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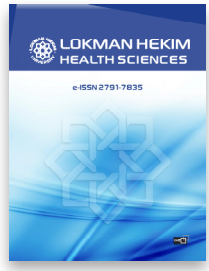

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ORIGINAL ARTICLE

Comparative Diagnostic Performance of Anthropometric and Composite Indices for Metabolic Syndrome in Adults with Obesity

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Abstract

Introduction: This study aimed to compare the diagnostic performance of conventional anthropometric and novel composite indices in identifying metabolic syndrome (MetS) in adults with obesity and to examine their associations with cardiometabolic risk markers and lipid profiles.

Methods: This study was designed as a descriptive diagnostic accuracy study and conducted in the Nutrition and Dietetics outpatient clinic of a university hospital. A total of 496 adults with a body mass index greater than 30 kg/m^2 were included. MetS was diagnosed according to the criteria of the Turkish Society of Endocrinology and Metabolism. In addition to anthropometric indices, composite indices such as the visceral adiposity index, lipid accumulation product, cardiometabolic index, and the triglyceride to high-density lipoprotein cholesterol (TG/HDL-C) ratio were also calculated. Statistical analyses included receiver operating characteristic curve analysis, logistic regression, and correlation analysis.

Results: Composite indices, including TG/HDL-C ratio, visceral adiposity index, lipid accumulation product, and cardiometabolic index, were significantly associated with MetS. Conventional anthropometric indices showed limited diagnostic value. TG/HDL-C ratio demonstrated the highest accuracy with an area under the curve of 0.721 and an optimal cutoff value of 2.68. Logistic regression identified TG/HDL-C ratio, age, and cardiometabolic index as significant predictors. The overall model had an area under the curve of 0.726 and a classification accuracy of 69.6 percent.

Discussion and Conclusion: Lipid-based indices outperform conventional anthropometric measures in diagnosing metabolic syndrome among individuals with obesity. Their use may improve cardiometabolic risk assessment in clinical settings.

Keywords: Anthropometric indices; Cardiometabolic risk; Metabolic syndrome; Obesity

Obesity is currently acknowledged as a significant worldwide health issue and constitutes a primary determinant for the development of various chronic non-communicable disorders. Despite the fact that public health organizations typically use Body Mass Index (BMI) values to categorize obesity, new research shows

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that people with the same BMI may have very different risks of developing conditions like type 2 diabetes or cardiovascular problems. Interestingly, a portion of people with obesity appear to retain partial protection against obesity-associated conditions, particularly metabolic syndrome (MetS), or display greater resilience to these disorders.[1] This heterogeneity in metabolic disease susceptibility among individuals with comparable BMI values has reinforced the importance of incorporating complementary anthropometric and metabolic indicators into the classification of obesity.[2,3]

Recent research has highlighted notable links between particular anthropometric indicators and metabolic characteristics. Dieny et al.,[4] for instance, observed that indices such as Body Mass Index (BMI), Waist to Height Ratio (WHtR), and Waist to Hip Ratio (WHR) are closely related to elements of MetS, thereby emphasizing their potential as predictive tools. Similarly, Zhou et al.[5] reported that indices calculated from a combination of anthropometric parameters were valuable in detecting the risk of insulin resistance among middle-aged populations, supporting the notion that a multidimensional evaluation of body composition enhances diagnostic precision. Moreover, Zheng et al.[6] demonstrated that the influence of various obesity-related indices on cardiometabolic risk factors differs across ethnicities, suggesting that demographic characteristics may affect the applicability of certain anthropometric measures.

Differences in fat distribution, particularly between visceral and subcutaneous adiposity, are known to add complexity to the evaluation of metabolic risk. Visceral adiposity has been consistently associated with unfavorable cardiometabolic outcomes. According to Lee et al.,[7] excessive visceral fat was found to have a stronger association with metabolic disturbances than overall body fat percentage or general obesity. Similarly, Tatsumi et al.[8] emphasized that individuals who present with high levels of visceral fat despite having a normal BMI are at greater risk for developing various metabolic disorders. Consequently, anthropometric measurements that show patterns of fat distribution, such as waist circumference (WC) and neck circumference (NC), along with indices derived from these measures, are suggested to provide more detailed information on cardiometabolic risk compared to traditional assessment methods.[9,10]

The relationship between specific cardiometabolic risk factors and anthropometric indices reveals a complex interplay. Yang et al.[11] for instance, showed a direct correlation between elevated triglyceride (TG), total cholesterol (TC), and lowered high-density lipoprotein cholesterol (HDL-C) and central obesity markers, specifically WC. Additionally, Strack et al.[12] proposed that variations in body fat distribution could account for sex-related disparities in both the occurrence and specific features of MetS, underscoring the critical role of gender in the interpretation of anthropometric findings. Therefore, although various anthropometric indices generally reflect overall body fat, it should be acknowledged that their associations with cardiometabolic markers may differ across populations.

In conclusion, a comprehensive analysis of various anthropometric indices associated with cardiometabolic risk factors is of critical importance. Evaluating these relationships through well-designed studies can contribute to the development of improved diagnostic criteria for MetS and ultimately reduce the health burden associated with these conditions. Anthropometric measurements that encompass both general adiposity and fat distribution not only enhance the understanding of MetS but also promote personalized preventive health strategies. This study aims to evaluate the roles of various anthropometric indices in diagnosing MetS among individuals with obesity, and to explore how these indices relate to cardiometabolic risk markers and plasma lipid levels.

Materials and Methods

Study Design, Location, and Duration

This study is a descriptive diagnostic accuracy investigation conducted on obese individuals (BMI >30 kg/m^2) who presented to the Nutrition and Dietetics outpatient clinic at Bolu Abant İzzet Baysal University Training and Research Hospital for various reasons. Metabolic syndrome was diagnosed according to the criteria specified in the Metabolic Syndrome Guideline of the Turkish Endocrinology and Metabolism Society, which is adapted from the International Diabetes Federation. The diagnostic criteria required the presence of at least one condition, including Diabetes Mellitus, insulin resistance, or impaired glucose tolerance, in combination with a minimum of two additional factors. These factors consisted of: Hypertension (defined as using antihypertensive medication at the moment, having a diastolic blood pressure (BP) of greater than 85 mmHg, or having a systolic BP of greater than 130 mmHg), dyslipidemia (characterized by TG levels >150 mg/dL or HDL-C <50 mg/dL in women and <40 mg/dL in men), and central obesity (WC exceeding 80 cm in women and 94 cm in men or BMI >30 kg/m^2).

Study Population and Sample Size

In biomedical informatics diagnostic studies with binary outcomes (positive/negative), accuracy, sensitivity, and specificity are the primary parameters for evaluating diagnostic performance, independent of disease prevalence.[13] The minimum sample size was calculated according to Hajian-Tilaki's method, resulting in a requirement of at least 365 participants to achieve 95% sensitivity with a 0.5% margin of error. Considering potential dropouts, a total of 496 obese patients were included. After being fully informed about the study's goals and methods, each participant gave their signed informed consent.

Participant Selection and Exclusion Criteria

Between April 1 and June 30, 2024, obese patients (BMI >30 kg/m^2) attending the clinic were enrolled. Participants with medical conditions potentially affecting anthropometric measurements (e.g., kidney failure, liver disease with ascites), history of bariatric surgery, or without recent (within one week) biochemical test results (TC, HDL-C, LDL-C, FBG, TG, and BP) were excluded.

Biochemical and Anthropometric Measurements

Anthropometric measurements such as body weight (BW), body height (BH), WC, NC, and hip circumferences (HC) were performed by a dietitian from the research team using standard instruments. Fasting blood glucose (FBG), TG, TC, and HDL-C were obtained from laboratory records within the previous week. To test BP, a digital sphygmomanometer was used.

Calculation of Indices

Based on anthropometric data, the following indices were calculated using established formulas: Body Mass Index (BMI), Body Roundness Index (BRI), Abdominal Volume Index (AVI), A Body Shape Index (ABSI), Body Adiposity Index (BAI), Conicity Index (CI), Waist to Hip Ratio (WHR), Waist to Height Ratio (WHtR), Fat Mass Index (FMI), and the product of waist and neck circumference (PWNC). Composite indices integrating anthropometric and biochemical parameters were also calculated, including the Lipid Accumulation Product Index (LAP), Cardiometabolic Index (CMI), and Visceral Adiposity Index (VAI). The formulas used for these indices are presented below:

- BMI: (BW [kg]) / (BH) [m])^2
- ABSI: (WC [cm] / ((BMI [kg/m^2])$^{2/3}$ x (BH [cm]))$^{1/2}$
- BRI: $364{,}2 - 365{,}5 \times \sqrt{[1 - [(WC / 2\pi)^2 / (0{,}5 \times BH)^2]]}$
- BAI: HC [cm] / (BH [m])$^{3/2}$ - 18
- AVI: [2 x (WC [cm])^2 + 0.7 x (WC - HC [cm])^2] / 1.000
- CI: WC (m)/ (0.109 x √ BW(kg)/ BH [m])
- WHR: WC (cm) / HC (cm)
- WHtR: WC (cm) / BH (cm)
- FMI: Fat mass [kg] / (BH [m])^2
- PWNC: WC (cm) × NC (cm)
- VAI:

  For men=WC (cm) / (39.68 + (1.88 x BMI)) x (TG [mmol/L] / 1.03) x (1.31 / HDL-K [mmol/L])

  For women: WC [cm] / (36.58 + (1.89 x BMI)) x (TG [mmol/L] / 0.81) x (1.52 / HDL-C [mmol/L])
- LAP:

  For men=(WC [cm]-65) × TG [mmol/L])

  For women: (WC [cm]-58) × TG [mmol/L])

  CMI: (TG [mmol/L] / HDL-C [mmol/L]) × WC [cm]/ BH [cm]

Data Collection Tools

Participant Information Form

Data were gathered using a structured questionnaire consisting of eight items, which addressed socio-demographic attributes, alcohol and tobacco consumption, history of chronic illnesses, and routine medication use.

Anthropometric Measurements

Body weight (BW) was measured using a digital scale (Tanita BC 545 N, Tanita, Tokyo, Japan) and a stadiometer (SECA 213, SECA, Hamburg, Germany); waist, hip, and neck circumferences were measured with a flexible tape measure (Lufkin, Cooper Tools, Apex, NC, USA). All measurements were conducted according to standardized protocols.

Laboratory Tests and Blood Pressure (BP)

Biochemical parameters were obtained from laboratory records within the previous week. Measurement of BP was performed using a digital sphygmomanometer.

Statistical Analysis

Data analysis was performed using JAMOVI software (Version 2.3; The Jamovi Project, Sydney, Australia) and SPSS software (Version 26; IBM Corp., Armonk, NY, USA). Frequencies, percentages, means, medians, standard deviations, and mean rank differences were all used to report descriptive statistics. The Kolmogorov-Smirnov test with Lilliefors correction was used to determine normality.

Participants with metabolic syndrome (MetS+) and those without (MetS–) were compared using the student's

Table 1. Anthropometric characteristics of participants

Variables	MetS+ (n=306)	MetS- (n=190)	Total (n=496)	p
Age (years)	42.5±13.9	37.3±13.3	39.5± 14.3	0.000*
BW (kg)	103.5±18.4	101.3±18.1	102.1±18.2	0.196
BH (m)	1.62±0.00	1.62±0.08	1.62±0.09	0.952
BMI (kg/m^2)	39.3±6.8	38.4±6.4	38.8±6.6	0.124
Fat mass (kg)	43.4±13.1	42.1±12.8	43.1±12.9	0.682
Muscle mass (kg)	57.9±10.5	56.8±9.8	57.3±10.0	0.203
% Fat	41.7±7.3	41.9±7.07	41.8±7.1	0.709
ABSI	0.080±0.003	0.080±0.002	0.080±0.002	0.176
BRI	9.143±1.712	9.220±1.575	9.190±1.62	0.562
BAI	43.76±4.73	43.80±4.52	43.79±9.19	0.927
AVI	29.01±4.77	29.18±4.05	29.12±4.34	0.593
CI	1.36±0.06	1.37±0.04	1.36±0.05	0.631
VAI	2.68±0.84	2.50±0.80	2.57±0.82	0.003*
WHR	0.94±0.03	0.94±0.02	0.94±0.03	0.355
WHtR	0.73±0.06	0.73±0.05	0.73±0.05	0.539
PWNC	4856.3±576.7	4887.7±488.8	4875.7±523.9	0.768
FMI	16.6±5.3	16.4±5.1	16.5±5.2	0.589
LAP	92.72±23.8	88.36±21.2	90.0±22.3	0.011*
CMI	406.28±128.26	385.60±143.55	393.52±138.13	0.008*
TG / HDL-C	4.20±2.55	2.80±1.99	3.34±2.32	0.001*

BMI: Body Mass Index; BW: Weight; BH: Height; ABSI: A Body Shape Index; BRI: Body Roundness Index; BAI: Body Adiposity Index; AVI: Abdominal Volume Index; CI: Conicity Index; VAI: Visceral Adiposity Index; WHR: Waist to Hip Ratio; WHtR: Waist to Height Ratio; PWNC: Product of Waist and Neck Circumference; FMI: Fat Mass Index; LAP: Lipid Accumulation Product Index; CMI: Cardiometabolic Index; TG / HDL-C: Triglyceride / High-Density Lipoprotein Cholesterol ratio; *: P<0.05.

t-test for continuous variables and the chi-square test for categorical variables. Correlations between variables were evaluated with correlation coefficients. Anthropometric indices and the existence of MetS were evaluated using logistic regression; the results were displayed as 95% CIs and odds ratios (ORs).

Specificity, sensitivity, likelihood ratios, positive and negative predictive values, and diagnostic accuracy measures were used to assess the performance of the diagnostic test. To find the best cutoff values that balance sensitivity and specificity, Youden's index, Area Under the Curve (AUC), and Receiver Operating Characteristic (ROC) curves were examined. Cohen's kappa coefficient assessed agreement between diagnostic tests. Comparisons of AUCs were conducted using the non-parametric DeLong test. Risk factors for the development of Mets+ were identified using binomial logistic regression. Statistical significance was established at the conventional threshold of $p<0.05$.

Ethical Considerations

The research protocol received approval from the Non-Interventional Clinical Research Ethics Committee of Bolu Abant İzzet Baysal University (Decision No: 2024/30) and was carried out in compliance with the ethical principles outlined in the Declaration of Helsinki. Prior to study participation, written informed consent was obtained from all individuals. No financial incentives were provided. Participant confidentiality was maintained by anonymizing identifying information during data analysis.

Results

The study included 496 participants (80.2% female, n=398; 19.8% male, n=98). Anthropometric characteristics are summarized in Table 1. Significant differences were observed between the MetS+ and MetS– groups concerning age, VAI, LAP, CMI, and the TG/HDL-C ratio ($p<0.05$). No statistically significant differences were detected in BH, BW,

percentage of body fat, fat mass, muscle mass, BMI, FFM, ABSI, BRI, BAI, AVI, CI, WHR, WHtR, PWNC, or FMI (p>0.05).

The strongest correlations in both MetS+ and MetS– groups were observed between BMI and FMI (r>0.60, p<0.01). In the MetS+ group, low but significant correlations were found among BRI, BAI, AVI, CI, WHtR, and PWNC (r>0.20, p<0.01). Similarly, in the MetS– group, BRI, BAI, AVI, WHtR, and PWNC showed low yet significant correlations (r>0.20, p<0.01). No significant correlations were detected between ABSI and other variables in either group (p>0.05) (Table 2).

ROC Analysis Results

According to the ROC analysis (Table 3), among the four indices examined, the highest AUC value in the MetS+ group belonged to the TG/HDL-C ratio, measured at 0.721 (95% CI: 0.677–0.766). This was followed by VAI (0.555; 95% CI: 0.502–0.607), CMI (0.549; 95% CI: 0.497–0.602), and LAP (0.547; 95% CI: 0.495–0.600). The optimal cutoff point for the TG/HDL-C ratio in the MetS+ group was determined to be 2.68. However, in the MetS– group, the TG/HDL-C ratio did not demonstrate significant discriminatory power (AUC=0.279).

Table 4 displays the multivariable adjusted odds ratios (ORs) and 95% CIs for MetS risk based on LAP, CMI, and TG/HDL-C index values. The VAI variable was excluded from the model due to multicollinearity issues (VIF >10, Tolerance <0.1).

The TG/HDL-C ratio (OR=0.67; 95% CI: 0.59–0.77) and age (OR=0.97; 95% CI: 0.96–0.99) were found to be statistically significant and positively associated with the presence of MetS. The CMI also showed a significant positive association with MetS (OR=1.00; 95% CI: 1.00–1.01). In contrast, the LAP (OR=0.99; 95% CI: 0.97–1.01) and gender (male/female) (OR=1.35; 95% CI: 0.80–2.28) were not significantly associated with MetS.

Regarding overall model fit, the chi-square test was significant ($\chi^2(5)=68.3$; p<0.001). Additionally, model explanatory power was calculated as McFadden's $R^2=0.10$ and Nagelkerke's $R^2=0.13$.

The predictive performance of the developed model is illustrated by the ROC analysis in Figure 1. According to the analysis results, the model demonstrated a moderate discriminatory power with an AUC value of 0.726. The sensitivity, or the true positive rate for correctly classifying individuals with metabolic syndrome (MetS+), was 0.889, whereas the correct classification rate for this group was determined to be 38.4%. The overall accuracy of the model was found to be 69.6%.

Table 2. Correlation matrix among anthropometric indices

		% Fat	BMI	ABSI	BRI	BAI	AVI	CI	FMI	VAI	WHR	WHtR	PWNC		
MetS+	% Fat	1	0.72**	-0.04	0.32**	0.35**	0.23**	0.12**	0.93**	0.00	-0.05	0.33*	0.21**	% Fat	MetS-
	BMI	0.69**	1	0.05	0.36**	0.34**	0.29**	0.19**	0.91**	-0.03	0.02	0.36**	0.29**	BMI	
	ABSI	0.13	0.15*	1	0.23**	-0.93	0.32**	0.64**	0.09	-0.10	0.54**	0.25**	0.25**	ABSI	
	BRI	0.35**	0.41**	0.47**	1	0.64**	0.82**	0.61**	0.36**	0.01	0.10	0.98**	0.75**	BRI	
	BAI	0.38**	0.42**	0.21**	0.63**	1	0.45**	0.24**	0.36**	0.14*	-0.34**	0.62**	0.45**	BAI	
	AVI	0.31**	0.37**	0.59**	0.91**	0.52**	1	0.73**	0.27**	0.10	0.22**	0.79**	0.89**	AVI	
	CI	0.23**	0.29**	0.81**	0.71**	0.36**	0.82**	1	0.14*	0.04	0.47**	0.63**	0.62**	CI	
	FMI	0.92**	0.90**	0.16*	0.41**	0.44**	0.36**	0.27**	1	-0.03	-0.03	0.36**	0.25**	FMI	
	VAI	0.03	0.00	0.27**	0.07	0.02	0.04	0.13	0.22	1	-0.28**	0.03	0.12*	VAI	
	WHR	-0.02	0.07	0.36**	0.31**	-0.13	0.29**	0.32**	0.002	0.11	1	0.13*	0.09	WHR	
	WHtR	0.34**	0.40**	0.49**	0.96**	0.67**	0.87**	0.73**	0.40**	0.04	0.29**	1	0.72**	WHtR	
	PWNC	0.26**	0.36**	0.63**	0.83**	0.46**	0.93**	0.86**	0.32**	0.06	0.28**	0.81**	1	PWNC	

BMI: Body Mass Index; ABSI: A Body Shape Index; BRI: Body Roundness Index; BAI: Body Adiposity Index; AVI: Abdominal Volume Index; CI: Conicity Index; FMI: Fat Mass Index; VAI: Visceral Adiposity Index; WHR: Waist to Hip Ratio; WHtR: Waist to Height Ratio; PWNC: Product of Waist and Neck Circumference; *: P<0.05; **: P<0.01.

Table 3. AUC, optimal cutoff points, and validity metrics of various anthropometric indices used for predicting metabolic syndrome

	MetS+						MetS-					
	AUC (95% CI)	p	Cut-off	Sen.	Spe.	YI	AUC (95% CI)	p	Cut-off	Sen.	Spe.	YI
VAI	0.555 (0.502–0.607)	0.041	2.59	11.58	96.41	0.0798	0.445	0.027	10.30	0.33	100.0	0.0327
LAP	0.547 (0.495–0.600)	0.023	90.44	13.68	94.12	0.078	0.453	0.023	32.25	99.35	2.63	0.01978
CMI	0.549 (0.497–0.602)	0.027	409.91	11.58	96.08	0.0766	0.451	0.027	1339.72	0.65	100.0	0.00654
TG/HDL-C	0.721 (0.677–0.766)	0.000	2.68	75.79	60.13	0.359	0.279	0.023	0.67	99.67	0	0.020

AUC: Area under the curve; VAI: Visceral Adiposity Index; LAP: Lipid Accumulation Product Index; CMI: Cardiometabolic Index; TG/HDL-C: Triglyceride/High-Density Lipoprotein Cholesterol ratio; YI: Youden Index; Sen: Sensitivity; Spe: Specificity.

Table 4. Logistic regression analysis results for LAP, CMI, and TG/HDL-C Indices predicting the presence of metabolic syndrome adjusted for gender and age

Index		Estimate	SE	Z	p	Adjusted OR	(95 CI%)	
Intercept		2.36019	0.50300	4.69	<0.001	10.593	3.952	28.390
TG/HDL-C		0.39892	0.06694	-5.96	<0.001	0.671	0.589	0.765
CMI		-0.00353	0.00144	2.44	0.015	1.004	1.001	1.006
LAP		0.01062	0.00827	-1.28	0.199	0.989	0.974	1.006
Gender		-0.29960	0.26861	1.12	0.265	1.349	0.797	2.284
Age		0.02610	0.00742	-3.52	<0.001	0.974	0.960	0.989
						Overall Model Test		
Model	Deviance	AIC	BIC	R^2McF	R^2CS	χ^2 df	p	
1	592	604	629	0.103	0.129	68.3	5	<0.001

OR: Odd ratios; SE: Standard error; TG/HDL-C: Triglyceride to High-Density Lipoprotein Cholesterol ratio; CMI: Cardiometabolic Index; LAP: Lipid Accumulation Product Index.

Discussion

This study aimed to evaluate the diagnostic performance of various anthropometric indices for identifying metabolic syndrome (MetS) in adults with obesity and to explore their associations with cardiometabolic risk markers. The findings revealed that commonly used anthropometric measures such as BMI, WC, and WHtR were not strong discriminatory diagnostic criteria within the studied cohort. Previous reports suggesting moderate interchangeability among these indicesmay partly explain their limited diagnostic capacity observed here.[14] Hu et al.[15] highlighted that although BMI is widely utilized for assessing obesity and metabolic abnormalities, its diagnostic accuracy remains limited because it does not distinguish between fat and lean mass or account for differences in fat distribution. Similarly, Oh et al.[16] emphasized that individuals with normal BMI but elevated visceral adiposity tend to exhibit greater insulin resistance, illustrating that BMI alone inadequately reflects true metabolic health.

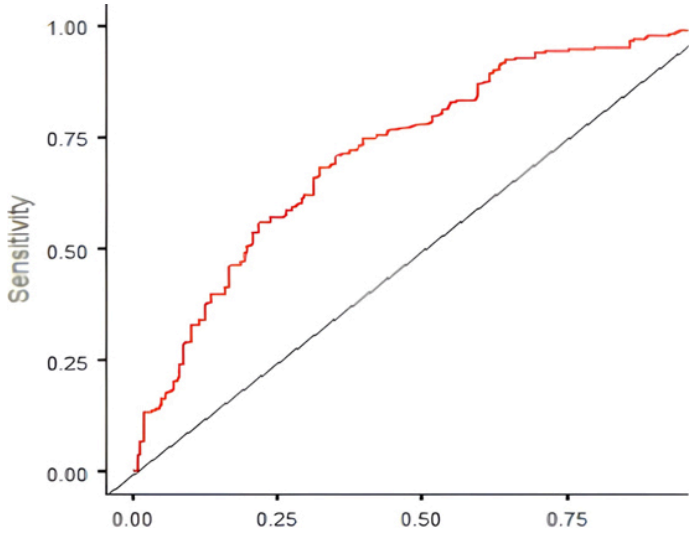

Figure 1. ROC analysis results for LAP, CMI, and TG/HDL-C Indice.

AUC=0.726, Specificity=0.384, Mets+ (% correct)=38.4%. Accuracy=0.696, Sensitivity=0.889, Mets- (% correct)=88.9%.

A key outcome of this research was the identification of the TG/HDL-C ratio as a significant diagnostic marker for MetS. This finding suggests that while traditional anthropometric indicators provide a limited view of metabolic risk among obese individuals, lipid profile–based ratios may deliver more specific and clinically informative insights. This interpretation aligns with the observations of Zhu et al.,[17] who reported that visceral adiposity, particularly in the abdominal region, is strongly linked with hypertension and type 2 diabetes risk, whereas peripheral fat distribution is associated with a lower metabolic burden.

Previous comparative studies have indicated that BMI and WHR are among the most suitable indicators for predicting total body fat in both sexes.[18] Nevertheless, several meta-analyses, including that of Okorodudu et al.[19] have demonstrated that BMI misclassifies a considerable proportion of individuals, failing to detect those with "normal-weight obesity," a phenotype characterized by metabolic dysregulation despite normal BMI values. The present findings, showing a strong correlation between BMI and WHR in both MetS and non-MetS participants, are consistent with these earlier observations. Similarly, Guan et al.[20] reported that although WHtR correlates with metabolic risk factors, it remains inadequate when body composition and fat distribution are not simultaneously assessed. Gao et al. [21] further demonstrated that WHR is more strongly associated with metabolic complications than BMI, reinforcing the need for more nuanced and multidimensional assessment tools.

Sex-specific differences in diagnostic accuracy were also notable. Among females, WHR and BAI showed higher sensitivity and negative predictive values than other anthropometric indices, suggesting that these measures may be useful for ruling out MetS rather than confirming it. Conversely, BMI and VAI exhibited the weakest diagnostic performance overall, implying that their isolated use may be inadequate for defining MetS. Hence, consideration of sex-based physiological and hormonal differences is crucial when determining diagnostic thresholds.[22] Supporting this, Anand et al.[23] reported that visceral and subcutaneous fat distribution exert greater influence on metabolic abnormalities than total body fat alone, underscoring the present study's emphasis on evaluating fat distribution patterns rather than relying solely on BMI or WC.[23]

Although the concept of metabolically healthy obesity is well documented in the literature, its underlying mechanisms and long-term implications remain ambiguous.[24] Given the multifactorial pathogenesis of MetS, expecting a single anthropometric measure to serve as a comprehensive diagnostic tool is unrealistic. The relationships among anthropometric indices, lipid accumulation parameters (LAP), cardiometabolic indices (CMI), and lipid profiles are complex, necessitating multidimensional approaches for effective evaluation.[25] Similarly, Mazidi et al.[26] observed that South Asians, despite lower BMI values, display higher body fat percentages and greater metabolic abnormalities compared with Caucasian and Black populations, emphasizing the limitations of BMI as a universal diagnostic criterion. Consequently, a holistic evaluation framework that integrates body composition analysis with cardiometabolic risk profiling is warranted for early MetS detection and prevention.[27]

The results of the present study indicate that, contrary to some previous reports, BMI and WHR are not robust discriminative markers for MetS. In contrast, indices incorporating lipid metabolism, such as TG/HDL-C ratio, VAI, LAP, and CMI, emerged as stronger diagnostic tools. Among these, only the TG/HDL-C ratio and CMI were statistically significant predictors, whereas LAP did not reach significance, suggesting that composite lipid-based indices may provide higher diagnostic precision in obese adults. These results are in line with studies reporting that LAP and CMI effectively discriminate individuals with MetS, even among physically active populations.[28]

Recent work by Pokharel et al.[29] also supports these findings. In a large adult cohort from Nepal's Gandaki Province, VAI demonstrated the highest diagnostic performance for MetS. This corroborates the current study's conclusion that lipid- and adiposity-based indices, including LAP, may serve as valuable diagnostic parameters for both sexes. Likewise, studies by Pokharel et al.[29] and Yoon et al.[30] reported the limited discriminative power of BMI for MetS, further highlighting the need to shift toward indices that better capture visceral adiposity and lipid metabolism.

Interpretation of these results should be made in light of certain limitations. The cross-sectional design precludes establishing causal relationships between the examined indices and MetS, a limitation acknowledged in prior studies. Future longitudinal research is needed to confirm the predictive validity of these anthropometric and lipid-derived indices. Additionally, the single-center setting and predominance of female participants (over 80%) restrict generalizability. Broader, multicenter studies with balanced gender representation and community-based sampling would strengthen external validity. Moreover, the restrictive exclusion criteria may have reduced variability within the sample, potentially influencing the strength of associations observed.

Limitations

This study has several limitations that should be acknowledged. First, its cross-sectional design limits the ability to establish causal relationships between the examined anthropometric and composite indices and the occurrence of MetS. Future longitudinal and prospective studies are warranted to evaluate the predictive validity and temporal stability of these indices in identifying individuals at metabolic risk. Second, the study sample was drawn from a single university hospital, which may restrict the external validity and generalizability of the findings to broader or community-based populations. Expanding future research to include multicenter and population-based cohorts would provide a more comprehensive understanding of these associations. Third, the study sample predominantly consisted of female participants (over 80%), which could have introduced a gender-related bias in the observed relationships and diagnostic performance of the indices. Ensuring a more balanced gender distribution in future studies would enhance the robustness of the conclusions. Additionally, while a wide range of anthropometric and composite indices were assessed, imaging-based measures of visceral adiposity (such as CT or MRI) were not included due to resource constraints. Incorporating such advanced imaging methods could further elucidate the mechanisms linking body fat distribution to metabolic risk.

Conclusion

The findings of this study suggest that, due to the multifactorial and complex nature of MetS, relying on a single biomarker or anthropometric index for diagnosis and risk assessment may be insufficient. Notably, novel indices such as the TG/HDL-C ratio, VAI, LAP, and CMI demonstrated higher discriminative power in identifying MetS compared with traditional anthropometric measures such as BMI and WHtR. This highlights the need for more comprehensive and integrated approaches that go beyond classical parameters in the evaluation of metabolic risk.

Moreover, the relatively low AUC values indicate the limited predictive capacity of the existing indices and underscore the necessity of identifying stronger predictors or developing new risk models incorporating multiple parameters. However, given the heterogeneous nature of MetS, no single test or index can fully capture all metabolic abnormalities. Therefore, holistic approaches considering the interplay of diverse anthropometric and biochemical markers, along with variables such as ethnicity, age, sex, and individual metabolic profiles, should be developed.

To enhance clinical applicability, the integration of these indices into composite scoring systems or algorithm-based clinical decision pathways is recommended. For instance, combining lipid-based markers (e.g., TG/HDL-C ratio and CMI) with anthropometric indices (e.g., WHR and VAI) within a weighted scoring framework could provide a more accurate stratification of metabolic risk. Such a model could be incorporated into digital clinical tools or electronic health record systems to facilitate early identification and personalized management of MetS in routine practice.

In clinical settings, detailed medical histories should be obtained, and comprehensive evaluations supported by physical examination findings (e.g., BP, WC) and laboratory tests (e.g., fasting glucose, lipid profile) should be conducted. Future research should aim to validate the clinical utility of such integrative scoring systems across diverse populations and healthcare contexts, which will enhance both diagnostic precision and preventive strategies for MetS.

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