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Evaluating the discriminatory capacity of traditional and novel anthropometric indices in cardiovascular disease risk factors, considering sex differences

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Abstract

Objective Cardiovascular disease (CVD) rates are rising rapidly worldwide, making it crucial to implement simple and effective screening measures to identify individuals at increased risk for CVD risk factors. This study aims to examine the relationship between innovative anthropometric indices and the occurrence of cardiovascular risk factors among the population of Mashhad, located in northeastern Iran, over a ten-year follow-up period.

Methods In this cohort study, a total of 9704 individuals aged 35–65 years were recruited at baseline, with 7560 individuals completing the study. Anthropometric indices were measured and calculated using standardized methods. After a 10-year follow-up, the incidence of hypertension (HTN), diabetes mellitus (DM), dyslipidemia, obesity, and metabolic syndrome (MetS) and their association with each anthropometric index were determined using Cox regression analysis. Receiver operating characteristic (ROC) analysis was employed to assess the predictive capacity of each index for the CVD risk factors.

Results We found that WHtR exhibited the strongest association with various CVD risk factors. However, the predictive capacity of BMI was higher than other indices in DM and MetS (AUCs: 0.69 and 0.78, respectively). Moreover, BMI, WHtR, and BRI showed equal discriminatory power to predict HTN (AUCs: 0.61). Our analysis indicated that Iranian individuals with a BMI of more than 24.71, 26, and 25.2 kg/m2 are at a 54%, 88%, and 121% increased risk for the development of HTN, DM, and MetS over 10 years; respectively.

Conclusion In this study, BMI was identified as the most powerful predictor of CVD risk factors among the anthropometric indices examined. These findings support previous research indicating that BMI is a valuable screening tool for identifying individuals at higher risk of developing CVDs and associated conditions.

Keywords Anthropometric indices, Cardiovascular risk factors, CVD

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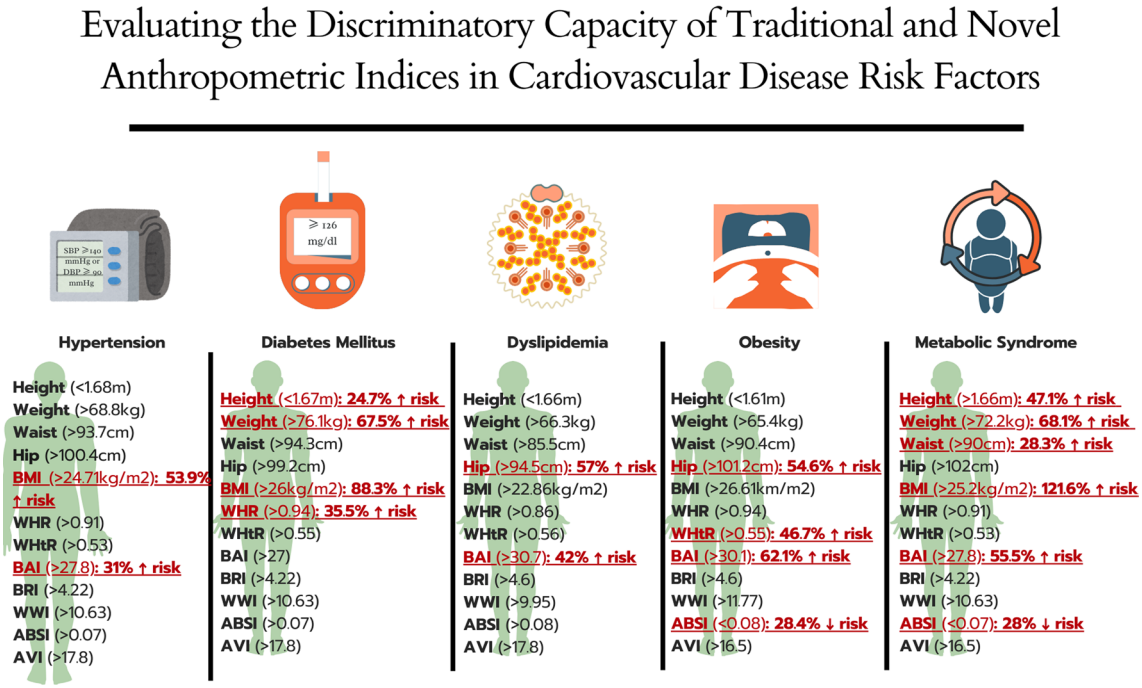
Graphical abstract



Introduction

Obesity, defined as having a Body Mass Index (BMI) of 30 or higher, presents a significant global health challenge. Research shows that the number of obese individuals has doubled from 1980 to 2015 across more than seventy countries, with a particularly concerning increase in obesity rates among children and adolescents. This rise heightens the risk of obesity-related health issues in middle age [1, 2]. In Iran, the obesity rate among adults is 21.38%, exceeding the global prevalence of 16% reported by the World Health Organization (WHO). Furthermore, the number of disability-adjusted life years (DALYs) attributable to obesity has increased by 6.7% from 1990 to 2019 [3]. Obesity is a known major risk factor for various non-communicable diseases. In 2015, Diabetes Mellitus (DM) was the second leading cause of mortality linked to BMI [1]. There is also well-documented evidence of the relationship between obesity and other metabolic disorders, such as dyslipidemia and hypertension [4–7, 7]. The growing prevalence of obesity and its detrimental effects underscore the urgent need to develop simple anthropometric indices that can effectively predict obesity-related metabolic disorders.

Numerous anthropometric indices have been developed to predict cardio-metabolic complications. The BMI is widely used to identify overweight and obesity; however, it has limitations in distinguishing between lean mass and fat mass and estimating overall body fat due to variations in age, sex, and race/ethnicity. Additionally, BMI does not account for the distribution of adipose tissue [8, 9]. In contrast, waist circumference (WC) is a simple and effective method for assessing abdominal obesity, which is closely linked to an increased risk of obesity-related complications [10]. Ratios involving WC, such as the waist-to-height ratio (WHtR) and the waist-to-hip ratio (WHR), have shown acceptable predictive value for cardio-metabolic conditions [11–13]. Other measures, including the Body Adiposity Index (BAI), the Body Shape Index (ABSI), and the Weight-Adjusted Waist Index (WWI), have also been proposed to improve predictions of cardiovascular complications associated with obesity [14–17]. Despite the development of various indices, the superiority of these indices in predicting obesity-related complications is still being investigated [18–20].

Various investigations have focused on finding the best anthropometric index associated with adiposity-related complications in different populations. A cross-sectional analysis of German individuals showed that WHtR has the highest predictive value for cardio-metabolic conditions [21]. Another cross-sectional investigation

conducted on 35256 individuals in China supports the superiority of WHtR's predictive value compared to BMI and WC for hypertension (HTN) and diabetes (DM) [22]. In contrast, an investigation of the Nigerian population showed a higher value of BMI compared to WHtR in the prediction of HTN [23]. Moreover, a recent publication on 10432 Chinese subjects revealed a higher predictive value of BMI compared to WHtR and WHR for HTN, dyslipidemia, and DM [24]. Few investigations have been conducted in Iran to identify the best anthropometric index. A cross-sectional study of 30429 participants represented WC as the most powerful tool in predicting DM and HTN. However, WHtR showed the highest odd ratio for cardio-metabolic risk factors [25]. Another investigation on the Iranian population showed that WHR has the highest correlation with cardiovascular disease (CVD) risk factors [26].

Despite considerable efforts, a consensus on the most effective anthropometric measure for predicting traditional cardiovascular risk factors remains elusive. The existing evidence is primarily derived from cross-sectional studies [25, 26]. As such, there is a pressing need for robust cohort studies to better elucidate the predictive value of various anthropometric indices regarding CVD risk factors, especially within the Iranian population. Additionally, the lack of reliable cut-offs for the association between anthropometric indicators and CVD risk factors prompted this study to investigate these cut-offs. This research aims to fill this gap by identifying which anthropometric index is most effective in forecasting the incidence of CVD risk factors—including HTN, DM, dyslipidemia, obesity, and metabolic syndrome (MetS)—over a 10-year follow-up period.

Materials and methods

Participants

The population was recruited from the Mashhad Stroke and Heart Atherosclerotic Disorder (MASHAD) study, which enrolled 9,704 individuals aged 35 to 65 for a 10-year follow-up period starting in 2010. Participants were selected using a stratified cluster random sampling method from three areas in Mashhad City, located in North-East Iran. In 2020, at the end of the 10 years, all participants were invited for a second visit. A total of 7,560 participants completed the study, and their information was collected again. All individuals who responded to our initial invitation and completed the follow-up period were included in the cohort investigation. Exclusion criteria were applied to individuals with pre-existing conditions such as coronary artery disease, stroke, cancer, and autoimmune diseases at baseline. This study aimed to evaluate the incidence of various CVD risk factors among individuals who were initially free of any specific risk factor.

The study protocol is thoroughly discussed separately [27]. The protocol has been approved by the ethics committee of Mashhad University of Medical Sciences (MUMS) (Code: 85134). Informed consent was obtained from all individuals before they enrolled in the study.

Data collection

The required data, including demographics, lifestyle, medical history, and drug history, was collected through a baseline questionnaire administrated by a trained healthcare professional. Systolic and diastolic blood pressure measurements were taken twice for each individual using a mercury sphygmomanometer, with a thirty-minute interval between readings recorded as the final result. Blood samples were collected after a fourteen-hour fast to assess lipid profile (including high-density lipoprotein cholesterol (HDL), low-density lipoprotein cholesterol (LDL), total cholesterol, and triglycerides) and fasting blood glucose (FBG) levels. The anxiety and depression status of individuals were evaluated using Beck's anxiety inventory and Beck's depression inventory II (BDI-II), respectively [28].

Anthropometric measurements

Height, weight, WC, and hip circumference (HC) were measured at baseline using standardized methods for all participants [29]. eight (cm), WC (cm), and HC (cm) were measured with a precision of one millimeter using a tape measure. Weight was measured using electrical scales with a precision of 0.1 kg [30]. Other anthropometric indices were calculated as follows:

Body mass index (BMI): $\frac{\text{weight(kg)}}{\text{height(m)}^2}$

Waist-hip ratio (WHR): $\frac{WC(\text{cm})}{HC(\text{cm})}$

Waist-height ratio (WHtR): $\frac{WC(\text{cm})}{height(\text{cm})}$

Body adiposity index (BAI): $\frac{HC(\text{cm})}{\text{height(m)}^{1.5}-18}$ [14].

Body round index (BRI): $364.2-365.5\times\sqrt{1-\frac{\left(\frac{WC(\text{cm})}{2\pi}\right)^2}{(0.5\text{height(m)})^2}}$ [31].

Weight-adjusted-waist index (WWI): $\frac{WC(\text{cm})}{\sqrt{weight(\text{kg})}}$ [17].

A body shape index (ABSI): $\frac{WC(\text{cm})}{BMI^{\frac{2}{3}}\,\text{height(m)}^{\frac{1}{2}}}$ [32].

Abdominal volume index (AVI): $\frac{2WC(\text{cm})^2+0.7(WC(\text{cm})-HC(\text{cm}))^2}{1000}$ [33].

Definitions of CVD risk factors

HTN, diabetes mellitus (DM), dyslipidemia, obesity, and MetSare are all recognized as CVD risk factors. HTN is defined as having a systolic blood pressure (SBP) above 140 mmHg, a diastolic blood pressure (DBP) above 90

mmHg, or being on anti-hypertensive medication. Individuals are classified as diabetic if their FBG level is above 125 mg/dl or if they are taking insulin or any hypoglycemic agents. Dyslipidemia is characterized by having total cholesterol levels above 200 mg/dl (5.18 mmol/l), LDL-C levels above 130 mg/dl (3.36 mmol/l), triglyceride levels above 150 mg/dl (1.69 mmol/l), or HDL-C levels below 40 mg/dl (1.03 mmol/l) in men and below 50 mg/dl (1.30 mmol/l) in women. Obesity is defined based on WHO recommendations, where a BMI of 25 or greater is considered overweight, and a BMI of 30 or greater is classified as obese [27]. MetS is defined based on criteria from the International Diabetes Federation (IDF) as discussed previously [34].

Statistical analysis

This study conducted a comprehensive statistical analysis to assess the predictive capability and optimal cut-off values of newly proposed anthropometric indices for screening CVD risk factors. Descriptive statistics were calculated for all study variables, such as means, standard deviations, numbers, and percentages. The normality of continuous variables was evaluated using the Kolmogorov–Smirnov test. To compare anthropometric indices based on CVD risk factors, the Sample t-test was utilized, and the results were presented as mean ± standard deviation (SD). Logistic regression models explored the associations between anthropometric indices and CVD risk factors. Adjusted odds ratios (ORs) with 95% confidence intervals (CIs) were determined, adjusting for age, sex, job status, education, marital status, physical activity levels (PAL), energy intake, depression, and anxiety. Receiver operating characteristic (ROC) curve analysis was conducted to evaluate the predictive performance of each anthropometric index in identifying CVD Risk factors, using MedCalc Software (2020) (MedCalc Statistical Software Version 19.2.6. MedCalc Software bv, Ostend, Belgium). The area under the ROC curve (AUC) was calculated as a measure of overall diagnostic accuracy, with values ranging from 0.5 (no discrimination) to 1.0 (perfect discrimination). Optimal cut-off values for each anthropometric index were identified by maximizing the Youden index, which determines the point on the ROC curve with the highest combined sensitivity and specificity. All statistical analyses were performed using SPSS (IBM Corp. IBM SPSS Statistics for Windows. Version 27.0. IBM Corp, 2020), with a two-sided p-value < 0.05 considered statistically significant.

Results

Characteristics of the study population

The baseline demographic data of participants are illustrated in Table 1. The mean age of included subjects is 47.53 ± 7.99, and female individuals constitute 60% of the study population. More than half (70.4%) of subjects reported no smoking history. The incidence of CVD risk factors, including HTN, dyslipidemia, DM, obesity, and MetS, was obtained by following the study population for 10 years. As shown in Table 1, the mean ± SD for physical activity level and energy intake was 1.59 ± 0.28 and 1906.98 ± 668.27, respectively. Additionally, the values for depression and anxiety scores are presented in this table. Table 2 provides the mean and SD of each anthropometric index in affected and non-affected groups during 10 years of follow-up.

Gender-stratified analysis for the association between anthropometric indices and incidence of CVD risk factors

As indicated in Table 3, we performed a ROC analysis to assess the AUC (95% CI), cut-off points, sensitivity, and specificity of each anthropometric index related to CVD risk factors, with separate evaluations for males and females. Our findings demonstrated no significant differences between the male and female groups concerning the predictive value of height, weight, WC, HC, WHtR, and BRI. However, Table 3 reveals notable disparities in the sensitivity and specificity of BMI, WHR, BAI, WWI, ABSI, and AVI between males and females. In particular, the sensitivity of BMI is consistently higher in males across all CVD risk factors, with the exception of HTN, where the sensitivity rates are 62 for males compared to 71.9 for females. For DM, the sensitivity is 77.18 for males versus 65.71 for females; for dyslipidemia, it is 77.56 for males compared to 59.9 for females; for MetS, 72.16 for males and 64.15 for females; and for obesity, the sensitivity is 89.17 for males compared to 78.46 for females (Fig. 1).

Association between anthropometric indices and incidence of CVD risk factors by logistic regression

After determining the cut-off values in Fig. 2, we performed a logistic regression analysis to investigate the relationship between anthropometric indices and the development of cardiovascular risk factors. The data was adjusted for age, sex, job status, education, marital status, physical activity levels (PAL), energy intake, depression, and anxiety. Our findings revealed that subjects with a BMI greater than 24.71 (as shown in Table 3) possess a 54% higher risk of developing hypertension over 10 years (OR 1.539, 95%Cl, 1.273–1.861, P-value < 0.001). Similarly, the risk of developing DM increased by 88% in those with a BMI of 26 or higher (OR: 1.883, 95%Cl, 1.516–2.339, P-value < 0.001). Also, individuals with a BMI of 25.2 or higher had a 2.216 (OR: 2.216, 95%Cl, 1.809–2.716, P-value < 0.001) times

Table 1 Demographic Characteristics of Study Participants

Age (year)		47.53 ± 7.99
Sex	Male	3023 (40%)
	Female	4538 (60%)
Marriage	Single	41 (0.5%)
	Married	7116 (94.1%)
	Divorced	88 (1.2%)
	Widow	316 (4.2%)
Education level	Low (illiterate and elementary)	3997 (52.9%)
	Moderate (Diploma and under diploma)	2685 (35.5%)
	High (University)	873 (11.6%)
Job status	Employee	2900 (38.4%)
	Unemployed	3936 (52.1%)
	Retired	722 (9.6%)
Smoking status	No	5323 (70.4%)
	Ex-smoker	703 (9.3%)
	Current smoker	1535 (20.3%)
Weight, kg		71.81 ± 12.83
Height, m		1.6 ± .09
BMI, kg/m2		27.87 ± 4.65
WC, cm		95.01 ± 11.88
HC, cm		103.68 ± 9.15
WHR		0.91 ± .07
WHtR		0.59 ± .08
BAI		33.25 ± 6.35
BRI		5.4 ± 1.86
WWI		11.25 ± 1.03
ABSI		0.08 ± .007
AVI		18.43 ± 4.53
Physical Activity Level (PAL)		1.59 ± 0.28
Energy intake		1906.98 ± 668.27
Depression score		10.35 ± 9.65
Anxiety score		12.15 ± 9.43

Data presented as mean ± SD or number and percentage

HTN hypertension, *DM* diabetes mellitus, *MetS* metabolic syndrome, *BMI* body mass index, *WC* waist circumference, *HC* hip circumference, *WHR* waist circumference to hip circumference, *WHtR* waist circumference to height, *BAI* body adiposity index, *BRI* body round index, *BRI* body round index, *WWI* weight-adjusted-waist index, *ABSI* a body shape index, *AVI* abdominal volume index

higher risk of developing MetS. Furthermore, our analysis indicated that higher BAI scores above the specified cut-off values were significantly associated with an increased incidence of HTN, dyslipidemia, obesity, and MetS in the MASHHAD cohort study population ($P < 0.05$, $P < 0.05$, $P < 0.01$, $P < 0.001$; respectively). Although ABSI did not play a significant role in predicting MetS in linear regression, logistic regression using cut-off values revealed a significant association between ABSI and the incidence of MetS. Specifically, individuals with ABSI scores below 0.07 had a 28% lower risk of developing MetS after 10 years (OR: 0.72, 95%Cl, 0.525–0.986, $P < 0.05$).

Discussion

In this extensive community-based cohort investigation, a significant correlation was observed between various anthropometric indices and CVD risk factors. In term of HTN, both BMI (OR: 1.539, 95% Cl, 1.273–1.861, $p < 0.001$) and BAI (OR: 1.31, 95% Cl, 1.068–1.608 $p < 0.05$) were linked to the development of HTN, with BMI demonstrating the highest sensitivity (72.82).

Table 2 Anthropometric Indices and Incidence of CVD Risk Factors Over a 10-Year Follow-Up

	HTN			DM			Dyslipidemia			MetS			Obesity		
	No (3616, 64.2%)	Yes (2017, 35.8%)	*p*-value	No (5454, 81.3%)	Yes (1256, 18.7%)	*p*-value	No (3085, 65.9%)	Yes (1599, 34.1%)	*p*-value	No (2256, 80.7%)	Yes (541, 19.3%)	*p*-value	No (4964, 87.4%)	Yes (718, 12.6%)	*p*-value
Height, m	1.61 ± 0.092	1.6 ± 0.09	< 0.001	1.6 ± 0.09	1.59 ± 0.09	< 0.001	1.62 ± 0.09	1.61 ± 0.09	0.003	1.61 ± 0.09	1.59 ± 0.09	< 0.001	1.61 ± 0.09	1.6 ± 0.08	< 0.001
Weight, kg	69.58 ± 12.29	72.51 ± 12.77	< 0.001	70.45 ± 12.48	76.24 ± 13.52	< 0.001	69.51 ± 13.11	68.88 ± 12.17	0.27	66.04 ± 10.94	73.69 ± 9.75	< 0.001	67.13 ± 10.54	72.31 ± 9.33	< 0.001
WC, cm	92.2 ± 11.46	95.7 ± 11.53	< 0.001	93.36 ± 11.64	99.33 ± 11.61	< 0.001	91.57 ± 11.85	92.63 ± 12.12	0.057	88.26 ± 10.04	96.7 ± 7.92	< 0.001	90.86 ± 10.01	95.56 ± 9.37	< 0.001
HC, cm	102.25 ± 8.74	103.95 ± 8.95	< 0.001	102.89 ± 8.91	106.39 ± 9.53	< 0.001	101.62 ± 9.03	102.48 ± 9.13	0.04	99.61 ± 7.3	105.83 ± 6.05	< 0.001	99.82 ± 6.88	104.8 ± 5.64	< 0.001
BMI, kg/m^2	26.79 ± 4.46	28.21 ± 4.52	< 0.001	27.22 ± 4.52	29.8 ± 4.62	< 0.001	26.44 ± 4.71	26.62 ± 4.59	0.39	25.27 ± 3.64	28.78 ± 2.76	< 0.001	25.62 ± 3.29	28.1 ± 1.9	< 0.001
WHR	0.9 ± 0.07	0.92 ± 0.07	< 0.001	0.9 ± 0.07	0.93 ± 0.07	< 0.001	0.9 ± 0.07	0.9 ± 0.08	0.36	0.88 ± 0.07	0.91 ± 0.08	< 0.001	0.91 ± 0.07	0.91 ± 0.07	0.55
WHtR	0.57 ± 0.07	0.59 ± 0.07	< 0.001	0.58 ± 0.07	0.62 ± 0.07	< 0.001	0.56 ± 0.07	0.57 ± 0.08	0.003	0.55 ± 0.06	0.6 ± 0.03	< 0.001	0.56 ± 0.06	0.59 ± 0.06	< 0.001
BAI	32.24 ± 6.17	33.5 ± 6.21	< 0.001	32.69 ± 6.24	34.95 ± 6.41	< 0.001	31.46 ± 6.17	32.47 ± 6.45	< 0.001	30.85 ± 4.98	34.19 ± 4.44	< 0.001	30.76 ± 5.05	33.94 ± 4.46	0.14
BRI	4.96 ± 1.74	5.51 ± 1.8	< 0.001	5.14 ± 1.79	6.08 ± 1.89	< 0.001	4.8 ± 1.79	5.05 ± 1.89	0.003	4.11 ± 1.37	5.63 ± 0.73	< 0.001	4.7 ± 1.44	5.44 ± 1.43	< 0.001
WWI	11.09 ± 1.01	11.28 ± .99	< 0.001	11.17 ± 1.04	11.42 ± .98	< 0.001	11.17 ± 1.75	11.42 ± 1.93	0.001	10.86 ± 0.94	11.13 ± 0.71	< 0.001	11.13 ± 1.01	11.28 ± 1.17	0.001
ABSI	0.81 ± 0.06	0.82 ± 0.06	0.028	0.81 ± 0.06	0.82 ± 0.06	0.14	0.81 ± 0.07	0.82 ± 0.08	0.014	0.81 ± 0.06	0.81 ± 0.06	0.04	0.82 ± 0.06	0.81 ± 0.08	0.072
AVI	17.37 ± 4.22	18.67 ± 4.4	< 0.001	17.81 ± 4.36	20.08 ± 4.64	< 0.001	17.16 ± 4.36	17.57 ± 4.73	0.049	16.54 ± 3.49	18.31 ± 2.46	< 0.001	16.8 ± 3.54	18.54 ± 3.65	< 0.001

Data presented as mean ± SD; student t-test has been done

HTN hypertension, *DM* diabetes mellitus, *MetS* metabolic syndrome, *BMI* body mass index, *WC* waist circumference, *HC* hip circumference, *WHR* waist circumference to hip circumference, *WHtR* Waist circumference to height, *BAI* body adiposity index, *BRI* body round index, *BRI* body round index, *WWI* weight-adjusted-waist index, *ABSI* a body shape index, *AVI* abdominal volume index

Table 3 ROC Analysis of Anthropometric Indices in Relation to CVD Risk Factors

Obesity	MetS	Dyslipidemia	DM	HTN		
AUC (95% CI); Cut-off point; Sensitivity and Specificity						
0.55 (0.54–0.56) < 1.61; Sen 60.58; Spe:49.47	0.53 (0.5–0.55) > 1.66; Sen: 69.96; Spe: 35.81	0.55 (0.52–0.58) < 1.66; Sen:48.14; Spe: 64.47	0.51 (0.49–0.53)- < 1.67; Sen: 44.87; Spe: 59.66	0.55 (0.53–0.57) < 1.68; Sen: 52.46; Spe: 54.53	Total	Height
	0.517 (0.497–0.538) ≤ 1.56; Sen: 13.34; Spe: 90.54	0.543 (0.515–0.572) < 1.66; Sen:48.14; Spe: 64.47	0.516 (0.488–0.534) ≤ 1.67; Sen: 52.42; Spe: 52.59	0.541 (0.522–0.56) < 1.64; Sen:38.11; Spe: 68.31	Male	
0.567 (0.511–0.622) > 1.6; Sen 38.46; Spe:75	0.522 (0.459–0.584) ≤ 1.62; Sen: 89.62; Spe: 23.38	0.589 (0.496–0.677) ≤ 1.66; Sen:52.56; Spe: 58.79	0.552 (0.501–0.601) ≤ 1.58; Sen: 68.57; Spe: 40.74	0.535 (0.480–0.590) ≤ 1.56; Sen: 52.89; Spe: 54.93	Female	
0.64 (0.63–0.65) > 65.4; Sen: 77.86; Spe: 44.68	0.77 (0.76–0.79) > 72.2; Sen: 77.22; Spe: 65.9	0.50 (0.47–0.53) > 66.3; Sen: 69.88; Spe: 37.36	0.67 (0.65–0.69) > 76.1; Sen: 65.38; Spe: 59.63	0.599 (0.545–0.652) > 68.8; Sen: 72.75; Spe: 39.84	Total	Weight
0.574 (0.555–0.593) * > 73.6; Sen: 54.63; Spe: 57.15	0.737 (0.719–0.755) * > 72; Sen: 71.5; Spe: 66.10	0.51 (0.482–0.538) > 66.3; Sen: 69.32; Spe: 38.29	0.657 (0.641–0.675) * > 76.1; Sen: 62.28; Spe: 62.74	0.574 (0.555–0.599) > 73.6; Sen: 54.63; Spe: 57.15	Male	
0.744 (0.692–0.791) * > 64.7; Sen: 76.92; Spe: 62.7	0.629 (0.567–0.688) * > 65; Sen: 66.04; Spe: 61.04	0.592 (0.5–0.68) ≤ 61.5; Sen: 52.27; Spe: 70.89	0.624 (0.574–0.672) * > 67; Sen: 75.71; Spe: 51.85	0.58 (0.56–0.6) * > 66.7; Sen: 64.46; Spe: 56.34	Female	
0.63 (0.62–0.64) > 90.4; Sen: 74.23; Spe: 46.22	0.75 (0.73–0.76) > 90; Sen: 76.81; Spe: 60.48	0.53 (0.5–0.56) > 85.5; Sen: 74.14; Spe: 32.11	0.67 (0.66–0.69) > 94.3; Sen: 68.79; Spe: 58.10	0.60 (0.58–0.62) > 93.7; Sen: 56.12; Spe: 59.69	Total	WC
0.698 (0.681–0.715) * > 91; Sen: 82.67; Spe: 49.05	0.728 (0.71–0.745) * > 90; Sen: 74.30; Spe: 59.72	0.529 (0.501–0.557) > 85.5; Sen: 73.79; Spe: 31.85	0.664 (0.647–0.68) * > 94.3; Sen: 68.09; Spe: 56.81	0.597 (0.579–0.612) * > 93.7; Sen: 56.68; Spe: 58.73	Male	
0.677 (0.623–0.728) * > 103; Sen: 47.69; Spe: 85.71	0.659 (0.598–0.716) * > 94.5; Sen: 69.81; Spe: 57.14	0.55 (0.458–0.64) ≤ 90; Sen: 43.18; Spe: 69.62	0.666 (0.617–0.712) > 98; Sen: 74.29; Spe: 54.01	0.649 (0.595–0.7) * > 93; Sen: 78.51; Spe: 46.48	Female	
0.72 (0.7–0.73) > 101.2; Sen: 75.59; Spe: 62.8	0.72 (0.7–0.74) > 102; Sen: 53.54; Spe: 79.01	0.54 (0.51–0.57) > 94.5; Sen: 82.55; Spe: 27.54	0.63 (0.61–0.65) > 99.2; Sen: 75.4; Spe: 43.57	0.57 (0.55–0.59) > 100.4; Sen: 57.07; Spe: 54.24	Total	HC
0.751 (0.735–0.763) > 101.2; Sen: 76.81; Spe: 62.29	0.712 (0.694–0.731) * > 102; Sen: 54.62; Spe: 76.29	0.545 (0.516–0.573) > 94.5; Sen: 83.48; Spe: 26.03	0.624 (0.607–0.641) * > 102.4; Sen: 58.03; Spe: 59.4	0.561 (0.542–0.58) * > 101.5; Sen: 51.52; Spe: 53.39	Male	
0.732 (0.68–0.78) * > 101; Sen: 84.62; Spe: 52.38	0.601 (0.538–0.661) * > 101.5; Sen: 72.64; Spe: 45.45	0.527 (0.435–0.618) ≤ 108; Sen: 72.73; Spe: 39.24	0.567 (0.516–0.616) > 103; Sen: 68.57; Spe: 45.06	0.586 (0.531–0.64) * > 113; Sen: 25.62; Spe: 87.79	Female	
0.75 (0.74–0.77) > 26.61; Sen: 86.63; Spe: 60.12	0.78 (7–0.76–0.80) > 25.2; Sen: 81.65; Spe: 61.45	0.53 (0.5–0.56) > 22.86; Sen 7:6.71; Spe:32.15	0.69 (0.67–0.71) * > 26; Sen: 75.63; Spe: 53.27	0.61 (0.58–0.63) > 24.71; Sen:72.82; Spe: 44.5	Total	BMI
0.817 (0.803–0.831) * > 26.79; Sen: 89.17; Spe: 66.57	0.766 (0.748–0.783) * > 26.02; Sen: 72.16; Spe: 68.59	0.528 (0.5–0.557) > 22.8; Sen: 77.56; Spe: 30.74	0.682(0.665–0.698) * > 26.02; Sen: 77.18; Spe: 50.79	0.601 (0.583–0.62) * > 25.96; Sen: 62; Spe: 54.92	Male	
0.752 (0.701–0.799) * > 26.46; Sen: 78.46; Spe: 68.25	0.648 (0.587–0.706) * > 26.63; Sen: 64.15; Spe: 61.04	0.568 (0.476–0.657) ≤ 25.84; Sen: 59.09; Spe: 62.03	0.657 (0.608–0.704) * > 28.52; Sen: 65.71; Spe: 61.42	0.627 (0.573–0.679) * > 26.15; Sen: 71.9; Spe: 48.83	Female	
0.50 (0.49–0.52) > 0.94; Sen: 34.17; Spe: 68.17	0.66 (0.64–0.68) > 0.91; Sen: 65.25; Spe: 58.89	0.50 (0.47–0.53) > 0.86; Sen:79.44; Spe: 25.13	0.65 (0.63–0.0.66) > 0.94; Sen: 53.76; Spe: 68.1	0.59 (0.57–0.61) > 0.91; Sen: 63.43; Spe: 50.43	Total	WHR
0.557 (0.538–0.575) > 0.9; Sen: 69.57; Spe: 42.16	0.639 (0.619–0.558) > 0.92; Sen: 53.63; Spe: 67.44	0.5 (0.472–0.528) > 0.92; Sen: 38.18; Spe: 57.42	0.628 (0.61–0.645) > 0.93; Sen: 56.09; Spe: 64.05	0.595 (0.576–0.613) * > 0.92; Sen: 57.83; Spe: 56.98	Male	
0.561 (0.504–0.616) > 0.95; Sen: 50.71; Spe: 69.44	0.634 (0.572–0.692) * > 0.92; Sen: 59.43; Spe: 62.34	0.577 (0.485–0.665) ≤ 0.84; Sen: 22.73; Spe: 92.41	0.679 (0.631–0.725) * > 0.94; Sen: 68.57; Spe: 58.95	0.624 (0.57–0.677) * > 0.87; Sen: 91.74; Spe: 27.7	Female	

Table 3 (continued)

Obesity	MetS	Dyslipidemia	DM	HTN		
0.65 (0.63–0.66) > 0.55; Sen: 77.86; Spe: 45.64	0.73 (0.7–0.75) > 0.53; Sen: 74.19; Spe: 57.92	0.54 (0.51–0.57) > 0.56; Sen: 0.42.06; Spe: 66.37	0.68 (0.66–0.69) > 0.55; Sen: 70.16; Spe: 56.23	0.61 (0.59–0.63) > 0.53; Sen: 69.87; Spe: 46.70	Total	WHtR
0.707 (0.69–0.723) > 0.56; Sen: 74.01; Spe: 60.82	0.724 (0.705–0.742) > 0.54; Sen: 72.82; Spe: 59.75	0.539 (0.51–0.569) > 0.58; Sen: 31.91; Spe: 75.68	0.665 (0.648–0.681) > 0.55; Sen: 73.5; Spe: 51.64	0.609 (0.59–0.63) > 0.54; Sen: 63.89; Spe: 52.64	Male	
0.651 (0.596–0.703) > 0.61; Sen: 67.69; Spe: 59.92	0.665 (0.604–0.722) * > 0.6; Sen: 71.7; Spe: 57.14	0.534 (0.441–0.624) ≤ 0.59; Sen: 50; Spe: 62.03	0.685 (0.637–0.731) * > 0.64; Sen: 68.57; Spe: 62.35	0.66 (0.606–0.710) * > 0.6; Sen: 75.21; Spe: 50.70	Female	
0.68 (0.67–0.69) > 30.1; Sen: 79.78; Spe: 48.65	0.67 (0.65–0.69) > 27.8; Sen: 63.43; Spe: 62.83	0.56 (0.53–0.59) > 30.7; Sen: 28.97; Spe: 82.23	0.619 (0.6–0.64) * > 27; Sen: 75.17; Spe: 42.66	0.60 (0.58–0.62) > 27.8; Sen: 59.42; Spe: 57.51	Total	BAI
0.716 (0.699–0.732) * > 28.24; Sen: 75.72; Spe: 57.67	0.683 (0.664–0.702) * > 27.89; Sen: 69.64; Spe: 58.91	0.556 (0.527–0.584) * > 30.79; Sen: 34.47; Spe: 76.03	0.612 (0.595–0.629) * > 29.23; Sen: 56.67; Spe: 60.05	0.58 (0.561–0.599) * > 27.83; Sen: 64.11; Spe: 51.06	Male	
0.646 (0.59–0.698) * > 32.3; Sen: 86.15; Spe: 37.3	0.603 (0.54–0.663) * > 32.9; Sen: 78.30; Spe: 42.21	0.509 (0.417–0.6) > 31.11; Sen: 86.36; Spe: 25.32	0.594 (0.544–0.643) > 35; Sen: 67.14; Spe: 50.31	0.605 (0.551–0.658) * > 34.9; Sen: 63.64; Spe: 56.81	Female	
0.65 (0.64–0.66) * > 4.6; Sen: 76.6; Spe: 47.78	0.73 (0.7–0.75) > 4.22; Sen: 67.34; Spe: 65.41	0.54 (0.51–0.57) > 4.6; Sen: 42.68; Spe: 65.99	0.68 (0.66–0.69) > 4.22; Sen: 72.44; Spe: 54.33	0.61 (0.6–0.63) > 4.22; Sen: 67.23; Spe: 49.57	Total	BRI
0.707 (0.69–0.72) * > 4.55; Sen: 74.01; Spe: 60.82	0.724 (0.705–0.742) * > 4.13; Sen: 72.81; Spe: 59.75	0.539 (0.51–0.56) * > 5.18; Sen: 31.91; Spe: 75.68	0.665 (0.648–0.681) * > 4.43; Sen: 73.5; Spe: 51.64	0.609 (0.59–0.62) * > 4.3; Sen: 63.89; Spe: 52.64	Male	
0.658 (0.603–0.710) * > 5.83; Sen: 67.69; Spe:61.90	0.667 (0.606–0.724) * > 5.72; Sen: 68.87; Spe:61.04	0.534 (0.442–0.625) ≤ 5.26; Sen: 50; Spe:64.56	0.686 (0.638–0.732) > 6.49; Sen: 68.57; Spe:62.65	0.661 (0.607–0.711) * > 5.67; Sen: 75.21; Spe:53.52	Female	
0.53 (0.51–0.54) > 11.77; Sen: 30.50; Spe: 75.26	0.57 (0.55–0.59) > 10.63; Sen: 66.27; Spe:44.33	0.54 (0.51–0.57) > 9.95; Sen: 90.65; Spe: 16.77	0.58 (0.56–0.59) > 10.63; Sen: 78.82; Spe:34.11	0.57 (0.55–0.59) > 10.63; Sen: 66.27; Spe:44.33	Total	WWI
0.545 (0.527–0.563) > 10.32; Sen: 83.39; Spe:24.12	0.587 (0.567–0.607) * > 10.69; Sen: 63.10; Spe:51.39	0.532 (0.504–0.561) > 9.97; Sen: 90.03; Spe:16.91	0.571 (0.554–0.589) * > 10.69; Sen: 70.6; Spe:41.68	0.569 (0.55–0.588) * > 10.63; Sen: 69.05; Spe:42.35	Male	
0.523 (0.467–0.579) > 12.17; Sen: 55.38; Spe:58.73	0.603 (0.541–0.663) * > 11.09; Sen: 65.09; Spe:53.9	0.523 (0.431–0.614) ≤ 12; Sen: 63.64; Spe:48.10	0.623 (0.573–0.671) * > 12.65; Sen: 38.57; Spe:82.41	0.607 (0.552–0.66) * > 11.84; Sen: 71.04; Spe:48.36	Female	
0.53 (0.51–0.55) < 0.08; Sen: 69.36; Spe: 34.09	0.51 (0.49–0.53) < 0.07; Sen: 13.10; Spe: 88.36	0.52 (0.49–0.55) > 0.08; Sen: 32.35; Spe: 71.08	0.50 (0.49–0.53) > 0.07; Sen: 94.53; Spe:9.63	0.507 (0.487–0.528) > 0.07; Sen: 91.84; Spe: 9.93	Total	ABSI
0.547 (0.529–0.565) < 0.082; Sen: 64.98; Spe: 45.62	0.5 (0.48–0.52) < 0.08; Sen: 52.88; Spe: 49.46	0.518 (0.489–0.546) > 0.08; Sen: 45.01; Spe: 59.43	0.501 (0.483–0.518) ≤ 0.07; Sen: 13.54; Spe: 80.46	0.524 (0.505–0.543) * > 0.08; Sen: 63.05; Spe: 42.40	Male	
0.531 (0.475–0.587) ≤ 0.08; Sen: 36.92; Spe: 70.63	0.52 (0.457–0.582) > 0.08; Sen: 62.26; Spe: 40.91	0.511 (0.419–0.602) ≤ 0.08; Sen: 43.18; Spe: 63.29	0.543 (0.493–0.593) > 0.08; Sen: 70; Spe:37.04	0.534 (0.479–0.588) > 0.09; Sen: 8.26; Spe: 95.77	Female	
0.63 (0.62–0.65) > 16.5; Sen: 72.25; Spe: 49.18	0.75 (0.73–0.77) > 16.5 Sen: 77.17; Spe: 60.31	0.52 (0.5–0.56) > 17.8; Sen: 42.63; Spe: 61.24	0.67 (0.64–0.69) > 17.8; Sen: 68.79; Spe: 58.11	0.60 (0.58–0.62) 17.8; Sen: 56.12; Spe: 59.71	Total	AVI
0.702 (0.685–0.718) > 17.03; Sen: 78.99; Spe: 53.23	0.73 (0.712–0.748) * > 16.02 Sen: 65.02; Spe: 69.26	0.53 (0.501–0.558) > 14.79 Sen: 74.07; Spe: 31.85	0.663 (0.64–0.68) > 17.5 Sen: 67.5; Spe: 57.47	0.597 (0.578–0.616) > 17.67 Sen: 56.68; Spe: 58.80	Male	
0.68 (0.625–0.731) * > 21.2; Sen: 49.23; Spe: 85.71	0.659 (0.698–0.716) * > 17.75; Sen: 70.75; Spe: 56.49	0.546 (0.454–0.636) ≤ 16.3; Sen: 43.18; Spe: 69.62	0.665 (0.616–0.711) > 19.6; Sen: 72.86; Spe: 56.48	0.648 (0.594–0.699) * > 17.4; Sen: 75.51; Spe: 46.01	Female	

The highlighted items show significant differences between women and men

Asterisk shows the significant differences in ROC curve analysis

HTN: Hypertension, DM: diabetes mellitus, MetS: metabolic syndrome, BMI: Body Mass Index, WC: Waist circumference, HC: Hip circumference, WHR: Waist circumference to Hip circumference, WHtR: Waist circumference to Height, BAI: Body Adiposity Index, BRI: Body Round Index, BRI: Body Round Index, WWI: Weight-adjusted-Waist Index, ABSI: A Body Shape Index, AVI: Abdominal Volume Index

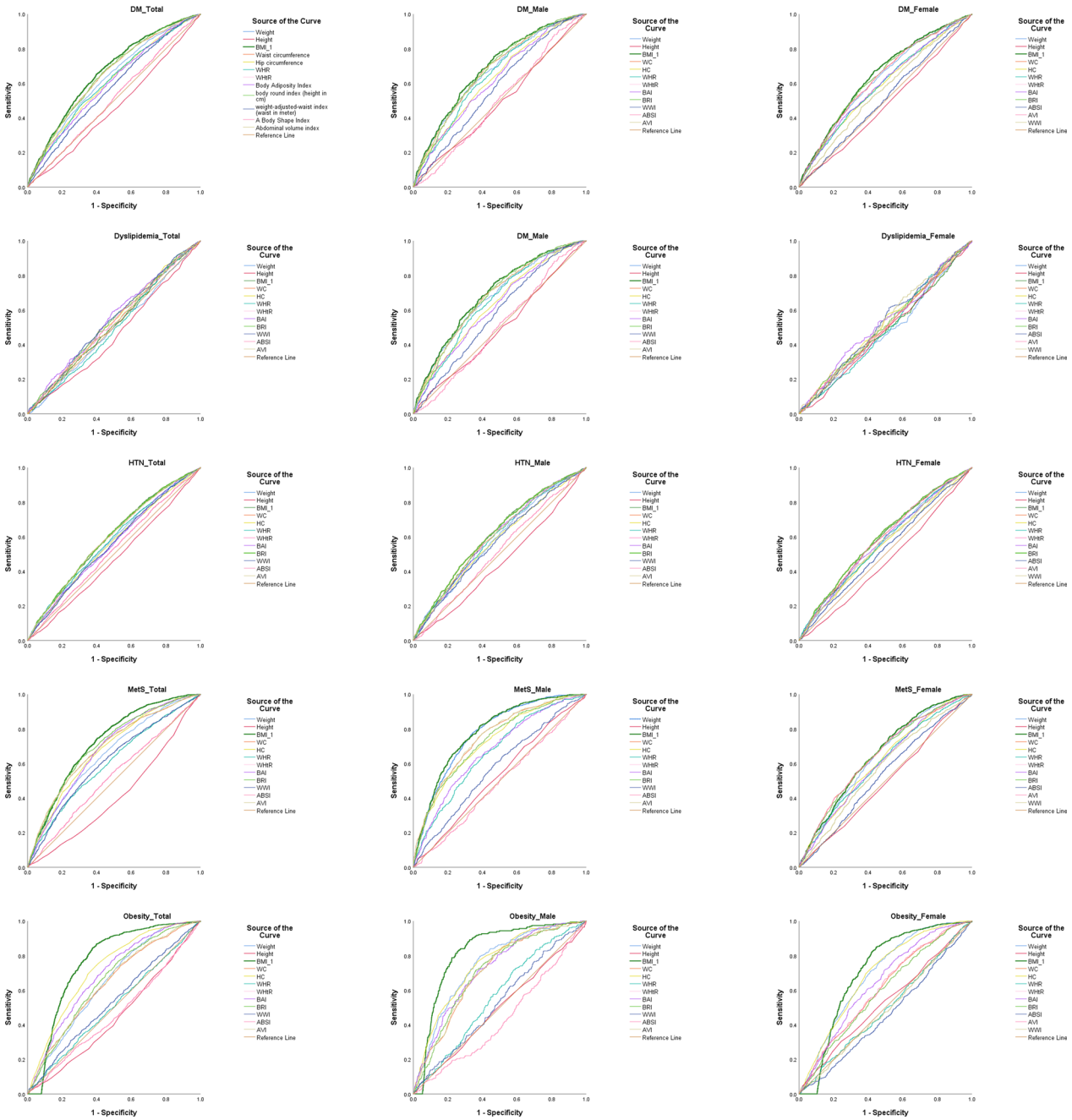


Fig. 1 ROC curves indicating discriminating power of each obesity index for incidence of each cardiovascular risk factor during 10 years of follow-up

A recent meta-analysis indicated that for every 5 kg/m^2 increase in BMI, there is a pooled mean difference of 3 mmHg in SBP [35]. Furthermore, BMI exhibited the most significant predictive capability among both the Chinese [36] and Indian populations [37]. Studies conducted in the Iranian population also showed that BMI is more effective than other anthropometric indices in predicting HTN [38, 39]. Multiple studies have supported our findings regarding BAI. For instance, a significant positive correlation was observed between mean arterial blood pressure and BAI in a South African population [40]. This association has also been validated in various other populations, including those in China [41], the USA [42], Brazil [43], India

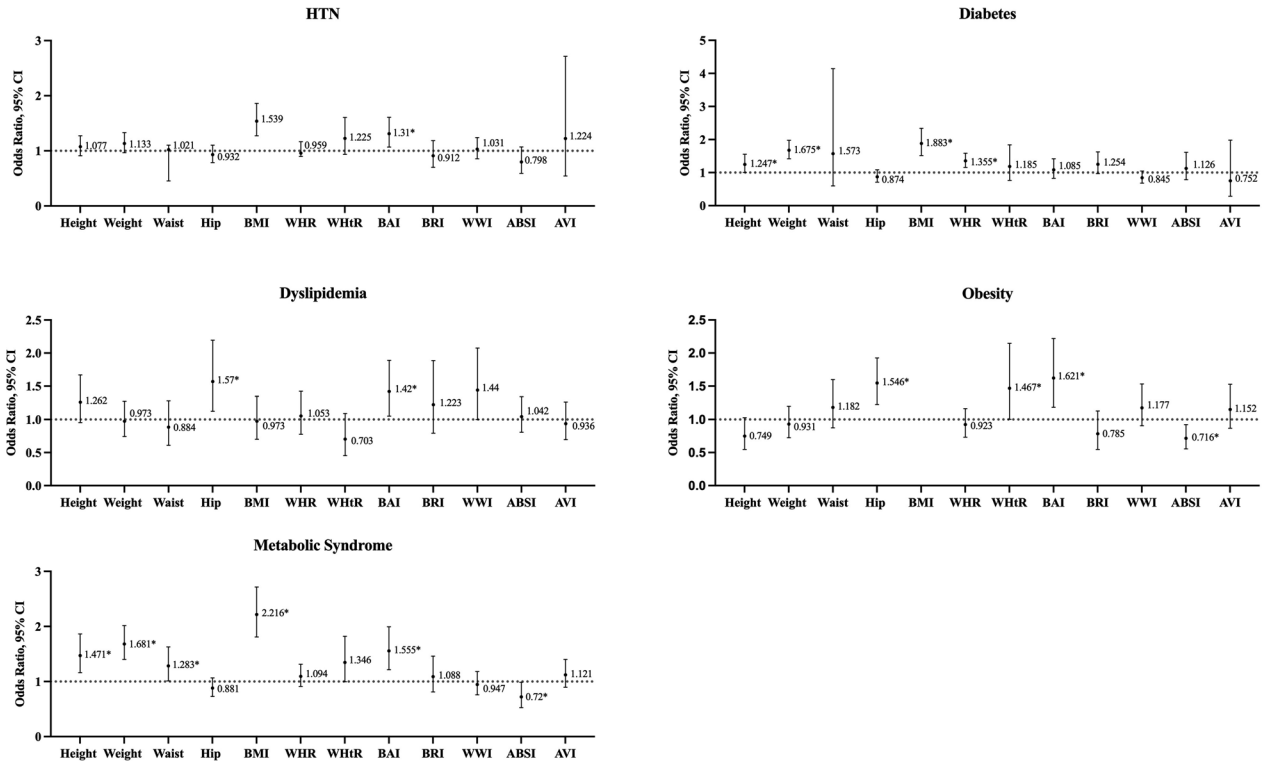


Fig. 2 Association between anthropometric indices according to CVD risk factors incidence during 10 years' follow-up; Cox regression model using new cut-off valued resulted from ROC analysis. Data is adjusted by age, sex, job status, education, and marital status, physical activity levels (PAL), energy intake, depression, and anxiety

[37], and Iran [39]. However, contrary to our findings, some studies in Iran have reported a direct association between HTN risk and WHtR, WC, and WHR, highlighting notable gender differences in these associations [38, 39].

Our study has made a unique contribution to understanding DM by identifying several risk factors. We found that height (OR: 1.247, 95%Cl, 1.000–1.555, $p<0.05$), weight (OR: 1.675, 95% CI, 1.420–1.977, $p<0.001$), BMI (OR: 1.883, 95% CI, 1.516–2.339, $p<0.001$), and WHR (OR: 1.355, 95% CI, 1.157–1.587, $p<0.001$) all played predictive roles in the risk of developing DM. Among these factors, BMI demonstrated the strongest predictive value, with an AUC of 0.69 and the highest odds ratio. A meta-analysis by Jayedi et al. also highlighted that BMI has the strongest association with DM compared to other anthropometric and adiposity indicators [44]. Consistent findings regarding WHR have been reported in other studies [45, 46]. While some research suggests an inverse association between height and DM [47], our findings indicate a positive association, which is noteworthy. Specifically, certain studies have highlighted a positive relationship between height and DM in men [48, 49].

The study found that HC (Dyslipidemia: OR: 1.57, 95% Cl, 1.123–2.194, $p<0.01$, Obesity: OR: 1.546, 95% Cl, 1.225–1.952, $p<0.001$) and BAI (Dyslipidemia: OR: 1.42, 95% Cl, 1.051–1.891, $p<0.05$, Obesity: OR: 1.621, 95% Cl, 1.184–2.22, $p<0.01$) were predictive of dyslipidemia and obesity. Additionally a higher WHtR (OR: 1.467, 95% Cl, 1.004–2.146, $p<0.05$) and lower ABSI (OR: 0.716, 95% Cl, 0.556–0.922, $p<0.05$) were associated with obesity. Other studies have also linked BAI [50, 51], HC, WHtR [52], and ABSI [53] to lipid profiles and CVD risk factors. However, our results showed that AVI, WWI, and BRI indices were unrelated to CVD risk factors.

In the context of MetS, our findings emphasize that BMI is the most robust predictor (OR: 2.216, 95% Cl, 1.809–2.716, $p<0.001$), showing the highest sensitivity (81.65). Additionally, variables such as height (OR: 1.471, 95% Cl, 1.161–1.863, $p<0.01$), weight (OR: 1.681, 95% Cl, 1.402–2.015, $p<0.001$), WC (OR: 1.283, 95% Cl, 1.01–1.629, $p<0.05$) and BAI (OR: 1.555, 95% Cl, 1.213–1.993, $p<0.001$) showed a positive correlation, while ABSI (OR: 0.72, 95%Cl, 0.525–0.986, $p<0.01$) had a negative correlation with the risk of developing MetS. Notably, ABSI had the highest specificity (88.36). Previous research has identified BMI as the most reliable indicator of MetS,

which aligns with our findings [54]. Studies conducted within the Iranian population have also shown positive associations between MetS, ABSI and WC [55, 56]. Interestingly, while some studies have reported a negative relationship between height and MetS [56], our research indicates a positive correlation.

Gender-based analyses have shown that, for most risk factors, men typically exhibit higher values in the AUC for anthropometric indices compared to women. However, women display higher AUC values in specific risk factors related to weight, WHR, and BRI. The significance of gender differences in cardio-metabolic risk cannot be overstated, with many risks being more pronounced in men [57]. For example, a significant correlation between higher oxidative balance and depression—a notable health concern—has been observed exclusively in hypertensive men, with no similar link found in women [58]. Conversely, women typically have higher estrogen levels, which can influence fat distribution—particularly in the hips and thighs—thereby affecting WHR and BRI [59]. Supporting these findings, research by Dang et al. indicates that among Vietnamese women, BRI is more strongly associated with metabolic abnormalities [60]. This suggests that while general trends indicate heightened risks for men, specific anthropometric measures may reveal important distinctions in how these risks manifest across genders.

Our study consistently shows that BMI is a superior predictor of CVD risk factors. It demonstrates greater sensitivity for all risk factors except dyslipidemia. Additionally, BMI is a practical and easily applicable measurement that can be used for large-scale screenings of individuals at high risk for cardiovascular disease (CVD) [61]. Many clinical guidelines and risk assessment tools include BMI in their predictive algorithms. For example, the Framingham Risk Score, which estimates the 10-year risk of developing coronary heart disease, incorporates BMI as one of its components [62]. This leads us to conclude that, despite being one of the oldest anthropometric indicators, BMI remains a highly effective tool for screening CVD risk factors, with the exception of dyslipidemia.

Strengths and limitations

The study has notable strengths, including its large population size and the use of actual measurements instead of relying on self-reported data. Additionally, it established cut-off points for the relationship between various anthropometric indices and CVD risk factors, which can serve as a valuable reference for future research. However, there are some limitations. One concern is that many anthropometric measurements were performed manually by trained staff across such a large dataset, which may lead to errors in reporting these measurements. Genetic variation is a significant factor that influences both CVD risk factors and anthropometric indicators [63, 64]. However, due to the lack of available information in our study, we recommend that future research not overlook its potential impact. Additionally, since CVD risk factors typically manifest at specific ages, we recommend that future studies conduct their analyses by age groups to better understand these variations [65]. Furthermore, using a traditional definition of MetS that included waist circumference measurements might have introduced bias into the results.

Conclusion

The results indicate that BMI has the highest discriminatory capability among anthropometric indices, making it a valuable tool for screening. However, while BMI shows strong sensitivity, its specificity is not equally robust. This highlights the importance of BMI in assessing the risk of CVDs. Nevertheless, relying solely on BMI to measure adiposity has notable limitations, suggesting that it may not accurately identify individuals at risk of developing CVDs. Other studies have suggested that combining BMI with additional anthropometric indicators is the most effective way to predict CVD risk factors [23]. Future research should focus on combining various anthropometric indices and establishing optimal, ethnicity-specific cut-off points in our region. Additionally, there was an unexpected lack of associations between the AVI, WWI, and BRI with all CVD risk factors. Therefore, future studies should explore the predictive utility of these indices.

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Mashhad University of Medical Sciences.

Author contributions

Behzad Ensan, Farzam Kamrani, Hanieh Gholamalizadeh (wrote manuscript) Mohsen Rezaee, Hamed Hashemi Shahri (data gathering) Habibollah Esmaily (Data analysis and study design) Mohsen Moohebati, Majid Ghayour-Mobarhan (study design) Susan Darroudi (corresponding author) All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Declarations

Ethical approval

Ethical Approval and Consent to participate: Informed consent was obtained from all subjects. Accordingly, the study protocol was validated by the Ethics Committee of the Mashhad University of Medical Sciences (MUMS) and the Institutional Review Board of Mashhad University Medical Center. This project

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Consent for publication
It is not applicable to the Consent of Image Publication for this manuscript. The figures were designed only in this manuscript for presenting the results of the current paper.

Competing interests
The Authors declare that there is no conflict of interest.

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