (0.82, 0.86)**	0.53	0.07	76	77
AVI	**1.00 (1.00, 1.00)**	1.00	17.50	100	100	**1.00 (0.99, 1.00)**	1.00	12.76	100	100
CI	**0.94 (0.93, 0.95)**	0.72	1.21	86	86	**0.92 (0.90, 0.93)**	0.69	1.14	87	82
BRI	**0.97 (0.96, 0.98)**	0.84	4.15	99	85	**0.91 (0.90, 0.93)**	0.65	3.62	74	91
LAP	**0.82 (0.81, 0.84)**	0.52	27.6	70	82	**0.76 (0.73, 0.78)**	0.42	30.6	57	85
WTI	**0.61 (0.59, 0.63)**	0.23	117	55	69	**0.59 (0.56, 0.61)**	0.13	114	42	71
BMI	**0.80 (0.78, 0.81)**	0.49	27.64	80	68	**0.65 (0.63, 0.68)**	0.24	25.39	68	56
BAI	**0.86 (0.85, 0.88)**	0.63	30.57	84	78	**0.80 (0.77, 0.82)**	0.48	25.65	86	63
WHtR	**0.97 (0.96, 0.98)**	0.83	0.53	100	83	**0.91 (0.90, 0.93)**	0.64	0.5	80	84
HC	**0.94 (0.93, 0.95)**	0.80	99	94	86	**0.94 (0.93, 0.95)**	0.76	91	90	86
BMI$\sqrt{WC}$	**0.90 (0.89, 0.91)**	0.64	27.52	80	80	**0.78 (0.75, 0.80)**	0.44	23.49	71	72
High FG										
ABSI	0.52 (0.50, 0.54)	0.07	0.08	97	10	**0.59 (0.57, 0.62)**	0.17	0.07	50	67
AVI	**0.55 (0.53, 0.57)**	0.10	12.24	55	55	**0.60 (0.57, 0.62)**	0.21	14.59	50	71
CI	0.51 (0.49, 0.53)	0.08	1.12	67	42	**0.61 (0.58, 0.63)**	0.19	1.19	47	72
BRI	**0.55 (0.53, 0.57)**	0.13	2.99	34	79	**0.58 (0.55, 0.61)**	0.20	4.22	37	83
LAP	**0.58 (0.57, 0.60)**	0.15	4.8	83	33	**0.60 (0.57, 0.62)**	0.17	16.12	71	47
WTI	**0.55 (0.53, 0.57)**	0.12	70.2	33	79	**0.57 (0.55, 0.60)**	0.17	46.28	79	38
BMI	**0.58 (0.56, 0.60)**	0.17	25.95	53	62	0.51 (0.48, 0.53)	0.08	24.26	33	76
BAI	**0.55 (0.53, 0.57)**	0.14	32.92	33	81	**0.54 (0.51, 0.57)**	0.13	29.93	42	70
WHtR	**0.59 (0.57, 0.61)**	0.16	0.52	66	50	**0.58 (0.56, 0.61)**	0.20	0.52	45	75
HC	**0.54 (0.52, 0.55)**	0.10	98	32	78	**0.57 (0.55, 0.60)**	0.19	98	50	69
BMI$\sqrt{WC}$	**0.58 (0.56, 0.60)**	0.14	24.23	44	70	0.53 (0.50, 0.55)	0.12	29.15	20	92
High BP										
ABSI	0.50 (0.49, 0.52)	0.03	0.07	31	72	**0.59 (0.56, 0.61)**	0.19	0.07	64	55
AVI	**0.55 (0.53, 0.57)**	0.14	15.22	32	81	0.51 (0.48, 0.54)	0.09	11.07	24	85
CI	0.51 (0.50, 0.53)	0.06	1.21	26	80	**0.57 (0.55, 0.60)**	0.16	1.16	57	59
BRI	**0.55 (0.54, 0.57)**	0.11	4.14	29	82	0.51 (0.48, 0.54)	0.06	4.27	35	70
LAP	**0.54 (0.52, 0.56)**	0.12	29.7	27	84	0.50 (0.48, 0.53)	0.08	46.4	27	81
WTI	**0.53 (0.51, 0.55)**	0.08	162.5	21	87	0.51 (0.49, 0.54)	0.06	27.9	82	12
BMI	**0.56 (0.54, 0.58)**	0.11	24.17	73	38	**0.58 (0.56, 0.60)**	0.14	24.14	78	36
BAI	**0.58 (0.56, 0.60)**	0.14	27.41	51	62	**0.54 (0.51, 0.56)**	0.12	28.8	53	58
WHtR	**0.55 (0.53, 0.57)**	0.10	0.54	27	83	0.51 (0.48, 0.54)	0.05	0.54	36	69
HC	**0.58 (0.57, 0.60)**	0.13	89	56	57	0.51 (0.48, 0.53)	0.12	108	23	89
BMI$\sqrt{WC}$	**0.56 (0.54, 0.58)**	0.12	28.3	25	87	**0.57 (0.54, 0.59)**	0.12	28.27	30	82

ABSI = a body shape index, AVI = abdominal volume index, CI = conicity index, BRI = body roundness index,
LAP = lipid accumulation product, WTI = waist circumference-triglyceride index, BMI = body mass index,
BAI = body adiposity index, WHtR = waist circumference-height ratio, HP = hip circumference,
Boldface indicates statistical significance at $P < 0.05$

ISSN: 0975-3583,0976-2833 VOL14, ISSUE 01, 2023

Table 5: (Continued)

	Males					Females				
High TG	AUC (95% CI)	YI	CP	SN	SP	AUC (95% CI)	YI	CP	SN	SP
ABSI	0.50 (0.48, 0.52)	0.05	0.08	22	82	0.52 (0.50, 0.55)	0.06	0.07	44	63
AVI	0.52 (0.50, 0.54)	0.09	9.90	20	89	0.52 (0.50, 0.54)	0.10	12.21	74	35
CI	0.51 (0.49, 0.53)	0.07	1.08	36	71	0.52 (0.49, 0.54)	0.07	1.16	55	52
BRI	0.50 (0.50, 0.53)	0.08	2.65	34	73	0.51 (0.48, 0.53)	0.08	5.32	19	89
LAP	**0.78 (0.76, 0.79)**	0.51	21.39	70	80	**0.90 (0.88, 0.91)**	0.65	39.6	79	86
WTI	**0.99 (0.99, 0.99)**	0.93	128	99	94	**0.99 (0.99, 0.99)**	0.91	128	97	94
BMI	0.51 (0.50, 0.53)	0.05	29.4	79	26	**0.54 (0.51, 0.56)**	0.12	27.41	51	61
BAI	0.48 (0.48, 0.52)	0.05	31.6	80	25	0.50 (0.48, 0.52)	0.04	27.22	47	58
WHtR	0.51 (0.50, 0.53)	0.06	0.52	65	29	0.51 (0.50, 0.53)	0.08	0.59	19	89
HC	0.51 (0.49, 0.53)	0.06	78	18	88	0.50 (0.47, 0.53)	0.05	98	43	52
BMI$\sqrt{WC}$	0.51 (0.49, 0.53)	0.06	25.35	71	35	**0.54 (0.51, 0.56)**	0.12	27.07	39	73
Low HDL-C										
ABSI	**0.58 (0.56, 0.60)**	0.18	0.07	34	83	**0.55 (0.53, 0.58)**	0.11	0.07	54	57
AVI	**0.57 (0.55, 0.60)**	0.18	10.68	38	80	**0.57 (0.55, 0.59)**	0.15	17	90	25
CI	**0.58 (0.56, 0.59)**	0.18	1/07	45	73	**0.56 (0.53, 0.59)**	0.15	1.23	81	34
BRI	0.54 (0.52, 0.55)	0.12	2.75	44	67	**0.56 (0.54, 0.59)**	0.16	4.37	85	31
LAP	**0.71 (0.69, 0.73)**	0.33	9.92	68	65	**0.63 (0.61, 0.66)**	0.23	24.3	69	54
WTI	**0.71 (0.70, 0.73)**	0.34	98.4	85	49	**0.63 (0.61, 0.66)**	0.28	98	79	50
BMI	0.51 (0.49, 0.53)	0.10	26.57	54	56	0.53 (0.50, 0.55)	0.09	30	83	25
BAI	0.53 (0.51, 0.56)	0.09	33.76	26	83	0.53 (0.51, 0.55)	0.10	27.22	52	58
WHtR	0.53 (0.52, 0.55)	0.10	0.46	40	69	**0.56 (0.54, 0.59)**	0.15	0.52	71	44
HC	0.52 (0.50, 0.54)	0.05	83	30	76	**0.56 (0.53, 0.58)**	0.14	102	81	33
BMI$\sqrt{WC}$	0.52 (0.50, 0.54)	0.06	21.5	43	64	**0.55 (0.52, 0.58)**	0.15	23.79	61	54

ABSI = a body shape index, AVI = abdominal volume index, CI = conicity index, BRI = body roundness index, LAP = lipid accumulation product, WTI = waist circumference-triglyceride index, BMI = body mass index, BAI = body adiposity index, WHtR = waist circumference-height ratio, HP = hip circumference,
Boldface indicates statistical significance at P <0.05