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The predictive power of conventional and novel obesity indices in identifying metabolic syndrome among the southern Iranian populations: findings from PERSIAN cohort study

Arash Rahimi[1], Shideh Rafati[2], Abnoos Azarbad[1], Hoda Safa[3], Mehdi Shahmoradi[4], Ali Salimi Asl[5], Mahtab Niazi[5], Salma Ahi[1], Shahrzad Tabasi[5] and Masoumeh Kheirandish[1*]

Abstract

Background Metabolic syndrome (MetS) contributes to an increased risk of cardiovascular diseases. Traditional metrics like body mass index (BMI) have limitations in discerning fat distribution. The purpose of this study was to evaluate the diagnostic accuracy of traditional and novel anthropometric indices in metabolic syndrome and its components in the south coast of Iran.

Methods In this cross-sectional study, 2694 adults aged 35 to 70 were included. Comprehensive anthropometric and biochemical data were collected and analyzed. There were eight anthropometric indices evaluated in this study, including a body shape index (ABSI), body mass index (BMI), waist circumference (WC), waist-hip ratio (WHR), body roundness index (BRI), abdominal volume index (AVI), weight-adjusted waist index (WWI) and waist-height ratio (WHtR).

Results WHtR (AUC: 0.766 for males, 0.799 for females), BRI (AUC: 0.766 for males, 0.799 for females), and AVI (AUC: 0.769 for males, 0.793 for females) were the best predictors of MetS. ABSI had the weakest correlation with metabolic variables.

Conclusions AVI, WHtR, BRI, and WHR were superior to other measures as anthropometric indexes for determining MetS and its components. The study contributes valuable insights into the utility of traditional and novel metrics in clinical practice, highlighting the need for standardized diagnostic approaches and further research in diverse populations.

Keywords Novel obesity indices, Traditional obesity indices, Prospective epidemiological research in IrAN (PERSIAN), Metabolic syndrome, Bandare-Kong non-communicable disease

*Correspondence:
Masoumeh Kheirandish
kheirandishm@yahoo.com

Full list of author information is available at the end of the article

Background

Metabolic syndrome is characterized by several clinical findings, including abdominal obesity, high glucose levels, high triglyceride levels, low high-density lipoprotein cholesterol levels, and hypertension. This might be a disguised disease, given the fact that it can present in many different ways based on the various components of the syndrome [1–3]. Prevalence estimates vary depending on the criteria used to define MetS. According to an Iranian study conducted in 2007, the prevalence of MetS ranged between 34.7% and 41.6% based on the ATP III criteria, the IDF definition, or the ATP III/AHA/NHLBI criteria. Tunisia, another Middle Eastern country, reported a prevalence of 45.5% based on IDF criteria but only 24.3% based on ATP III criteria [4, 5]. However, in all Middle Eastern countries, the prevalence is higher among women than men. Over the past two decades, an increase in the prevalence of MetS has been observed worldwide [6]. Therefore, early and precise prediction of metabolic syndrome is essential to prevent its complications. Body mass index (BMI) is one of the most commonly used morphological indices in clinical practice to estimate central obesity and body fat. However, the lack of differentiation between fat and muscle and the inability to recognize fat distribution are two critical limitations of BMI. Some other indices of abdominal obesity, such as waist circumference (WC), waist-hip ratio (WHR), and waist-height ratio (WHtR), have been shown to be better discriminators of metabolic risk factors than BMI [7]. The abdominal volume index (AVI) indirectly reflected visceral fat content by assessing the entire abdominal volume. There is a close relationship between AVI and impaired glucose tolerance (IGT) as well as diabetes mellitus (DM) [8]. A Body Shape Index (ABSI) was proposed in 2012 as a tool for predicting the risk of pathologies that cannot be easily identified by BMI. ABSI has been associated with all-cause mortality, metabolic syndrome, diabetes, and hypertension [9]. In 2013, Thomas DM et al. suggested that the Body Roundness Index (BRI) predicts visceral adiposity tissue and body fat percentage [10]. A systematic review and meta-analysis by Rico-Martín et al. [11] evaluated the effectiveness of BRI in predicting MetS across diverse populations and aimed to investigate whether BRI is superior to conventional anthropometric indices in predicting MetS. It was also the first study to show BRI as an effective predictor of metabolic syndrome in men and women of diverse ethnicities and nationalities. The weight-adjusted waist index (WWI) was proposed by Yousung Park et al. [12] to assess adiposity by standardizing waist circumference for weight.

Nevertheless, research from different countries and ethnicities regarding the superiority of obesity indices and their cut-off points for diagnosing obesity and MetS has produced contrary results [13]. Therefore, our study aimed to compare the predictive capacity of traditional and novel anthropometric indices for identifying MetS in the Bandar Kong cohort population in the south of Iran.

Methods

Study design and participants

We investigated the baseline data from the Bandare-Kong Cohort Study, a population-based cohort study, within the Prospective Epidemiological Research Studies in IrAN (PERSIAN). The PERSIAN cohort study recruited individuals aged 35–70 from 18 geographically distinct areas of Iran, the details of which are available [14]. A total of 4063 individuals aged 35–70 years were recruited between November 17, 2016, and November 22, 2018, from Bandare-Kong, Hormozgan Province, in the south of Iran [15]. Pregnant women, subjects with missing variables, and those with cardiovascular diseases, cancer, and hepatitis were excluded from the final analysis. Finally, 2694 subjects were included in the study. Informed consent was obtained from the study participants. A number of essential characteristics, including age, gender, education, occupation, and social data, such as smoking status, diet, and physical activity, were collected. The information was collected through face-to-face interviews conducted by trained staff using valid and reliable questionnaires designed to collect data at all PERSIAN cohort sites.

Anthropometric and biochemical measurements

A digital scale was used to measure the subjects' weight while wearing light clothing and no shoes (to the nearest 0.5 kg). Height was measured while participants stood on the stadiometer without shoes. WC was measured at the midpoint between the top of the iliac crest and the last palpable rib's inferior margin in the mid-axillary line after several consecutive breaths. WC was measured twice for every participant, and the average of the two measurements was recorded. Hip circumference (HC) was measured at the maximum circumference of the buttocks. Trained staff did all measurements using the same stretch-resistant tape to the nearest 0.5 cm. To determine the waist-to-hip ratio (WHR), WC was divided by HC to the nearest 0.01. BMI was calculated by dividing weight in kilograms by height in square meters. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured using a standard mercury sphygmomanometer in the seated position after 15 min of rest with the arm placed at heart level. The mean of two successive measurements was recorded. Blood samples were collected after 8 h of overnight fasting. The glucose oxidase method was applied to measure fasting plasma glucose (FPG) levels. Furthermore, venous blood samples were taken to evaluate total cholesterol (TC), triglyceride (TG), low-density lipoprotein (LDL), and high-density lipoprotein (HDL) levels after 12 h of overnight fasting. The enzymatic method was used for lipid measurements.

Based on the study by Azizi et al., the cut-off value for WC of Iranian men and women was 95 cm [16]. The Iranian National Committee of Obesity considered this cut-off as well as the following criteria for MetS, with any three out of five criteria qualifying a person for MetS [17]:

1) WC ≥ 95 cm.
2) FPG ≥ 100 mg/dL or drug treatment for elevated blood glucose.
3) HDL < 40 mg/dL in men, < 50 mg/dL in women, or drug treatment for low HDL.
4) TG ≥ 150 mg/dL or drug treatment for elevated TG.
5) BP ≥ 130/85 mmHg or drug treatment for hypertension.

$$\mathrm{BMI} = \frac{\mathrm{Weight\ (kg)}}{\mathrm{Height(m)}^2},\quad \mathrm{WHtR} = \frac{\mathrm{WC\ (cm)}}{\mathrm{Height\ (cm)}},$$
$$\mathrm{WHR} = \frac{\mathrm{WC}}{\mathrm{HC}},\quad \mathrm{ABSI} = \frac{\mathrm{WC}}{\mathrm{BMI}^{2/3}\,\mathrm{Height}^{1/2}}$$

$$\mathrm{BRI} = 364.3 - 365.5 \times \sqrt[2]{1 - \left(\frac{\left(\mathrm{WC}/2\pi\right)^2}{(0.5 \times \mathrm{Height})^2}\right.},$$
$$\mathrm{AVI} = \frac{2 \times (\mathrm{waist})^2 + 0.7 \times (\mathrm{waist} - \mathrm{hip})^2}{1000}$$

$$\mathrm{WWI} = \frac{\mathrm{WC}}{\sqrt{\mathrm{weight}}}$$

Research ethics and patient consent

The study received ethics approval (ethics code: IR.HUMS.REC.1402.247) from the Ethics Committee of Hormozgan University of Medical Sciences, and it complies with the statements of the Declaration of Helsinki. Informed consent was obtained from all subjects. For the vulnerable population, informed consent was obtained from parents or legal guardians.

Statistical analysis

The data were examined, and if an anthropometric index was more than Q3+3IQR or less than Q1−3IQR, an influential outlier was removed (Q1: first quartile, Q3: third quartile, IQR: Q3−Q1). Continuous variables were described by mean and standard deviation and categorical variables by frequency and percentage. In order to compare the mean of continuous variables between two groups, males and females, the t-test was used. Furthermore, the Chi-square test was used to examine the association between gender and each categorical variable. Partial correlation analysis was used to assess the correlation between metabolic variables (SBP, DBP, TG, HDL-C, and FBG) and traditional and novel anthropometric indices (WHtR, BMI, WHR, BRI, AVI, WWI, and ABSI) whilst controlling for the effect of age.

An analysis of binary logistic regression was conducted to evaluate the relationship between anthropometric indicators and MetS and its components. The ROC and AUC were used to evaluate the ability of different anthropometric indices to predict MetS and its components. Hanley and McNeil's method was used to determine AUC differences in MetS between traditional and novel anthropometric indices [25]. Finally, the optimal cut-off values of various anthropometric indicators for MetS identification were determined by Youden's J statistic (maximum [sensitivity+specificity −1]). The ROC curve comparison was conducted using MedCalc Version 20, and the other statistical analyses were conducted using IBM SPSS 23.0. A two-sided P-value<0.05 was considered statistically significant. Moreover, P-values were adjusted for multiple comparisons. Taking into account the Bonferroni correction (dividing the significance level of 0.05 by the number of comparisons being made [depending on the circumstances, 6 or 7 comparisons]), the significance level for a given comparison would be 0.008 or 0.007.

Results

There were 2694 participants in total, of which 1359 were females (50.4%), and 1591 had a BMI≥25 (59.1%). The prevalence of MetS was 29.8% (17.0% among females and 12.8% among males). The prevalence of abdominal obesity (1093; 40.6%), low HDL-C (1062; 39.4%), and impaired glucose levels (985; 36.6%) were higher than other MetS components. Anthropometric indices (WC, WHtR, BMI, WHR, BRI, AVI, WWI, ABSI) were significantly higher in females than in their counterparts. Also, among clinical indicators, SBP, DBP, and TG were significantly higher in males than females; however, FPG, TC, LDL-C, and HDL-C were higher in females than males. Individual characteristics, anthropometric indices, clinical indices, and MetS components based on gender and BMI (<25 and ≥25) are shown in Tables 1 and 2, respectively.

After adjusting for age, most anthropometric measures were significantly correlated with metabolic variables for both males and females. ABSI had the weakest correlation with metabolic variables. Among metabolic variables, LDL-C had the weakest correlation with anthropometric measures. All anthropometric measures had a negative correlation with HDL-C (Table 3).

Based on Table 4, after adjusting for age, most anthropometric measures were significantly correlated with

Table 1 Characteristics of the study participants by gender

Variables	Total (*n* = 2694)	Male (*n* = 1335; 49.6%)	Female (*n* = 1359; 50.4%)	*P* value
Age(years); Mean (SD)	47.34(9.09)	47.32(9.17)	47.37(9.02)	0.898
Education				
Low (< 6 years)	1520(56.4%)	565(21.0%)	955(35.4%)	< 0.001
Middle (6–12 years)	927(34.4%)	600(22.3%)	327(12.1%)	
High (> 12 years)	247(9.2%)	170(6.3%)	77(2.9%)	
Residence				
Urban	2275(84.4%)	1148(42.6%)	1127(41.8%)	0.029
Rural	419(15.6%)	187(6.9%)	232(8.6%)	
Marital Status				
Single	73(2.7%)	21(0.8%)	52(1.9%)	< 0.001
Married	2433(90.3%)	1299(48.2%)	1134(42.1%)	
Widowed/Divorced	188(7.0%)	15(0.6%)	173(6.4%)	
Job				
No	1311(48.7%)	167(6.2%)	1144(42.5%)	< 0.001
Yes	1383(51.3%)	1168(43.4%)	215(7.9%)	
Smoke cigarette				
No	2268(84.2%)	913(33.9%)	1355(50.3%)	< 0.001
Yes	426 (15.8%)	422(15.7%)	4(0.1%)	
Hookah				
No	2223(82.7%)	1038(38.6%)	1185(44.1%)	< 0.001
Yes	465(17.3%)	295(11.0%)	170(6.3%)	
Height (cm)	163.36(9.21)	170.31(6.44)	156.53(5.77)	< 0.001
Weight (kg)	70.39(14.05)	74.23(14.18)	66.62(12.86)	< 0.001
WC (cm)	92.36(11.54)	89.71(11.07)	94.96(11.41)	< 0.001
WHtR	0.57(0.08)	0.53(0.06)	0.61(0.07)	< 0.001
BMI	26.36(4.73)	25.53(4.37)	27.17(4.94)	< 0.001
WHR	0.93(0.06)	0.92(0.06)	0.94(0.07)	< 0.001
BRI	4.84(1.75)	3.96(1.29)	5.71(1.72)	< 0.001
AVI	17.38(4.28)	16.40(3.99)	18.36(4.33)	< 0.001
WWI	11.07(0.92)	10.44(0.62)	11.68(0.74)	< 0.001
ABSI	0.82(0.05)	0.79(0.04)	0.84(0.05)	< 0.001
SBP	117.60(16.86)	119.60(16.06)	115.63(17.39)	< 0.001
DBP	76.42(10.26)	77.98(9.77)	74.89(10.50)	< 0.001
FPG	105.83(40.66)	103.89(36.31)	107.74(44.46)	0.014
TC (mg/dl)	202.00(38.50)	199.57(36.22)	204.39(40.49)	0.001
TG (mg/dl)	127.05(59.24)	136.24(63.42)	118.02(53.33)	< 0.001
HDL-C (mg/dl)	47.90(10.41)	45.08(9.39)	50.67(10.63)	< 0.001
LDL-C (mg/dl)	128.71(32.64)	127.31(31.23)	130.08(33.92)	0.027
High BP level (n, %)	873(32.4%)	442(16.4%)	431(16.0%)	0.459
Abdominal Obesity (n, %)	1093(40.6%)	420(15.6%)	673(25.0%)	< 0.001
Impaired glucose levels (n, %)	985(36.6%)	483(17.9%)	502(18.7%)	0.689
High TG level (n, %)	873(32.4%)	491(18.2%)	382(14.2%)	< 0.001
Low HDL-C level (n, %)	1062(39.4%)	380(14.1%)	682(25.3%)	< 0.001
MetS (n, %)	803(29.8%)	346(12.8%)	457(17.0%)	< 0.001

P value: Calculated by $\chi 2$ test or t-test; WC: waist circumference; WHR: waist-hip ratio; WHtR: waist-height ratio; BMI: body mass index; AVI: abdominal volume index; ABSI: A Body Shape Index; MetS: metabolic syndrome; BRI: Body Roundness Index; WWI: weight-adjusted waist index; SBP: systolic blood pressure; DBP: diastolic blood pressure, FPG: fasting plasma glucose; TC: total cholesterol; TG: triglyceride

metabolic variables, both for individuals with BMI < 25 as well as those with BMI ≥ 25. ABSI had the weakest correlation with metabolic variables.

Binary logistic regression analysis was conducted using anthropometric Z-scores after adjusting the age variable where the response was MetS and its components (Tables 5 and 6). There were significant relationships between anthropometric indices and MetS; WHtR (males OR = 3.76, $p < 0.001$; females OR = 3.75, $p < 0.001$) and BRI (males OR = 3.88, $p < 0.001$; females OR = 3.26,

Table 2 Characteristics of the study participants by BMI

Variables	Total (*n* = 2694)	BMI < 25 (*n* = 1103;40.9%)	BMI ≥ 25 (*n* = 1591;59.1%)	*P* value
Age(years); Mean (SD)	47.34(9.09)	47.88(9.54)	46.98(8.75)	0.013
Gender				
Male	1335(49.6%)	640(23.8%)	695(25.8%)	< 0.001
Female	1359(50.4%)	463(17.2%)	896(33.3%)	
Education				
Low (< 6 years)	1520(56.4%)	625(23.2%)	895(33.2%)	0.053
Middle (6–12 years)	927(34.4%)	394(14.6%)	533(19.8%)	
High (> 12 years)	247(9.2%)	84(3.1%)	163(6.1%)	
Residence				
Urban	2275(84.4%)	914(33.9%)	1361(50.5%)	0.066
Rural	419(15.6%)	189(7.1%)	230(8.5%)	
Marital Status				
Single	73(2.7%)	47(1.7%)	26(1.0%)	< 0.001
Married	2433(90.3%)	991(36.8%)	1442(53.5%)	
Widowed/Divorced	188(7.0%)	65(2.4%)	123(4.6%)	
Job				
No	1311(48.7%)	474(17.6%)	837(31.1%)	< 0.001
Yes	1383(51.3%)	629(23.3%)	754(28.0%)	
Cigarette smoking				
No	2268(84.2%)	866(32.1%)	1402(52.1%)	< 0.001
Yes	426 (15.8%)	237(8.8%)	189(7.0%)	
Hookah				
No	2223(82.7%)	886(33.0%)	1337(49.7%)	0.007
Yes	465(17.3%)	217(8.1%)	248(9.2%)	
Height (cm)	163.36(9.21)	164.35(8.91)	162.67(9.36)	< 0.001
Weight (kg)	70.39(14.05)	59.54(8.75)	77.91(11.96)	< 0.001
WC (cm)	92.36(11.54)	82.71(7.65)	99.04(8.71)	< 0.001
WHtR	0.57(0.08)	0.50(0.05)	0.61(0.06)	< 0.001
BMI	26.36(4.73)	21.98(2.19)	29.39(3.49)	< 0.001
WHR	0.93(0.06)	0.90(0.06)	0.95(0.06)	< 0.001
BRI	4.84(1.75)	3.51(1.03)	5.76(1.54)	< 0.001
AVI	17.38(4.28)	13.88(2.46)	19.81(3.52)	< 0.001
WWI	11.07(0.92)	10.77(0.92)	11.27(0.87)	< 0.001
ABSI	0.82(0.05)	0.82(0.06)	0.81(0.05)	0.003
SBP	117.60(16.86)	114.77(16.64)	119.56(16.75)	< 0.001
DBP	76.42(10.26)	74.56(10.49)	77.72(9.89)	< 0.001
FPG	105.83(40.66)	103.67(41.88)	107.33(39.73)	0.021
TC (mg/dl)	202.00(38.50)	197.91(38.49)	204.84(38.27)	< 0.001
TG (mg/dl)	127.05(59.24)	112.43(56.96)	137.18(58.69)	< 0.001
HDL-C (mg/dl)	47.90(10.41)	49.10(10.71)	47.07(10.12)	< 0.001
LDL-C (mg/dl)	128.71(32.64)	126.33(32.33)	130.35(32.77)	0.002
High BP level (n, %)	873(32.4%)	281(10.4%)	592(22.0%)	< 0.001
Abdominal Obesity (n, %)	1093(40.6%)	45(1.7%)	1048(38.9%)	< 0.001
Impaired glucose levels (n, %)	985(36.6%)	331(12.3%)	654(24.3%)	< 0.001
High TG level (n, %)	873(32.4%)	248(9.2%)	625(23.2%)	< 0.001
Low HDL-C level (n, %)	1062(39.4%)	346(12.8%)	716(26.6%)	< 0.001
MetS (n, %)	803(29.8%)	126(4.7%)	677(25.1%)	< 0.001

P-value: Calculated by χ2 test or t-test. WC: waist circumference; WHR: waist-hip ratio; WHtR: waist-height ratio; BMI: body mass index; AVI: abdominal volume index; ABSI: A Body Shape Index; MetS: metabolic syndrome; BRI: Body Roundness Index; WWI: weight-adjusted waist index; SBP: systolic blood pressure; DBP: diastolic blood pressure, FPG: fasting plasma glucose; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol

Table 3 Partial correlation between different anthropometric indices and metabolic variables based on gender

Variable	WHtR	BMI	WHR	BRI	AVI	WWI	ABSI
Male							
SBP	0.258 (< 0.001)	0.252 (< 0.001)	0.212 (< 0.001)	0.250 (< 0.001)	0.251 (< 0.001)	0.175 (< 0.001)	0.060 (0.028)
DBP	0.259 (< 0.001)	0.259 (< 0.001)	0.218 (< 0.001)	0.252 (< 0.001)	0.265 (< 0.001)	0.169 (< 0.001)	0.063 (0.022)
FPG	0.105 (< 0.001)	0.103 (< 0.001)	0.146 (< 0.001)	0.102 (< 0.001)	0.093 (0.001)	0.072 (0.008)	0.021 (0.448)
TC	0.135 (< 0.001)	0.121 (< 0.001)	0.101 (< 0.001)	0.130 (< 0.001)	0.114 (< 0.001)	0.108 (< 0.001)	0.035 (0.200)
TG	0.263 (< 0.001)	0.241 (< 0.001)	0.277 (< 0.001)	0.251 (< 0.001)	0.256 (< 0.001)	0.203 (< 0.001)	0.106 (< 0.001)
HDL-C	-0.158 (< 0.001)	-0.147 (< 0.001)	-0.181 (< 0.001)	-0.143 (< 0.001)	-0.161 (< 0.001)	-0.118 (< 0.001)	-0.075 (0.006)
LDL-C	0.097 (< 0.001)	0.087 (0.001)	0.059 (0.032)	0.092 (0.001)	0.076 (0.005)	0.079 (0.004)	0.020 (0.474)
Female							
SBP	0.239 (< 0.001)	0.234 (< 0.001)	0.199 (< 0.001)	0.237 (< 0.001)	0.234 (< 0.001)	0.122 (< 0.001)	-0.011 (0.678)
DBP	0.204 (< 0.001)	0.220 (< 0.001)	0.144 (< 0.001)	0.200 (< 0.001)	0.196 (< 0.001)	0.074 (0.007)	-0.053 (0.052)
FPG	0.117 (< 0.001)	0.053 (0.052)	0.233 (< 0.001)	0.116 (< 0.001)	0.121 (< 0.001)	0.156 (< 0.001)	0.130 (< 0.001)
TC	0.095 (< 0.001)	0.088 (0.001)	0.060 (0.028)	0.088 (0.001)	0.065 (0.016)	0.060 (0.026)	-0.014 (0.596)
TG	0.274 (< 0.001)	0.258 (< 0.001)	0.278 (< 0.001)	0.265 (< 0.001)	0.257 (< 0.001)	0.159 (< 0.001)	0.009 (0.736)
HDL-C	-0.123 (< 0.001)	-0.125 (< 0.001)	-0.189 (< 0.001)	-0.111 (< 0.001)	-0.135 (< 0.001)	-0.056 (0.041)	-0.008 (0.773)
LDL-C	0.067 (0.013)	0.065 (0.017)	0.045 (0.100)	0.059 (0.031)	0.041 (0.130)	0.041 (0.135)	-0.016 (0.545)

The partial correlation is adjusted for age; z-scores of clinical indicators and anthropometric indices were used. Partial correlation coefficient (P-value) has been reported in cells. The adjusted significance level based on Bonferroni Correction is equal to 0.007 ;WC: waist circumference; WHR: waist-hip ratio; WHtR: waist-height ratio; BMI: body mass index; AVI: abdominal volume index; ABSI: A Body Shape Index; MetS: metabolic syndrome; BRI: Body Roundness Index; WWI: weight-adjusted-waist index; SBP: systolic blood pressure; DBP: diastolic blood pressure, FPG: fasting plasma glucose; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol

$p<0.001$) had the strongest relationship with MetS, and ABSI had the weakest OR (males OR = 1.19, $p<0.05$; females OR = 1.18, $p<0.05$) (Table 5). Based on Table 6, the relationship between ABSI and Mets is the weakest both for people who had BMI < 25 (OR = 1.41, $p<0.001$) and those with BMI ≥ 25(OR = 1.39, $p<0.001$) and AVI had the strongest relationship with MetS than other anthropometric measures (BMI < 25: OR = 4.35, $p<0.001$; BMI ≥ 25: OR = 2.21, $p<0.001$).

Based on Table 7; Fig. 1, WHtR (AUC: 0.766 for males, 0.799 for females), BRI (AUC: 0.766 for males, 0.799 for females), and AVI (AUC: 0.769 for males, 0.793 for females) had the best ability to predict MetS.

Based on Table 8; Fig. 2, WHR (AUC: 0.765 for BMI < 25, 0.692 for BMI ≥ 25) and AVI (AUC: 0.731 for BMI < 25, 0.702 for BMI ≥ 25) had the best ability to predict MetS. WHtR and BRI both showed similar ability to predict MetS (AUC: 0.699 for BMI < 25 and 0.677 for BMI ≥ 25).

Based on Table 10, for people with BMI < 25, there was no significant difference between the ability of WHtR and BRI, as well as between WWI and ABSI, to predict MetS. For people with BMI ≥ 25, there were no significant differences between WHtR, WHR, and BRI, as well as between WHR and AVI.

Table 11 shows the optimal cut-off value for each anthropometric index to identify MetS by gender. Based on the findings of this table, WHR had the highest sensitivity (0.798), and AVI had the highest specificity (0.816) for screening MetS in males. Among females, WHtR and BRI had the highest sensitivity (0.849), and WHR had the highest specificity (0.693).

Table 12 shows the optimal cut-off value for each anthropometric index to identify MetS by BMI. Based on the findings of this table, WHR had the highest sensitivity (0.738), and WWI had the highest specificity (0.853) for screening MetS in people with BMI < 25. For people with BMI ≥ 25, AVI had the highest sensitivity (0.860), and WWI had the highest specificity (0.677).

Table 4 Partial correlation between different anthropometric indices and metabolic variables based on BMI

Variable	WHtR	BMI	WHR	BRI	AVI	WWI	ABSI
BMI < 25							
SBP	0.100 (0.001)	0.223 (< 0.001)	0.132 (< 0.001)	0.096 (0.001)	0.163 (< 0.001)	-0.010 (0.750)	-0.036 (0.231)
DBP	0.049 (0.106)	0.174 (< 0.001)	0.085 (0.005)	0.044 (0.149)	0.122 (< 0.001)	-0.045 (0.137)	-0.055 (0.066)
FBG	0.175 (< 0.001)	0.133 (< 0.001)	0.249 (< 0.001)	0.182 (< 0.001)	0.172 (< 0.001)	0.140 (< 0.001)	0.117 (< 0.001)
TC	0.149 (< 0.001)	0.125 (< 0.001)	0.108 (< 0.001)	0.147 (< 0.001)	0.123 (< 0.001)	0.117 (< 0.001)	0.081 (< 0.001)
TG	0.118 (< 0.001)	0.233 (< 0.001)	0.247 (< 0.001)	0.112 (< 0.001)	0.243 (< 0.001)	0.010 (0.743)	0.028 (0.362)
HDL-C	0.014 (0.640)	-0.167 (< 0.001)	-0.147 (< 0.001)	0.023 (0.454)	-0.140 (< 0.001)	0.120 (< 0.001)	0.082 (0.007)
LDL-C	0.130 (< 0.001)	0.123 (< 0.001)	0.091 (0.003)	0.126 (< 0.001)	0.108 (< 0.001)	0.094 (0.002)	0.059 (0.052)
BMI ≥ 25							
SBP	0.023 (0.370)	0.100 (< 0.001)	0.116 (< 0.001)	0.026 (0.296)	0.111 (< 0.001)	-0.050 (0.045)	-0.032 (0.200)
DBP	-0.014 (0.583)	0.097 (< 0.001)	0.088 (< 0.001)	-0.011 (0.657)	0.090 (< 0.001)	-0.098 (< 0.001)	-0.075 (0.003)
FBG	0.084 (0.001)	0.036 (0.149)	0.167 (< 0.001)	0.086 (0.001)	0.089 (< 0.001)	0.090 (< 0.001)	0.094 (< 0.001)
TC	0.072 (< 0.001)	0.047 (0.063)	0.032 (0.203)	0.071 (0.005)	0.032 (0.209)	0.067 (0.007)	0.027 (0.274)
TG	-0.033 (0.183)	0.029 (0.243)	0.130 (< 0.001)	-0.032 (0.205)	0.037 (0.136)	-0.071 (0.004)	-0.040 (0.108)
HDL-C	0.176 (< 0.001)	0.060 (0.016)	-0.052 (0.038)	0.176 (< 0.001)	0.052 (0.037)	0.203 (< 0.001)	0.115 (< 0.001)
LDL-C	0.043 (0.088)	0.026 (0.302)	0.007 (0.782)	0.040 (0.109)	0.008 (0.760)	0.042 (0.095)	0.011 (0.662)

The partial correlation is adjusted for age; z-scores of clinical indicators and anthropometric indices were used. Partial correlation coefficient (P-value) has been reported in cells. The adjusted significance level based on Bonferroni Correction is equal to 0.007 ;WC: waist circumference; WHR: waist-hip ratio; WHtR: waist-height ratio; BMI: body mass index; AVI: abdominal volume index; ABSI: A Body Shape Index; MetS: metabolic syndrome; BRI: Body Roundness Index; WWI: weight-adjusted-waist index; SBP: systolic blood pressure; DBP: diastolic blood pressure, FPG: fasting plasma glucose; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol

Discussion

The present study aimed to determine and compare the predictive power of novel versus conventional anthropometric parameters for identifying metabolic syndrome in the Bandare-Kong population in the south of Iran. In clinical practice, anthropometric indices such as AVI, WHtR, and WC could be useful for identifying individuals at risk of metabolic syndrome. These indices are non-invasive, easily measurable, and low-cost options and can be easily incorporated into routine screenings to help identify at-risk patients, particularly in resource-limited healthcare settings. We evaluated these indexes in overweight/obese and non-overweight/obese subjects of both genders. According to our findings, the overall prevalence of Mets was 29.8% (male:12.8% and female:17.0%), which is lower than previous studies in other parts of Iran and some other countries [18–20].

We found the weakest correlation between ABSI and metabolic components, which is consistent with previous studies [21–24]. However, most other anthropometric measures exhibited a significant correlation with metabolic variables. Further, a non-MetS parameter, LDL-C, showed the lowest correlation with anthropometric indices in females. The results demonstrated that most obesity indices were significantly associated with metabolic syndrome, especially in participants with BMI < 25 (non-overweight/obese), except for ABSI and slightly WWI. This is in accordance with a recent study by Lihong et al. in China [25].

In both genders, binary logistic analyses revealed significant relationships between anthropometric indices and MetS, especially for WHtR and BRI. Even though some published studies have shown an association between ABSI and metabolic syndrome, we found only a weak correlation with MetS recognition [26, 27]. Further assessment according to BMI showed that AVI had a robust relationship with MetS in subjects with BMI < 25, but the extent of this connection, though still significant, decreased in subjects with BMI > 25. The estimated pooled AUC by gender for WHtR, BRI, and

Table 5 Binary logistic findings to evaluate the relationship between anthropometric indices and MetS by gender

Variable	High BP		Impaired glucose levels		Low HDL-C		High TG		MetS	
	OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Male										
WHtR	1.66	1.42–1.95*	1.58	1.37–1.84*	1.43	1.23–1.66*	2.09	1.78–2.44*	**3.76**	3.07–4.61*
BMI	1.61	1.40–1.84*	1.50	1.32–1.70*	1.33	1.16–1.51*	1.79	1.57–2.05*	3.22	2.71–3.84*
WHR	1.47	1.27–1.69*	1.55	1.35–1.77*	1.43	1.24–1.65*	1.86	1.62–2.14*	2.57	2.16–3.05*
BRI	1.67	1.41–1.97*	1.60	1.36–1.87*	1.42	1.21–1.67*	2.14	1.81–2.53*	**3.88**	3.14–4.80*
AVI	1.53	1.34–1.75*	1.44	1.27–1.63*	1.37	1.21–1.56*	1.82	1.59–2.07*	3.09	2.60–3.66*
WWI	1.34	1.14–1.67#	1.41	1.18–1.68*	1.41	1.17–1.70*	1.93	1.61–2.32*	2.34	1.90–2.88*
ABSI	1.02	0.87–1.19^	1.07	0.92–1.25^	1.23	1.05–1.44#	1.27	1.09–1.47#	1.19	1.01–1.40#
Female										
WHtR	1.78	1.54–2.07*	1.59	1.39–1.82*	1.24	1.09–1.40*	1.78	1.54–2.06*	**3.75**	3.13–4.48*
BMI	1.54	1.36–1.74*	1.43	1.28–1.60*	1.19	1.07–1.32#	1.48	1.31–1.67*	2.67	2.31–3.09*
WHR	1.71	1.49–1.97*	1.54	1.36–1.74*	1.39	1.24–1.55*	1.86	1.62–2.14*	2.76	2.37–3.23*
BRI	1.70	1.48–1.94*	1.54	1.36–1.74*	1.19	1.07–1.34#	1.67	1.45–1.91*	**3.26**	2.77–3.83*
AVI	1.66	1.46–1.89*	1.52	1.35–1.71*	1.22	1.10–1.36*	1.62	1.43–1.84*	3.16	2.70–3.69*
WWI	1.59	1.32–1.90*	1.44	1.22–1.69*	1.16	1.00-1.34#	1.74	1.46–2.07*	2.52	2.09–3.03*
ABSI	1.09	0.95–1.26^	1.08	0.95–1.23^	1.04	0.92–1.17^	1.19	1.04–1.37#	1.18	1.04–1.35#

The binary logistic regression analyses are adjusted for age; OR: odds ratio, 95% CI: 95% confidence interval, and z-scores of anthropometric indices were used. The adjusted significance level based on Bonferroni Correction is equal to 0.007, * $p<0.007$; #$p<0.05$; ^$p>0.05$. WC: waist circumference; WHR: waist-hip ratio; WHtR: waist-height ratio; BMI: body mass index; AVI: abdominal volume index; ABSI: A Body Shape Index; MetS: metabolic syndrome; BRI: Body Roundness Index; WWI: weight-adjusted-waist index; BP: blood pressure; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol

Table 6 Binary logistic findings to evaluate the relationship between anthropometric indices and MetS by BMI

Variable	High BP		Impaired glucose levels		Low HDL-C		High TG		MetS	
	OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
BMI < 25										
WHtR	1.46	1.16–1.83#	1.68	1.37–2.06*	2.28	1.84–2.81*	1.73	1.38–2.16*	2.73	1.99–3.72*
WHR	1.43	1.21–1.69*	1.70	1.45–1.98*	1.71	1.47–1.99*	1.86	1.57–2.20*	2.51	1.98–3.18*
BRI	1.51	1.17–1.95#	1.78	1.41–2.24*	2.49	1.97–3.16*	1.82	1.42–2.34*	3.02	2.15–4.22*
AVI	1.72	1.31–2.25*	2.15	1.69–2.74*	2.27	1.78–2.88*	2.53	1.93–3.31*	**4.35**	2.98–6.34*
WWI	1.07	0.92–1.24^	1.18	1.03–1.35#	1.70	1.48–1.96*	1.20	1.03–1.39#	1.53	1.25–1.86*
ABSI	0.99	0.86–1.14^	1.11	0.98–1.25^	1.55	1.36–1.76*	1.18	1.03–1.35#	1.41	1.18–1.69*
BMI ≥ 25										
WHtR	1.20	1.05–1.37#	1.22	1.07–1.39#	1.31	1.15–1.48*	1.03	0.91–1.17^	2.01	1.75–2.31*
WHR	1.38	1.21–1.57*	1.30	1.15–1.48*	1.23	1.09–1.38#	1.40	1.24–1.58*	2.05	1.78–2.35*
BRI	1.19	1.04–1.34#	1.20	1.07–1.36#	1.26	1.12–1.41*	1.04	0.92–1.16^	1.65	1.48–1.85*
AVI	1.33	1.16–1.52*	1.27	1.12–1.45*	1.10	0.98–1.24^	1.22	1.08–1.38#	**2.21**	1.92–2.54*
WWI	1.08	0.96–1.22^	1.10	0.98–1.23^	1.37	1.22–1.53*	0.96	0.86–1.08^	1.51	1.34–1.70*
ABSI	1.09	0.96–1.23^	1.07	0.96–1.21^	1.27	1.14–1.43*	1.03	0.92–1.16^	1.39	1.24–1.57*

The binary logistic regression analyses are adjusted for age; OR: odds ratio, 95% CI: 95% confidence interval, and z-scores of anthropometric indices were used. The adjusted significance level based on Bonferroni Correction is equal to 0.008, * $p<0.008$; #$p<0.05$; ^$p>0.05$. WC: waist circumference; WHR: waist-hip ratio; WHtR: waist-height ratio; BMI: body mass index; AVI: abdominal volume index; ABSI: A Body Shape Index; MetS: metabolic syndrome; BRI: Body Roundness Index; WWI: weight-adjusted-waist index; BP: blood pressure; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol

Table 7 AUC and CI for each anthropometric index according to MetS and its components by gender

Variable	High BP		Impaired glucose levels		Low HDL-C		High TG		MetS	
	AUC	95% CI	AUC	95% CI	AUC	95% CI	AUC	95% CI	AUC	95% CI
Male										
WHtR	**0.615**	0.584–0.646*	**0.604**	0.574–0.635*	0.583	0.551–0.615*	**0.660**	0.631–0.690*	**0.766**	0.739–0.794*
BMI	0.586	0.554–0.617*	0.589	0.558–0.620*	**0.584**	0.552–0.617*	0.653	0.624–0.683*	0.758	0.729–0.787*
WHR	**0.636**	0.605–0.666*	**0.623**	0.592–0.653*	0.579	0.547–0.612*	0.643	0.613–0.672*	0.727	0.698–0.755*
BRI	**0.615**	0.584–0.646*	**0.604**	0.574–0.635*	0.583	0.551–0.615*	**0.660**	0.631–0.690*	**0.766**	0.739–0.794*
AVI	0.593	0.562–0.625*	0.596	0.565–0.627*	**0.597**	0.565–0.629*	**0.657**	0.628–0.686*	**0.769**	0.741–0.798*
WWI	0.614	0.583–0.646*	0.586	0.554–0.617*	0.551	0.518–0.584*	0.608	0.577–0.639*	0.666	0.635–0.698*
ABSI	0.565	0.533–0.597*	0.538	0.507–0.570*	0.540	0.506–0.574*	0.551	0.519–0.583#	0.559	0.525–0.593#
Female										
WHtR	0.670	0.640–0.700*	**0.638**	0.608–0.668*	0.546	0.516–0.577#	**0.664**	0.633–0.694*	**0.799**	0.776–0.823
BMI	0.602	0.570–0.633*	0.588	0.558–0.619	0.555	0.524–0.585*	0.613	0.582–0.645*	0.737	0.711–0.764*
WHR	**0.706**	0.676–0.735*	**0.663**	0.633–0.693*	**0.561**	0.531–0.592*	**0.694**	0.664–0.724*	0.774	0.748-0.800*
BRI	0.670	0.640–0.700*	**0.638**	0.608–0.668*	0.546	0.516–0.577#	**0.664**	0.633–0.694*	**0.799**	0.776–0.823*
AVI	0.645	0.615–0.676*	0.629	0.599–0.659*	**0.559**	0.529–0.590*	0.650	0.619–0.681*	**0.793**	0.769–0.817*
WWI	**0.680**	0.650–0.711*	0.637	0.607–0.668*	0.507	0.476–0.538^	0.662	0.631–0.693*	0.728	0.700-0.756*
ABSI	0.618	0.586–0.649*	0.582	0.551–0.613*	0.513	0.483–0.544^	0.597	0.564–0.630*	0.609	0.577–0.640*

The adjusted significance level based on Bonferroni Correction is equal to 0.007, * $p<0.007$; #$p<0.05$; ^$p>0.05$. Bold shows the maximum. WC: waist circumference; WHR: waist-hip ratio; WHtR: waist-height ratio; BMI: body mass index; AVI: abdominal volume index; ABSI: A Body Shape Index; MetS: metabolic syndrome; BRI: Body Roundness Index; WWI: weight-adjusted-waist index; BP: blood pressure; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol

AVI to predict MetS were more than others. However, these amounts were the least for WWI and ABSI. This aligns with the findings of Behboudi et al., who similarly reported that ABSI lacked efficacy as a predictor for MetS [28]. Consistently, other studies in China indicated that ABSI failed to predict MetS in both genders [29, 30]. Khan et al. also observed that WHtR and AVI had significantly higher mean AUC values compared to other metrics [31]. Further stratification based on BMI revealed slightly different results. WHR and AVI emerged as having the highest AUC, while WHtR and BRI demonstrated a similar AUC, suggesting a comparatively better ability to determine MetS. Notably, among non-overweight subjects, WHR marginally outperformed AVI as the most effective identifier of MetS, while in overweight/obese individuals, AVI showed a slightly superior ability compared to WHR. Wu et al.'s investigation in non-overweight/obese adults corroborated this by highlighting AVI's superior capability to determine MetS [25]. This study emphasized the diverse predictive power of anthropometric indices for different components of MetS. Consequently, choosing the most suitable marker for clinical use would depend on the specific metabolic elements requiring assessment. For instance, WHR exhibited the highest AUC for high blood pressure in both genders, whereas BMI and ABSI showed the lowest values. Conversely, AVI and BMI demonstrated the largest AUC for low HDL in men, whereas in women, it was WHR and AVI. Guo et al. concluded that while all obesity indices showed a similar capacity to predict MetS overall, there were sex-based differences. BMI demonstrated the largest AUC in men, while WHtR and BRI exhibited this in women [32].

A pairwise comparison of ROC curves for MetS identification power by gender revealed no significant differences between WHtR, BRI, and AVI in males. However, there were significant disparities between the other measures. In females, WHtR, WHR, BRI, and AVI all showed statistically similar prediction abilities. In participants with BMI<25, there were no significant differences between WHtR and BRI in the ability to predict MetS, as well as between WWI and ABSI. According to the comparison results for individuals with BMI>25, there were no statistically significant differences between WHR and AVI, nor were there significant differences between WHtR, WHR, and BRI. The lack of significant differences in these anthropometric indices' ability to detect MetS may reflect the strong correlations between these indices, as they share similar underlying variables, such as waist circumference, as well as their shared ability to capture similar aspects of central obesity and overall body fat distribution. This similarity limits their ability to provide distinct predictive power.

The proposed optimal cut-off value for each anthropometric index to determine MetS showed that WHR had the highest sensitivity and AVI had the highest specificity in males. However, WHtR and BRI displayed the highest sensitivity, and WHR displayed the highest specificity among females. This suggests that in clinical practice, we should use gender-specific parameters. The results of this study indicated that although most indicators were more sensitive in females, they were less sensitive in males. We found that the optimal WHtR cut-off value (0.52) for

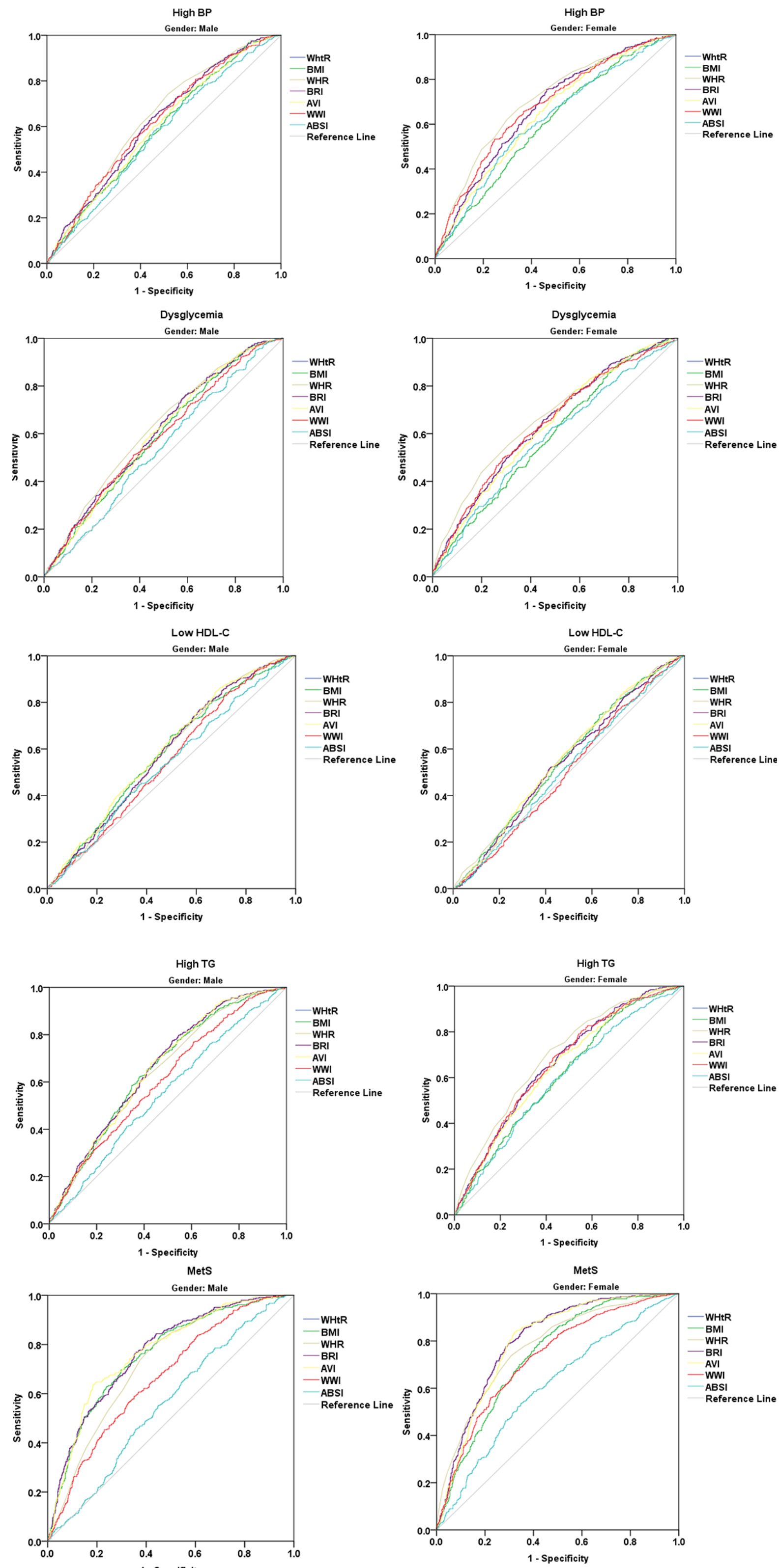

Fig. 1 The ROC curves evaluate the ability of various anthropometric indices to predict MetS and its components by gender

Table 8 AUC and CI for each anthropometric index according to MetS and its components by BMI

Variable	High BP		Impaired glucose levels		Low HDL-C		High TG		MetS	
	AUC	95% CI	AUC	95% CI	AUC	95% CI	AUC	95% CI	AUC	95% CI
BMI < 25										
WHtR	0.611	0.574–0.648*	0.610	0.575–0.646*	**0.637**	0.603–0.671*	0.622	0.584–0.659*	0.699	0.650–0.748*
WHR	**0.677**	0.641–0.713*	**0.656**	0.622–0.691*	0.611	0.576–0.646*	**0.682**	0.646–0.718*	**0.765**	0.723–0.807*
BRI	0.611	0.574–0.648*	0.610	0.575–0.646*	**0.637**	0.603–0.671*	0.622	0.584–0.659*	0.699	0.650–0.748*
AVI	**0.613**	0.576–0.650*	**0.632**	0.598–0.667*	0.622	0.587–0.657*	**0.662**	0.626–0.698*	**0.731**	0.685–0.777*
WWI	0.579	0.541–0.618*	0.563	0.526-0.600#	0.633	0.598–0.667*	0.572	0.532–0.612#	0.646	0.594–0.698*
ABSI	0.569	0.530–0.607#	0.547	0.510–0.584#	0.620	0.586–0.655*	0.570	0.530–0.610#	0.638	0.587–0.689*
BMI ≥ 25										
WHtR	0.577	0.548–0.606*	0.569	0.540–0.598*	**0.564**	0.536–0.592*	0.516	0.486–0.545^	0.677	0.651–0.704*
WHR	**0.629**	0.601–0.657*	**0.605**	0.577–0.633*	0.536	0.508–0.564#	**0.589**	0.561–0.617*	**0.692**	0.666–0.718*
BRI	0.577	0.548–0.606*	0.569	0.540–0.598*	**0.564**	0.536–0.592*	0.516	0.486–0.545^	0.677	0.651–0.704*
AVI	0.576	0.547–0.605*	**0.570**	0.541–0.598*	0.533	0.505–0.562#	**0.552**	0.524–0.581*	**0.702**	0.676–0.727*
WWI	0.579	0.550–0.608*	0.568	0.539–0.597*	**0.573**	0.545–0.601*	0.506	0.476–0.535^	0.639	0.611–0.666*
ABSI	**0.582**	0.553–0.611*	0.563	0.534–0.591*	0.555	0.527–0.583*	0.523	0.494–0.552^	0.618	0.590–0.646*

The adjusted significance level based on Bonferroni Correction is equal to 0.008, * $p<0.008$; #$p<0.05$; ^$p>0.05$. Bold shows the maximum. WC: waist circumference; WHR: waist-hip ratio; WHtR: waist-height ratio; BMI: body mass index; AVI: abdominal volume index; ABSI: A Body Shape Index; MetS: metabolic syndrome; BRI: Body Roundness Index; WWI: weight-adjusted-waist index; BP: blood pressure; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol

identifying MetS in a Chinese study was similar to our results [33]. In a separate study [34], Baveicy et al. found similar cut-off values for men and women (4.75 and 6.17, respectively). In subjects with BMI < 25, WHR and WWI had the highest optimal cut-off values' sensitivity and specificity, respectively. Nevertheless, for people with BMI > 25, AVI and WWI had the highest optimal cut-off value sensitivity and specificity, respectively.

There are certain limitations and strengths to the current study that should be acknowledged. As this is a cross-sectional study, a prospective cohort study could be used to verify the conclusions. Since this is a cross-sectional study, it only allows for the evaluation of associations between anthropometric indices and MetS and cannot establish a cause-effect relationship or assess the risk of developing MetS over time. Future prospective studies are needed to establish causal relationships.

In addition, the participants were from the same ethnic group and shared a similar lifestyle and culture. As a result, future studies should be conducted in multiethnic populations to ensure that the results are applicable to a wider population. This study possesses critical strength in that it stratifies anthropometric indices in obese and non-obese individuals, as well as takes gender analysis into account. Moreover, we analyzed cut-points for each indicator separately for men and women and obese and non-obese populations.

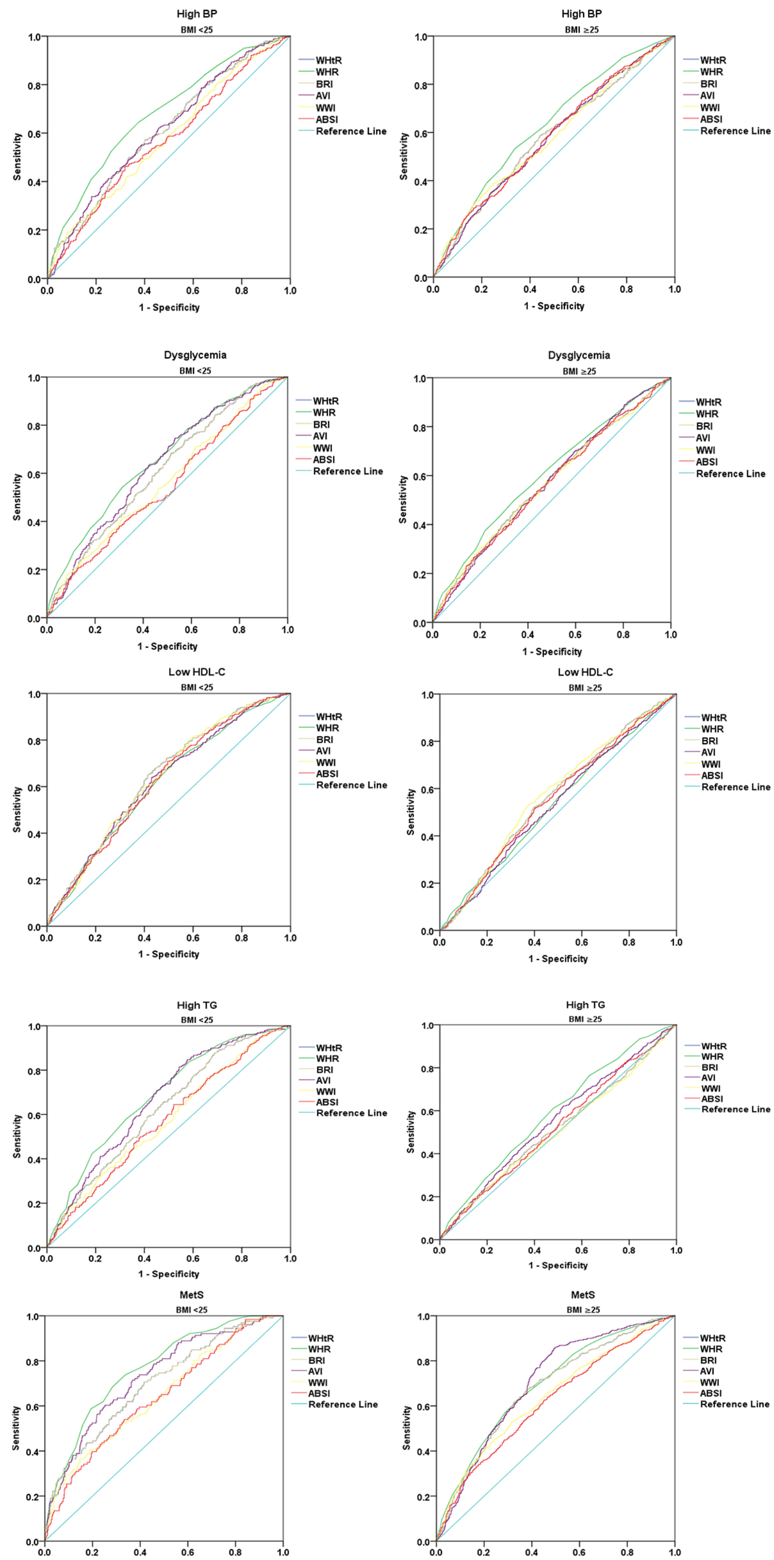

Fig. 2 The ROC curves evaluate the ability of various anthropometric indices to predict MetS and its components by BMI. Based on Table 9, for males, there were no significant differences between WHtR, BRI, and AVI, while there were significant differences between other measures to predict MetS. There were no statistically significant differences between WHtR, WHR, BRI, and AVI in identifying MetS among females

Table 9 Pairwise comparison for ROC curves for the identification of MetS by gender

	WHtR-WHR	WHtR-BRI	WHtR-AVI	WHtR-WWI	WHtR-ABSI	WHR-BRI	WHR- AVI	WHR-WWI	WHR-ABSI	BRI- AVI	BRI-WWI	BRI-ABSI	AVI -WWI	AVI -ABSI	WWI-ABSI
Male															
Diff.AUC	0.040	< 0.001	0.003	0.100	0.207	0.040	0.043	0.060	0.168	0.003	0.100	0.207	0.103	0.210	0.107
SE	0.011	< 0.001	0.006	0.012	0.019	0.011	0.012	0.010	0.015	0.006	0.012	0.020	0.015	0.020	0.011
P value	**< 0.001**	> 0.999	0.647	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	0.647	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Female															
Diff.AUC	0.025	< 0.001	0.006	0.071	0.190	0.025	0.019	0.046	0.165	0.006	0.071	0.190	0.065	0.184	0.119
SE	0.013	< 0.001	0.005	0.012	0.019	0.013	0.014	0.011	0.013	0.005	0.012	0.019	0.014	0.019	0.010
P value	0.059	> 0.999	0.245	**< 0.001**	**< 0.001**	0.059	0.165	**< 0.001**	**< 0.001**	0.245	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**

AUC area under curve; SE standard error; significant P values are marked in bold. WHtR: waist-height ratio; WHR: waist-hip ratio; AVI: abdominal volume index; ABSI: A Body Shape Index; BRI: Body Roundness Index; WWI: weight-adjusted waist index

Table 10 Pairwise comparison for ROC curves for the identification of MetS by BMI

	WHtR-WHR	WHtR-BRI	WHtR- AVI	WHtR-WWI	WHtR-ABSI	WHR-BRI	WHR- AVI	WHR-WWI	WHR-ABSI	BRI- AVI	BRI-WWI	BRI-ABSI	AVI -WWI	AVI -ABSI	WWI-ABSI
BMI < 25															
Diff.AUC	0.066	< 0.001	0.032	0.052	0.061	0.066	0.034	0.119	0.127	0.032	0.052	0.061	0.085	0.093	0.008
SE	0.016	< 0.001	0.016	0.015	0.018	0.016	0.016	0.018	0.018	0.016	0.012	0.018	0.023	0.022	0.010
P value	**< 0.001**	> 0.999	**0.041**	**< 0.001**	**0.001**	**< 0.001**	**0.029**	**< 0.001**	**< 0.001**	**0.041**	**< 0.001**	**0.001**	**< 0.001**	**< 0.001**	0.420
BMI ≥ 25															
Diff.AUC	0.014	< 0.001	0.024	0.039	0.059	0.014	0.010	0.053	0.073	0.024	0.039	0.059	0.063	0.084	0.020
SE	0.013	< 0.001	0.009	0.008	0.013	0.013	0.013	0.012	0.011	0.009	0.008	0.013	0.014	0.015	0.007
P value	0.295	> 0.999	**0.009**	**< 0.001**	**< 0.001**	0.295	0.452	**< 0.001**	**< 0.001**	**0.009**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**0.005**

AUC area under curve; SE standard error; significant P values are marked in bold. WHtR: waist-height ratio; WHR: waist-hip ratio; AVI: abdominal volume index; ABSI: A Body Shape Index; BRI: Body Roundness Index; WWI: weight-adjusted waist index

Table 11 The optimal cut-off values and their sensitivity and specificity for identification of MetS by gender

Index	Male			Female		
	Cut-off	Sensitivity	Specificity	Cut-off	Sensitivity	Specificity
WHtR	0.53	0.769	0.641	0.60	**0.849**	0.642
WHR	0.91	**0.798**	0.569	0.95	0.737	**0.693**
BRI	4.00	0.769	0.641	5.45	**0.849**	0.642
AVI	18.09	0.636	**0.816**	18.05	0.838	0.678
WWI	10.56	0.590	0.649	11.67	0.731	0.619
ABSI	0.77	0.763	0.349	0.86	0.536	0.651

The adjusted significance level based on Bonferroni Correction is equal to 0.008; WHtR: waist-height ratio; WHR: waist-hip ratio; AVI: abdominal volume index; ABSI: A Body Shape Index; BRI: Body Roundness Index; WWI: weight-adjusted waist index

Table 12 The optimal cut-off values and their sensitivity and specificity for identification of MetS by BMI

Index	BMI < 25			BMI ≥ 25		
	Cut-off	Sensitivity	Specificity	Cut-off	Sensitivity	Specificity
WHtR	0.51	0.706	0.583	0.60	0.675	0.617
WHR	0.91	**0.738**	0.662	0.95	0.637	0.647
BRI	3.56	0.706	0.583	5.50	0.675	0.617
AVI	15.21	0.603	0.748	18.08	**0.860**	0.503
WWI	11.67	0.365	**0.853**	11.45	0.535	**0.677**
ABSI	0.84	0.540	0.667	0.81	0.623	0.550

The adjusted significance level based on Bonferroni Correction is equal to 0.008; WHtR: waist-height ratio; WHR: waist-hip ratio; AVI: abdominal volume index; ABSI: A Body Shape Index; BRI: Body Roundness Index; WWI: weight-adjusted waist index

Conclusions

Except for ABSI, all anthropometric indices were valuable for evaluating the risk of MetS. There were no significant differences among AVI, WHtR, BRI, and WHR in identifying MetS. No index was decisively superior to others as a single anthropometric measure to determine MetS and its components. However, it would be more appropriate to use different indices based on race, sex, BMI, and aspects of metabolic syndrome that will be assessed.

Abbreviations

PERSIAN	Prospective Epidemiological Research Studies in IrAN
BKNCD	Bandare-Kong NonCommunicable Disease
ADA	American Diabetes Association
MetS	Metabolic Syndrome
ATP III	Adult Treatment Panel III
DM	Diabetes Mellitus
FPG	Fasting Plasma Glucose
SBP	Systolic Blood Pressure
DBP	Diastolic Blood Pressure
WHO	World Health Organization
TC	Total Cholesterol
TG	Triglyceride
HDL-c	High-Density Lipoprotein
LDL-c	Low-Density Lipoprotein
OR	Odds Ratio
CI	Confidence Interval
WC	Waist Circumference
BMI	Body Mass Index
WHR	Waist-Hip Ratio
WHtR	Waist-Height Ratio
AVI	Abdominal Volume Index
HC	Hip Circumference
ABSI	A Body Shape Index
BRI	Body Roundness Index
WWI	Weight-adjusted Waist Index

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Author contributions

MK designed and wrote the manuscript. AR supervised the study. SR & SA: performed the statistical analysis and interpreted the analyzed data. HS wrote the manuscript. AA & ST: Wrote and revised the manuscript. MS, AS & MN were consulted on the possible associated factors to be considered. All authors read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The cohort study was given ethical approval by the Ethics Committee of Hormozgan University of Medical Sciences. Ethics code: IR.HUMS.REC.1402.247.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Endocrinology and Metabolism Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran

[2]Social Determinants in Health Promotion Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran
[3]Department of Gastroenterology, Hormozgan University of Medical Sciences, Bandar Abbas, Iran
[4]Molecular Medicine Research Center, Hormozgan Health Institute, Hormozgan University of Medical Sciences, Bandar Abbas, Iran
[5]Student Research Committee, Faculty of Medicine, Hormozgan University of Medical Sciences, Bandar Abbas, Iran

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