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Contribution of body adiposity index and conicity index in prediction of metabolic syndrome risk and components

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ABSTRACT

Background and aims: Body adiposity index (BAI) and conicity index have been known as useful measures in predicting cardio-metabolic diseases. This study aimed to evaluate the predictive potential of BAI and conicity index for the risk of metabolic syndrome (MetS) in comparison with body mass index (BMI), waist circumference (WC), hip circumference (HC), and waist-hip ratio (WHR).

Methods: In this cross-sectional study, 174 adults (87 with MetS and 87 healthy individuals) were recruited from a medical weight loss center. Anthropometric parameters, systolic and diastolic blood pressures (SDP and DBP), lipid profile, and fasting blood sugar (FBS) were measured.

Results: All anthropometric parameters were significantly higher in subjects with MetS than in healthy subjects. Both in MetS and healthy subjects, females had significantly higher BAI and BMI than males. In the fully adjusted model, the odds of MetS increased for each unit increase in BAI by 27 % ($p = 0.001$), in BMI by 33 % ($p = 0.001$), in WC by 13 % ($p < 0.001$), and in HC by 9 % ($p = 0.005$). ROC curve analysis showed that all the anthropometric parameters displayed clinical importance in predicting MetS, but WHR had the largest area under the curve (AUC) in total, male, and female patients. In participants with MetS, the conicity index was negatively correlated with FBS; BAI was positively associated with HDL level.

Conclusion: All studied anthropometric parameters had acceptable accuracy for predicting MetS. Traditional parameters, particularly the WHR, exhibited a higher predictive power concerning MetS. The results underscore the reliability of conventional anthropometric measures in clinical and epidemiological settings.

1. Introduction

Metabolic syndrome (MetS) is a collection of at least three of five medical risk factors including high blood pressure, high fasting blood sugar (FBS), central obesity, high serum triglyceride (TG), and low serum high-density lipoprotein (HDL). Metabolic syndrome increases the chance of developing chronic diseases such as cardiovascular disease, stroke, and diabetes [1–4]. According to the criteria used for the definition of MetS, the prevalence estimates differ across and within the regions.

Metabolic syndrome is closely related to overweight or obesity. With the increase of obesity, the clustering of MetS components increases remarkably [5]. Body mass index (BMI) is a widely used method for assessing body fat content and degree of obesity. Waist circumference (WC) is also the most commonly used method for assessing the degree of abdominal obesity. Although, both methods are easy and practical anthropometric indices to assess the general and visceral fat in adults, however, the methods have some shortcomings such as they may be influenced by age, gender, and ethnic differences [6]. BMI does not consider muscle mass, bone density, and body composition [7]. The WC evaluation method is not univocally standardized. Moreover, in people with grade 2 or 3 obesity, it is difficult to measure the WC. In addition, WC does not distinguish between visceral fat and subcutaneous fat [8]. For that, new methods including body adiposity index (BAI) and conicity index have been projected as obesity indices, to overcome the defects of BMI and WC.

Body adiposity index is a method of calculating the amount of body fat by comparing a person's height to the size of hips, without

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considering body weight. BAI has been established to be a useful measure in estimating the risk of developing chronic diseases such as type 2 diabetes [9], and cardiovascular diseases [10]. BAI may also be beneficial in predicting cardiometabolic risk factors in adults [11].

The conicity index is an anthropometric indicator to evaluate central adiposity using waist circumference, height, and weight measures. The conicity index has been known as a superior abdominal obesity index in predicting cardiometabolic diseases and their risk factors [12–14].

Prior research in this domain has predominantly focused on specific population groups, such as individuals with diabetes, postmenopausal women, or the elderly [15], [-17] or has been geographically concentrated in African and East Asian countries [17–20]. There is a notable paucity of studies within the Middle Eastern region. Given the distinct cultural and lifestyle factors in this area, which may significantly influence the association between obesity indices and the risk of MetS, this study aimed to address this gap. Therefore, the objective of this study was to compare the predictive potential of anthropometric parameters including conicity index, BAI, BMI, WC, hip circumference (HC), and waist-hip ratio (WHR) concerning the risk of MetS in the XXX population.

2. Methods

2.1. Participants

One hundred and seventy-four adult volunteers (aged 30–50 years) were recruited from a medical weight loss center (XXX) using a convenience sampling method. According to the ATP (III) criteria, 87 of the participants (20 males and 67 females) had MetS and another 87 healthy individuals (23 males and 64 females, recruited from those who attended the nutrition clinic for routine health examinations) served as the control group. Written informed consent was obtained from each subject. The study was approved by the Ethical Committee of XXX, on March 6, 2023.

Inclusion criteria for MetS group comprised having at least 3 of 5 ATP (III) criteria as follows: abdominal obesity, given as WC > 88 cm for women and >102 for men, serum triglyceride (TG) ≥ 150 mg/dL, high-density lipoprotein cholesterol (HDL-c) < 50 mg/dL for women and <40 mg/dL for men, blood pressure ≥130/85 mm Hg, fasting blood glucose (FBG) ≥ 100 mg/dL. The inclusion criteria for the control group were an age range between 30 and 50 years, having no obvious symptoms of other disease, and not taking any medication at the time of sampling.

Exclusion criteria were BMI ≥40 kg/m^2, infectious or chronic inflammatory diseases, history of psychiatric diseases, receiving anti-obesity, anti-inflammatory or anti-hypertensive medications, thyroid disorders, endocrine diseases, smoking, excessive consumption of alcohol, pregnancy and lactating, menopause and diet therapy during three months before the study.

2.2. Anthropometric measurements

The participant's body weight was assessed using a SECA scale (Model 769, Hamburg, Germany) to the nearest 0.1 kg; subjects had light clothes with no shoes and their standing height was measured to the nearest 0.5 cm. BMI was computed as the body weight (kg)/height (m) [2]. Waist circumference was measured horizontally midway between the lower border of the ribs and the iliac crest using inelastic tape. Hip circumference was measured at the widest point of the hip. Body adiposity index and conicity index were calculated with the following formulas [18].

$$\text{Conicity index} = 0.109^{-1}\ \text{WC(m)}[\ \text{Weight(Kg)/Height(m)}]^{-1/2}$$

$$\text{Body adiposity index} = [100^{*}\text{hip circumference (m)/height (m)}^{1.5}] - 18$$

2.3. Blood pressure, lipid profile, and fasting blood sugar

The participant's systolic and diastolic blood pressures (SBP and DBP, respectively) were evaluated by an automatic oscillometric device. After overnight fasting, five ml of venous blood was collected and serum was separated and stored at −70 °C until analysis. Serum levels of HDL-c and triglyceride (TG) concentrations were assessed using a Biochemical Auto-analyzer Instrument and enzymatic kits (XXX). Serum FBS level was measured using the glucose oxidase method with the commercial kit (XXX).

2.4. Assessment of physical activity

To evaluate the physical activity of participants, the study utilized a shortened form of the International Physical Activity Questionnaire (IPAQ) over a seven-day recall period, as described by Craig et al. [21] This questionnaire assessed different physical activity levels, including walking, moderate-intensity, and vigorous-intensity activities. Physical activity was quantified using the metabolic equivalent of task (MET) minutes per week. Based on the IPAQ results, participants' total MET-min/week scores were categorized into low, moderate, and high activity levels.

2.5. Statistical analysis

The data were examined using SPSS 21 software (SPSS Inc., Chicago, IL, USA). The normality of the data was assessed using the skewness and kurtosis test. The results were presented as frequency (%) for the qualitative data and as mean ± SD or median (IQR) for normal or non-normal distributed quantitative data, respectively. To compare the two groups, the independent samples test or Mann-Whitney *U* test was used. Binary regression was used to calculate the odds ratio (OR) and 95 % confidence interval (CI) for MetS as the outcome considering age, gender, physical activity, SBP, DBP, TG, FBS, and HDL as confounder factors. The Partial test was used to assess the relationship between anthropometric factors and MetS components, with considering age, gender, and physical activity as covariates. The relative abilities of various anthropometric criteria were compared using receiver operator characteristics (ROC) to predict MetS. A p-value <0.05 was considered significant for all statistical assessments.

3. Results

As shown in Table 1, participants in the MetS group were significantly older than healthy individuals ($p = 0.004$). Participants in the MetS group had mostly moderate physical activity levels, while healthy individuals had mostly low physical activity ($p = 0.049$). All anthropometric parameters (conicity index, BAI, BMI, WC, HC, and WHR) were significantly higher in subjects with MetS than in healthy subjects ($p < 0.01$). Subjects with MetS had significantly higher levels of SBP, DBP, TG, FBG, and lower levels of HDL compared to healthy individuals ($p < 0.01$) (Table 1).

As shown in Table 2, in the total studied population, females had significantly greater BAI ($p < 0.001$), BMI ($p < 0.001$), and WHR ($p = 0.002$) than males. Other anthropometric parameters (conicity index, WC, and HC) did not significantly differ between females and males, in the total population. In subjects with MetS, females had significantly higher BAI ($p < 0.001$) and BMI ($p = 0.005$) than males. In healthy people, females had significantly higher BAI ($p < 0.001$), BMI ($p = 0.001$), and WHR ($p = 0.002$).

As shown in Table 3, in multivariate analysis after adjusting for age, gender, and physical activity each unit increase in BAI increased the odds of MetS by 12 % [OR (95 % CI): 1.12 (1.04, 1.20), $p = 0.002$]. Each unit increase in BMI increased the odds of MetS by 23 % [OR (95 % CI): 1.23 (1.12, 1.34), $p < 0.001$]. Each unit increase in WC increased the odds of MetS by 7 % [OR (95 % CI): 1.07 (1.04, 1.10), $p < 0.001$]. Each

Table 1
Characteristics of participants.

	MetS (n = 87)	Healthy individuals (n = 87)	p
Age (year)[a]	40.09 ± 6.89	37.29 ± 5.87	0.004
Gender[b]			
Male	20 (23.0)	23 (26.4)	0.60
Female	67 (77.0)	64 (73.6)	
Physical activity level[b]			
Low	35 (40.2)	48 (55.2)	0.049
Moderate	52 (59.8)	39 (44.8)	
High	0	0	
Conicity Index[a]	1.37 ± 0.10	1.28 ± 0.11	<0.001
BAI[a]	37.69 ± 5.72	34.39 ± 6.82	0.001
BMI[a]	33.39 ± 4.05	29.57 ± 4.93	<0.001
WC[a]	109.41 ± 11.24	97.31 ± 14.04	<0.001
HC[a]	114.31 ± 9.54	109.59 ± 10.19	0.002
WHR[a]	0.96 ± 0.06	0.88 ± 0.07	<0.001
SBP[c]	120.00 (110.00, 135.00)	110.00 (100.00, 130.00)	0.003
DBP[c]	80.00 (70.00, 90.00)	80.00 (70.00, 80.00)	<0.001
TG[c]	182.00 (146.00, 254.00)	99.00 (76.00, 140.00)	<0.001
FBS[c]	107.00 (99.00, 114.00)	93.50 (85.00, 98.00)	<0.001
HDL[c]	40.29 ± 8.21	48.68 ± 10.82	<0.001

BAI: body adiposity index; BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist-hip ratio; SBP: systolic blood pressures; DBP: diastolic blood pressures; TG: triglyceride; FBS: fasting blood sugar; HDL: high-density lipoprotein.
[a] Data are presented as mean ± SD.
[b] Data are presented as number (percent).
[c] Data are presented as median (percentiles 25, 75).

unit increase in HC increased the odds of MetS by 5 % [OR (95 % CI): 1.05 (1.01, 1.08), p = 0.007]. In model 2, considering age, gender, and physical activity, SBP, DBP, TG, FBS, and HDL as confounding factors, each unit increase in BAI increased the odds of MetS by 27 % [OR (95 % CI): 1.27 (1.10, 1.45), p = 0.001]. Each unit increase in BMI increased the odds of MetS by 33 % [OR (95 % CI): 1.33 (1.12, 1.59), p = 0.001]. Each unit increase in WC increased the odds of MetS by 13 % [OR (95 % CI): 1.13 (1.06, 1.21), p < 0.001]. Each unit increase in HC increased the odds of MetS by 9 % [OR (95 % CI): 1.09 (1.03, 1.16), p = 0.005].

In participants with MetS, the conicity index was negatively correlated with FBS ($r = -0.35$, $p = 0.002$). BAI had a positive association with HDL level ($r = 0.30$, $p = 0.007$). BMI, WC, HC, and WHR were not significantly correlated with MetS components ($p > 0.05$) (data are not shown). In healthy subjects, there was a significant positive relationship between FBS with BAI ($r = 0.28$, $p = 0.009$), BMI ($r = 0.36$, $p = 0.001$), WC ($r = 0.31$, $p = 0.005$), and HC ($r = 0.30$, $p = 0.005$). There was also a significant positive relationship between HDL and BAI ($r = 0.25$, $p = 0.02$) (data are not shown).

According to ROC curve analysis, all the anthropometric parameters displayed clinical importance in predicting MetS, but WHR had the largest area under the curve (AUC) (Fig. 1). As shown in Table 4, AUC (95 % CI) was 0.719 (0.643, 0.795) for conicity index, 0.644 (0.561, 0.726) for BAI, 0.712 (0.635, 0.788) for BMI, 0.739 (0.665, 0.813) for WC, 0.629 (0.547, 0.712) for HC, and 0.790 (0.721, 0.859) for WHR. Both in males and females, WHR was superior to other parameters in predicting MetS (Fig. 1 and Table 4).

4. Discussion

In the present study, subjects with MetS had a significantly higher conicity index, BAI, BMI, WC, HC, and WHR than healthy subjects. The findings were in agreement with the results of Quaye et al. study for all the parameters, except for the conicity index which had no significant difference between MetS and healthy subjects [18]. Wang et al. also found higher BAI, conicity index, BMI, WC, and WHR in MetS participants than their healthy counterparts, both in men and women [22]. Khosravian et al. in a study on 1488 people found a significant difference in conicity index, BMI, WC, HC, and WHR between people with Mets and without MetS [16].

In the present study, the odds of MetS increased by increasing BAI, BMI, WC, and HC. Similar results have also been reported by Djibo et al. in a study on postmenopausal women [23] and Amiri et al. in a study on patients with type 2 diabetes [24]. In our work, the odds ratio and CI were irrationally too large and wide for the conicity index and WHR, therefore we did not include the results in the article.

In the present study, WHR, followed by WC, was the strongest predictor of MetS. In agreement with our result, Gadelha et al., in a study on postmenopausal women, found that WC and WHR had a stronger

Table 3
Correlation of MetS Odds ratio with anthropometric indices.

	Univariate		Multivariate (model 1)		Multivariate (model 2)	
	Odds ratio (CI)	p	Odds ratio (CI)	p	Odds ratio (CI)	p
Conicity Index	–	–	–	–	–	–
BAI	1.09 (1.03, 1.14)	0.001	1.12 (1.04, 1.20)	0.002	1.27 (1.10, 1.45)	0.001
BMI	1.21 (1.12, 1.31	<0.001	1.23 (1.12, 1.34)	<0.001	1.33 (1.12, 1.59)	0.001
WC	1.08 (1.05, 1.11)	<0.001	1.07 (1.04, 1.10)	<0.001	1.13 (1.06, 1.21)	<0.001
HC	1.05 (1.02, 1.08)	0.003	1.05 (1.01, 1.08)	0.007	1.09 (1.03, 1.16)	0.005
WHR	–	–	–	–	–	–

BAI: body adiposity index; BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist-hip ratio.
Model1: Covariates considered are age, gender, and physical activity; Model 2: Covariates considered are covariates for model 1 plus SBP, DBP, TG, FBS, and HDL.

Table 2
Comparison of anthropometric indices between females and males.

	Total			Mets			Healthy individuals		
	Female (n = 131)	Male (n = 43)	p	Female (n = 67)	Male (n = 20)	p	Female (n = 64)	Male (n = 23)	p
Conicity Index	1.33 ± 0.11	1.30 ± 0.13	0.12	1.37 ± 0.09	1.36 ± 0.15	0.91	1.30 ± 0.12	1.24 ± 0.08	0.06
BAI	38.10 ± 5.60	29.75 ± 4.75	<0.001	39.53 ± 4.48	31.52 ± 5.10	<0.001	36.61 ± 6.26	28.22 ± 3.90	<0.001
BMI	32.37 ± 4.71	28.76 ± 4.43	<0.001	34.05 ± 3.90	31.20 ± 3.85	0.005	30.62 ± 4.88	26.63 ± 3.81	0.001
WC	104.11 ± 13.84	101.09 ± 14.61	0.22	109.15 ± 10.90	110.30 ± 12.56	0.69	98.83 ± 14.68	93.09 ± 11.29	0.06
HC	111.80 ± 9.86	112.39 ± 11.01	0.74	113.61 ± 8.95	116.65 ± 11.23	0.21	109.91 ± 10.46	108.69 ± 9.57	0.63
WHR	0.93 ± 0.07	0.89 ± 0.07	0.002	0.96 ± 0.06	0.94 ± 0.07	0.22	0.90 ± 0.08	0.84 ± 0.04	0.002

BAI: body adiposity index; BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist-hip ratio.
Data presented as mean ± SD. Independent Samples Test.

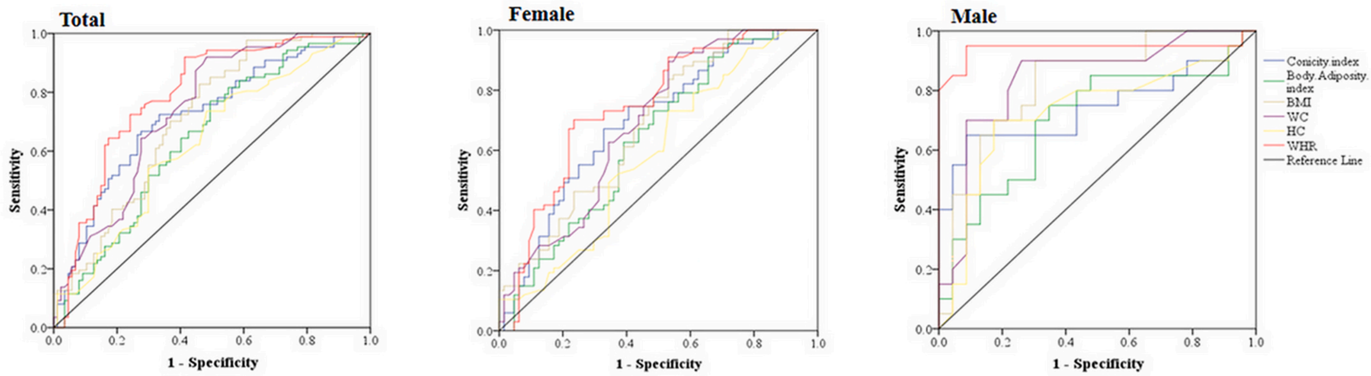

Fig. 1. Receiver Operating Characteristic curve according to sensitivity (y-axis) and specificity (x-axis). BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist-hip ratio.

Table 4
Area Under the Curve (AUC) of anthropometric indices in predicting MetS.

	Total		Males		Females	
	AUC (CI)	p	AUC (CI)	p	AUC (CI)	p
Conicity Index	0.719 (0.643, 0.795)	<0.001	0.743 (0.583, o.904)	0.006	0.695 (0.605, 0.785)	<0.001
BAI	0.644 (0.561, 0.726)	0.001	0.700 (0.537, 0.863)	0.02	0.637 (0.541, 0.732)	0.007
BMI	0.712 (0.635, 0.788)	<0.001	0.824 (0.697, 0.951)	<0.001	0.682 (0.591, 0.773)	<0.001
WC	0.739 (0.665, 0.813)	<0.001	0.838 (0.711, 0.965)	<0.001	0.690 (0.599, 0.781)	<0.001
HC	0.629 (0.547, 0.712)	0.003	0.729 (0.568, 0.891)	0.01	0.587 (0.489, 0.685)	0.08
WHR	0.790 (0.721, 0.859)	<0.001	0.942 (0.850, 1.000)	<0.001	0.744 (0.659, 0.830)	<0.001

BAI: body adiposity index; BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist-hip ratio.

association with MetS [15]. Correia et al., in a cross-sectional study of 152 postmenopausal women, showed that WC and WHR had higher AUC in predicting MetS [25]. In addition, Khosravian et al. showed that WHR had the largest AUC for predicting MetS [16]. Quaye et al. showed that BMI and WC had larger AUCs than BAI, and conicity index in predicting MetS [18]. Jao et al. in a study on 1872 patients with type 2 diabetes reported that BMI had the greatest AUC in predicting MetS, in both sexes [26]. Collectively, it appears that old anthropometric indices are more effective in predicting MetS than new indices.

In the current study, even though WHR and WC were better predictors of MetS, but they had no relationship with MetS components. This observation indicates that the predictor potential of WHR and WC might be independent of MetS other components. In addition to traditional predictors of MetS (FBG, TG, HDL cholesterol, blood pressure, and WC) several other factors can contribute to predicting MetS, including insulin resistance and inflammation [27]. Increased WC or WHR can predict MetS through several mechanisms: Excess fat around the waist is strongly associated with insulin resistance, a key component of MetS. Fat cells, particularly visceral fat, release substances that can impair insulin signaling [28]. Adipose tissue, especially visceral fat, secretes pro-inflammatory cytokines like TNF-alpha and IL-6. Chronic inflammation is linked to MetS and its components [29]. Excess visceral fat can also affect the balance of hormones such as leptin and adiponectin, which play roles in appetite regulation and insulin sensitivity [29,30]. These mechanisms collectively contribute to the development of MetS, making WC and WHR valuable predictors of the condition.

We demonstrated that BAI had a lower discriminatory potential for diagnosing MetS than BMI, WC, and WHR. The finding was in line with several previous studies. Shin et al. in a study on 20,961 adults concluded that BMI might be a better candidate than BAI to assess risk of MetS [31]. Moreover, Liu et al. in a study on 817 participants showed that the MetS predictive ability of the traditional anthropometric measures was significantly stronger than BAI [32]. Al-Daghri et al. in a study on 6821 adults reported that BAI was the least sensitive adiposity index in identifying cardiometabolic diseases [33].

Contrary to our expectation, BAI was positively associated with HDL levels both in MetS patients and healthy subjects. Quaye et al. [18], in a cross-sectional study of 160 healthy normoglycemic normotensive adults, identified individuals with MetS using the joint interim statement criteria. Using the linear regression analysis, the authors found a direct relation between BAI and HDL levels. However, Shin et al. [31], in a study of 20,961 Korean adults, using the American Heart Association/National Heart, Lung, and Blood Institute (AHA/NHLBI) criteria to diagnose MetS, found a negative association between BAI and HDL using Pearson's or Spearman's correlation analyses. It appears that the role of covariates has not been considered in this study. Also, Zaki et al. [34], in a cross-sectional research on 180 women, using the International Diabetes Federation criteria to diagnose MetS, found a negative association between BAI and HDL by bivariate correlations. This study also did not account for the role of confounding factors in its statistical analysis.

The positive correlation between BAI and HDL levels can be attributed to the leptin hormone levels. Studies have demonstrated a positive correlation between BAI and leptin concentrations [35–37]. Elevated BAI reflects increased adiposity, which in turn enhances leptin secretion. Moreover, leptin has been shown to positively affect HDL levels by inducing hepatic scavenger receptor class B type I (SR-BI) [38,39]. Furthermore, when the association of two constituent elements of BAI, including HC and height, with leptin was reviewed, it was found that high HC, a factor contributing to higher BAI, was positively correlated with leptin levels [40–42], implying that a greater HC corresponds to increased leptin secretion. Furthermore, short stature, another increasing factor of BAI, was also correlated with increased levels of leptin [43,44]. According to earlier studies, there was also an inverse association between height and HDL level [45–47]. Furthermore, the observed negative relationship between height and HDL levels, in the present study, further supports the previous findings. Elevated BAI or its enhancing components, all are linked to increased leptin secretion, enhancing HDL levels.

4.1. *Strengths of the study*

Recruiting participants from a medical weight loss center provides a diverse sample, which can enhance the generalizability of findings to similar populations. Advanced statistical methods, such as binary regression and ROC analysis, strengthened outcome validity and helped to identify the most predictive anthropometric indices.

4.2. Limitations of the study

The cross-sectional nature of this study limits the ability to generalize the findings to broader populations. The irrationally large and wide odds ratio and CI for conicity index and WHR did not allow us to find their correlation with the odds of MetS, however, ROC curve analysis covered this limitation and recognized their diagnostic value concerning MetS.

5. Conclusions

The predictive potential of BAI and conicity index for MetS were compared to BMI, WC, HC, and WHR. According to the findings, all the anthropometric parameters had acceptable accuracy for predicting MetS. Traditional parameters, particularly the WHR, exhibited a higher predictive power concerning MetS. The results underscore the reliability of conventional anthropometric measures, particularly WHR, in clinical and epidemiological settings. Healthcare providers can prioritize WHR in routine screenings to identify individuals at risk of MetS more effectively. Public health initiatives can focus on WHR as a key metric in interventions aimed at reducing the prevalence of MetS.

CRediT authorship contribution statement

Sorayya Kheirouri: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Mohammad Alizadeh:** Supervision, Resources, Project administration, Data curation.

Ethics approval and consent to participants

The study was approved by the Ethical Committee of XXX (XXX) and written informed consent was obtained from each subject.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] M.J. Guembe, C.I. Fernandez-Lazaro, C. Sayon-Orea, E. Toledo, C. Moreno-Iribas, Risk for cardiovascular disease associated with metabolic syndrome and its components: a 13-year prospective study in the RIVANA cohort, Cardiovasc. Diabetol. 19 (2020) 195, https://doi.org/10.1186/s12933-020-01166-6.

[2] S. Low, K.C.J. Khoo, J. Wang, B. Irwan, C.F. Sum, T. Subramaniam, et al., Development of a metabolic syndrome severity score and its association with incident diabetes in an Asian population-results from a longitudinal cohort in Singapore, Endocrine 65 (1) (2019) 73–80, https://doi.org/10.1007/s12020-019-01970-5.

[3] M.K. Lee, K. Han, M.K. Kim, E.S. Koh, E.S. Kim, G.E. Nam, H.S. Kwon, Changes in metabolic syndrome and its components and the risk of type 2 diabetes: a nationwide cohort study, Sci. Rep. 10 (2020) 2313, https://doi.org/10.1038/s41598-020-59203-z.

[4] X. Li, Y. Zhai, J. Zhao, H. He, Y. Li, Y. Liu, et al., Impact of metabolic syndrome and it's components on prognosis in patients with cardiovascular diseases: a meta-analysis, Front Cardiovasc Med 8 (2021) 704145, https://doi.org/10.3389/fcvm.2021.704145.

[5] B. Damiri, M.S. Abualsoud, M. Amjad, A.M. Samara, S.K. Salameh, Metabolic syndrome among overweight and obese adults in Palestinian refugee camps, Diabetol Metab Syndr 10 (2018) 34, https://doi.org/10.1186/s13098-018-0337-2.

[6] A.M. Nevill, A.D. Stewart, T. Olds, R. Holder, Relationship between adiposity and body size reveals limitations of BMI, Am. J. Phys. Anthropol. 129 (1) (2006) 151–156, https://doi.org/10.1002/ajpa.20262.

[7] M. Rahman, A.B. Berenson, Accuracy of current body mass index obesity classification for white, black, and hispanic reproductive-age women, Obstet. Gynecol. 115 (5) (2010) 982–988, https://doi.org/10.1097/aog.0b013e3181da9423.

[8] P. Piqueras, A. Ballester, J.V. Durá-Gil, S. Martinez-Hervas, J. Redón, J.T. Real, Anthropometric indicators as a tool for diagnosis of obesity and other health risk factors: a literature review, Front. Psychol. 12 (2021) 631179, https://doi.org/10.3389/fpsyg.2021.631179.

[9] C.M.D. Oliveira, J. Pavani, J.E. Krieger, R.D.O. Alvim, C.A. Mourão-Junior, A.D. C. Pereira, Body adiposity index in assessing the risk of type 2 diabetes mellitus development: the Baependi Heart Study, Diabetol Metab Syndr 11 (2019) 76, https://doi.org/10.1186/s13098-019-0467-1.

[10] A.I. García, L.A. Niño-Silva, K. González-Ruíz, R. Ramírez-Vélez, Body adiposity index as marker of obesity and cardiovascular risk in adults from Bogotá, Colombia, Endocrinol. Nutr. 62 (3) (2015) 130–137, https://doi.org/10.1016/j.endonu.2014.11.007.

[11] A. Zwierzchowska, D. Celebańska, B. Rosołek, K. Gawlik, A. Żebrowska, Is body mass index (BMI) or body adiposity index (Bai) a better indicator to estimate body fat and selected cardiometabolic risk factors in adults with intellectual disabilities? BMC Cardiovasc. Disord. 21 (1) (2021) 119, https://doi.org/10.1186/s12872-021-01931-9.

[12] N. Motamed, D. Perumal, F. Zamani, H. Ashrafi, M. Haghjoo, F.S. Saeedian, et al., Conicity index and waist-to-hip ratio are superior obesity indices in predicting 10-Year cardiovascular risk among men and women, Clin. Cardiol. 38 (9) (2015) 527–534, https://doi.org/10.1002/clc.22437.

[13] L.C. Milagres, K.O. Martinho, D.C. Milagres, F.S. Franco, A.Q. Ribeiro, J.F. D. Novaes, Waist-to-height ratio and the conicity index are associated to cardiometabolic risk factors in the elderly population, Cien Saude Colet 24 (4) (2019) 1451–1461, https://doi.org/10.1590/1413-81232018244.12632017.

[14] Y. Zhang, Q. Zeng, X. Li, P. Zhu, F. Huang, Application of conicity index adjusted total body fat in young adults-a novel method to assess metabolic diseases risk, Sci. Rep. 8 (2018) 10093, https://doi.org/10.1038/s41598-018-28463-1.

[15] A.B. Gadelha, J. Myers, S. Moreira, M.T. Dutra, M.P. Safons, R.M. Lima, Comparison of adiposity indices and cut-off values in the prediction of metabolic syndrome in postmenopausal women, Diabetes Metab Syndr 10 (3) (2016) 143–148, https://doi.org/10.1016/j.dsx.2016.01.005.

[16] S. Khosravian, M.A. Bayani, S.R. Hosseini, A. Bijani, S. Mouodi, R. Ghadimi, Comparison of anthropometric indices for predicting the risk of metabolic syndrome in older adults, Rom. J. Intern. Med. 59 (1) (2021) 43–49, https://doi.org/10.2478/rjim-2020-0026.

[17] E.O. Anto, J. Frimpong, W.I.O. Boadu, V.C.K.T. Tamakloe, C. Hughes, B. Acquah, et al., Prevalence of cardiometabolic syndrome and its association with body shape index and a body roundness index among type 2 diabetes mellitus patients: a hospital-based cross-sectional study in a Ghanaian population, Front Clin Diabetes Healthc 2 (2022) 807201, https://doi.org/10.3389/fcdhc.2021.807201.

[18] L. Quaye, W.K.B.A. Owiredu, N. Amidu, P.P.M. Dapare, Y. Adams, Comparative abilities of body mass index, waist circumference, abdominal volume index, body adiposity index, and conicity index as predictive screening tools for metabolic syndrome among apparently healthy Ghanaian adults, J Obes 2019 (2019) 8143179, https://doi.org/10.1155/2019/8143179.

[19] T.H. Chiu, Y.C. Huang, H. Chiu, P.Y. Wu, H.Y.C. Chiou, J.C. Huang, S.C. Chen, Comparison of various obesity-related indices for identification of metabolic syndrome: a population-based study from Taiwan biobank, Diagnostics 10 (12) (2020) 1081, https://doi.org/10.3390/diagnostics10121081.

[20] M.R. Nkwana, K.D. Monyeki, S.L. Lebelo, Body roundness index, a body shape index, conicity index, and their association with nutritional status and cardiovascular risk factors in south African rural young adults, Int J Environ Res Public Health 18 (1) (2021) 281, https://doi.org/10.3390/ijerph18010281.

[21] C.L. Craig, A.L. Marshall, M. Sjöström, A.E. Bauman, M.L. Booth, B.E. Ainsworth, et al., International physical activity questionnaire: 12-country reliability and validity, Med. Sci. Sports Exerc. 35 (8) (2003) 1381–1395.

[22] H. Wang, A. Liu, T. Zhao, X. Gong, T. Pang, Y. Zhou, et al., Comparison of anthropometric indices for predicting the risk of metabolic syndrome and its components in Chinese adults: a prospective, longitudinal study, BMJ Open 7 (2017) e016062, https://doi.org/10.1136/bmjopen-2017-016062.

[23] D.A. Djibo, M.R.G. Araneta, D. Kritz-Silverstein, E. Barrett-Connor, W. Wooten, Body adiposity index as a risk factor for the metabolic syndrome in postmenopausal caucasian, African American, and Filipina women, Diabetes Metab Syndr 9 (2) (2015) 108–113, https://doi.org/10.1016/j.dsx.2014.04.011.

[24] P. Amiri, A.Z. Javid, L. Moradi, N. Haghighat, R. Moradi, H.B. Behbahani, et al., Associations between new and old anthropometric indices with type 2 diabetes mellitus and risk of metabolic complications: a cross-sectional analytical study, J Vasc Bras 20 (2021) e20200236, https://doi.org/10.1590/1677-5449.200236.

[25] E.S. Correia, J.C.M. Godinho-Mota, R.M. Schincaglia, K.A. Martins, J.S. Martins, P. R. Vilella, et al., Metabolic syndrome in postmenopausal women: prevalence, sensibility, and specificity of adiposity indices, Clinical Nutrition Open Science 41 (2022) 106–114, https://doi.org/10.1016/j.nutos.2022.01.001.

[26] H.F. Jao, C.H. Wung, H.C. Yu, M.Y. Lee, P.C. Chen, S.C. Chen, et al., Sex difference in the associations among obesity-related indices with metabolic syndrome in patients with type 2 diabetes mellitus, Int. J. Med. Sci. 18 (15) (2021) 3470–3477, https://doi.org/10.7150/ijms.63180.
[27] E. Ingelsson, J. Hulthe, L. Lind, Inflammatory markers in relation to insulin resistance and the metabolic syndrome, Eur. J. Clin. Invest. 38 (7) (2008) 502–509.
[28] J.I. Ramírez-Manent, A.M. Jover, C.S. Martinez, P. Tomás-Gil, P. Martí-Lliteras, A. A. López-González, Waist circumference is an essential factor in predicting insulin resistance and early detection of metabolic syndrome in adults, Nutrients 15 (2) (2023) 257, https://doi.org/10.3390/nu15020257.
[29] D. Ackermann, J. Jones, J. Barona, M.C. Calle, J.E. Kim, B. LaPia, et al., Waist circumference is positively correlated with markers of inflammation and negatively with adiponectin in women with metabolic syndrome, Nutr. Res. 31 (3) (2011) 197–204, https://doi.org/10.1016/j.nutres.2011.02.004.
[30] V. Monti, J.J. Carlson, S.C. Hunt, T.D. Adams, Relationship of ghrelin and leptin hormones with body mass index and waist circumference in a random sample of adults, J. Am. Diet Assoc. 106 (6) (2006) 829–830, https://doi.org/10.1016/j.jada.2006.03.015, 822-8.
[31] K.A. Shin, S.B. Hong, K.S. Shin, Body adiposity index and metabolic syndrome risk factors in Korean adults: a comparison with body mass index and other parameters, Biomed Sci Letters 23 (2017) 57–63, https://doi.org/10.15616/BSL.2017.23.2.57.
[32] P.J. Liu, F. Ma, H.P. Lou, Y.N. Zhu, Body roundness index and body adiposity index: two new anthropometric indices to identify metabolic syndrome among Chinese postmenopausal women, Climacteric 19 (5) (2016) 433–439, https://doi.org/10.1080/13697137.2016.1202229.
[33] N.M. Al-Daghri, O.S. Al-Attas, K. Wani, A.M. Alnaami, S. Sabico, A. Al-Ajlan, et al., Sensitivity of various adiposity indices in identifying cardiometabolic diseases in Arab adults, Cardiovasc. Diabetol. 14 (2015) 101, https://doi.org/10.1186/s12933-015-0265-5.
[34] M.E. Zaki, S. Kamal, H. Reyad, W. Yousef, N. Hassan, I. Helwa, et al., The validity of body adiposity indices in predicting metabolic syndrome and its components among Egyptian women, Open Access Maced J Med Sci 4 (1) (2016) 25–30, https://doi.org/10.3889/oamjms.2016.036.
[35] A. Melmer, C. Lamina, A. Tschoner, C. Ress, S. Kaser, M. Laimer, et al., Body adiposity index and other indexes of body composition in the SAPHIR study: association with cardiovascular risk factors, Obesity 21 (4) (2013) 775–781, https://doi.org/10.1002/oby.20289.
[36] A.F. Godoy-Matos, R.O. Moreira, C.M. Valerio, P.B. Mory, R.S. Moises, A new method for body fat evaluation, body adiposity index, is useful in women with familial partial lipodystrophy, Obesity 20 (2) (2012) 440–443, https://doi.org/10.1038/oby.2011.343.
[37] M.C. Amato, G. Pizzolanti, V. Torregrossa, G. Misiano, S. Milano, C. Giordano, Visceral adiposity index (VAI) is predictive of an altered adipokine profile in patients with type 2 diabetes, PLoS One 9 (3) (2014) e91969, https://doi.org/10.1371/journal.pone.0091969.
[38] T. Lundåsen, W. Liao, B. Angelin, M. Rudling, Leptin induces the hepatic high density lipoprotein receptor scavenger receptor B type I (SR-BI) but not cholesterol 7α-hydroxylase (Cyp7a1) in leptin-deficient (ob/ob) mice, J. Biol. Chem. 278 (44) (2003) 43224–43228, https://doi.org/10.1074/jbc.M302645200.
[39] M. Haluzík, J. Fiedler, J. Nedvídková, R. Ceska, Serum leptin levels in patients with hyperlipidemias, Nutrition 16 (6) (2000) 429–433, https://doi.org/10.1016/s0899-9007(00)00288-4.
[40] A.I. Al-Sultan, A.H. Al-Elq, Leptin levels in normal weight and obese saudi adults, J Family Community Med 13 (3) (2006) 97–102.
[41] F.I. Bennett, N. McFarlane-Anderson, R. Wilks, A. Luke, R.S. Cooper, T.E. Forrester, Leptin concentration in women is influenced by regional distribution of adipose tissue, Am. J. Clin. Nutr. 66 (6) (1997) 1340–1344, https://doi.org/10.1093/ajcn/66.6.1340.
[42] G.H. Mohamadzadeh, N. Zarghami, S. Zahedi-Asl, Comparison of serum leptin levels of non-diabetic and diabetic obese subjects and its relationship to anthropometric indices, Iranian Journal of Endocrinology & Metabolism 10 (4) (2008) 353–362.
[43] K. Adamczewska, Z. Adamczewski, A. Lewiński, R. Stawerska, Leptin does not influence TSH levels in obese short children, Front. Endocrinol. 13 (2022) 838881, https://doi.org/10.3389/fendo.2022.838881.
[44] N. Kausar, M. Akram, G. Shahid, A.A. Naseem, M. Qayyum, F. Tahir, et al., A comparison of the level of appetite, food intake, metabolic hormones, basal metabolic rate and adiposity in normal and short stature children, Endocr. Abstr. (2020) 70 AEP270, https://doi.org/10.1530/endoabs.70.AEP270.
[45] K. Kouda, H. Nakamura, W.Y. Fan, H. Takeuchi, Negative relationships between growth in height and levels of cholesterol in puberty: a 3-year follow-up study, Int. J. Epidemiol. 32 (6) (2003) 1105–1110, https://doi.org/10.1093/ije/dyg207.
[46] J.G. Eriksson, T. Forsen, J. Tuomilehto, V.W.V. Jaddoe, C. Osmond, D.J.P. Barker, Effects of size at birth and childhood growth on the insulin resistance syndrome in elderly individuals, Diabetologia 45 (2002) 342–348.
[47] N.K. Oh, Y.M. Song, S.H. Kim, M.J. Park, Short stature is associated with increased risk of dyslipidemia in Korean adolescents and adults, Sci. Rep. 9 (1) (2019) 14090, https://doi.org/10.1038/s41598-019-50524-2.