Original Article

Diagnostic Performance using Obesity and Lipid-Related Indices and Atherogenic Index of Plasma to Predict Metabolic Syndrome in the Adult Sudanese Population

AS Mosad[1], GA Elfadil[1], SH Elhassan[1], ZA Elbashir[2], NEOSA Husain[3], T Karar[4], EM Elfaki[5]

[1]Department of Clinical Chemistry, College of Medical Laboratory Science, Sudan University of Science and Technology, Khartoum, [2]Department of Internal Medicine, Faculty of Medicine, University of Khartoum, Khartoum, [3]Department of Pathology, Faculty of Medicine and Health Sciences, Omdurman Islamic University, Khartoum, Sudan, [4]Clinical Laboratory Department, College of Applied Medical Sciences, King Saud bin Abdulaziz University for Health Science Al-Ahsa, International Medical Research Center Al-Ahsa, KSA, [5]Clinical Laboratory Sciences Department, College of Applied Medical Science, Al-Qurayyat, Jouf University, KSA

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Abstract

Background: Simple and accurate clinical indicators to detect metabolic abnormalities might be helpful for early management and lowering the risk of future consequences like cardiovascular disease and type 2 diabetes mellitus. **Aim:** The visceral adiposity index (VAI), lipid accumulation product (LAP), and atherogenic index of plasma (AIP) have been proposed as reliable, straightforward clinical markers and indications of metabolic syndrome (MetS). This study aimed to see how well these obesity and lipid-related indicators will predict MetS in adult Sudanese patients. **Subjects and Methods:** This community hospital-based case-control study included 420 middle-aged people (154 men and 266 women). Anthropometric measurements, weight (kilogram), height (meters), and waist circumference (WC) were evaluated, and the body mass index (BMI) and waist-to-height ratio (WHtR) were calculated. Fasting blood samples were collected for glycated hemoglobin (HbA1c) and lipid profile assessment. VAI, LAP, and AIP were calculated. **Results:** Significantly higher means of BMI, WC, WHtR, HbA1c, triglycerides (TG), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), triglycerides/high-density lipoprotein cholesterol (TG/HDL-C) ratio, LAP, VAI, AIP, and significantly decrease in high-density lipoprotein cholesterol (HDL-C) were seen among MetS when compared with non-MetS group. LAP had a significant proportion with BMI, WC, WHtR, TG, TG/HDL-C, VAI, and AIP, and it is inversely related to HDL-C in the MetS group. On ROC analysis, LAP had the largest operating characteristic curves (AUC) for both gender 0.970 (0.948–0.993) for men and 0.964 (0.945–0.982) for women, followed by WC, and VAI, while BMI showed the lowest AUCs for men and women. In multiple regression analyses, AIP values increased significantly with LDL-C, DBP, HbA1c, LAP, and VAI. **Conclusion:** The LAP was considerably higher in middle-aged people with MetS in both gender and was considered the best diagnostic performance.

Keywords: *Atherogenic index of plasma, Cardiovascular disease, Lipid accumulation product, Metabolic syndrome, Visceral adiposity index*

Introduction

Metabolic syndrome (MetS), a group of conditions that include abdominal obesity, hypertension, high fasting blood glucose, and dyslipidemia, is a risk factor for type 2 diabetes mellitus (T2DM) and

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Address for correspondence: T Karar, Clinical Laboratory Department, College of Applied Medical Sciences, King Saud bin Abdulaziz University for Health Science Al-Ahsa, International Medical Research Center Al-Ahsa, KSA.
E-mail: Tarig.karar@yahoo.com

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cardiovascular disease (CVD).[1] It is rapidly becoming a significant public health issue due to the global obesity epidemic.[1-3] According to research, patients with MetS have a two-fold greater risk of CVD and a five-fold increased risk of T2DM.[4] The prevalence of MetS was 16.6% among the Sudanese population.[5] Because of the increasing frequency of MetS and its impact on public health, early detection and management of MetS are critical to prevent the development of T2DM, CVD, and other consequences developing chronic kidney diseases, stroke, and all-cause mortality. Therefore, a simple indicator to identify persons at high risk of MetS might be helpful in clinical screening.

The etiology of MetS is complicated and poorly understood, although visceral adiposity has been shown to play a crucial role in most of the disease's pathogenic pathways.[1]

Obesity was represented by waist circumference (WC) and body mass index (BMI). WC is a simple, affordable technique for measuring central obesity.[4] Waist-to-height ratio (WHtR) has been connected with obesity-related disorders. Meta-analysis has supported the use of WHtR as a superior predictor of CVD risk factors.[4] Obesity is the fifth leading cause of death globally, and central obesity, sometimes known as abdominal fat, includes both visceral and subcutaneous fat, which is strongly linked to MetS and CVD.[4,6] Various obesity and lipid-related parameters reflect abdominal adiposity. The WC may represent visceral adiposity better than BMI.[1,7,8] WHtR, an anthropometric index based on WC which reflects abdominal fat, has been a better indicator of MetS than BMI.[1,7] In addition, triglyceride-to-high-density lipoprotein cholesterol (TG/HDL-C), lipid accumulation product (LAP), and visceral adiposity index (VAI) have all been used to predict MetS in prior research, with each of these parameters being identified as the best predictor for predicting MetS.[9,10]

LAP is a visceral obesity clinical sign that has been presented as a simple, affordable, and reliable technique for estimating cardiovascular risk and mortality. However, because the gold standard methods for evaluating visceral fat are expensive, and the measurement of WC alone does not distinguish between subcutaneous and visceral fat, it combines anthropometric parameters and metabolic variables as effective and reliable markers to predict MetS.[6,11,12] Also, the atherogenic index of plasma (AIP) is a novel index composed of TG and HDL-C.[13] Therefore, it has been studied as a biomarker of cardiovascular risk.[12,14]

Several studies[1,9,10] have looked at the links between these indices and metabolic risk in people of various ethnicities and geographies. In Sudan, however, no investigators have looked at the effectiveness of obesity-related factors in detecting MetS in the general population. As a result, the research goal is to see how well these obesity and lipid-related indicators will predict MetS in adult Sudanese patients.

Methodology

This community hospital-based case-control study was conducted in Khartoum, Sudan, targeting the middle-aged population. Between July 2019 and July 2021, 420 Sudanese were recruited for this

Table 1: Demographic data of the study groups

Variable	Men (*n*=154)			Women (*n*=266)		
	MetS	Non-MetS	*P*	MetS	Non-MetS	*P*
Age (year)						
Mean (SD)#	55.1 (7.6)	54.3 (7.2)	0.526	53.4 (8.4)	53.6 (6.9)	0.813
BMI (Kg/m^2)						
Mean (SD)#	30.7 (5.3)	23.0 (3.6)	0.000*	31.3 (5.1)	23.9 (4.2)	0.000*
Normal BMI	8 (10.4)‡	57 (74.0)	0.000[a]	10 (7.5)	87 (65.4)	0.000[a]
Overweight	32 (41.6)	16 (20.8)		38 (28.6)	38 (28.6)	
Obese	37 (48.0)	4 (5.2)		85 (63.9)	8 (6.0)	
WC (Cm)						
Mean (SD)#	111.4 (9.2)	87.8 (12.2)	0.000*	108.5 (1.58)	84.0 (12.1)	0.000*
Normal	5 (6.5)‡	71 (92.2)	0.000[a]	0 (0.0)	83 (62.4)	0.000[a]
Central obesity	72 (93.5)	6 (7.8)		133 (100)	50 (37.6)	
WHtR						
Mean (SD)#	0.66 (0.05)	0.51 (0.07)	0.000*	0.68 (0.08)	0.52 (0.07)	0.000*
Normal	0 (0.0)‡	39 (50.6)	0.000[a]	0 (0.0)	55 (41.4)	0.000[a]
High	77 (100.0)	38 (49.4)		133 (100.0)	78 (58.6)	

#Mean=Geometric mean; SD=standard deviation; ‡Values are numbers and percentages; **P* value is obtained using independent *t*-test, [a]*P* value is obtained using Chi-test. BMI: body mass index, WC: waist circumference, WHtR: waist-to-height ratio. $P \leq 0.05$ was considered as statistically significant

study. After receiving approval from the Research Committee of Sudan University of Science and Technology (DRS-IEC-04-08) and authorized by the Ministry of Health's ethical committee. All participants were given a written informed consent form after the study's goal was explained to them. According to their hospital records, patients with liver disease, renal failure, autoimmune diseases, corticosteroid therapy, and patients with incomplete recorded information were excluded from this study. After further investigation, 420 middle-aged people (154 men and 266 women) with complete data were finally included in this study. Participants were grouped according to the absence or presence of MetS diagnosed according to the National Cholesterol Education Program Adult Treatment Panel III criteria. The diagnosis of MetS was made depending on the presence of at least 3 of the following parameters: abdominal obesity (WC more than 102 cm, 88 cm in men and women, respectively), TG over 150 mg/dL, HDL-C less than 40 mg/dL, 50 mg/dL in men and women, respectively, systolic blood pressure (SBP)/diastolic blood pressure (DBP) over 130/85 mmHg, fasting glucose level more than 100 mg/dL or known T2DM.[5,15]

Data collection and analysis

Patients' weights were measured using a weight balance, their heights were measured with a meter, and their waists were measured with stretch-resistant tape between the bottom edge of the lower rib and the iliac crest.

The participants were allowed to rest for 10 min before the blood pressure was taken (twice) using a mercury sphygmomanometer and average of both readings was taken. In the morning, 5 mL of fasting venous blood was collected into two containers: a plain container to obtain serum for TG, TC, LDL-C, and

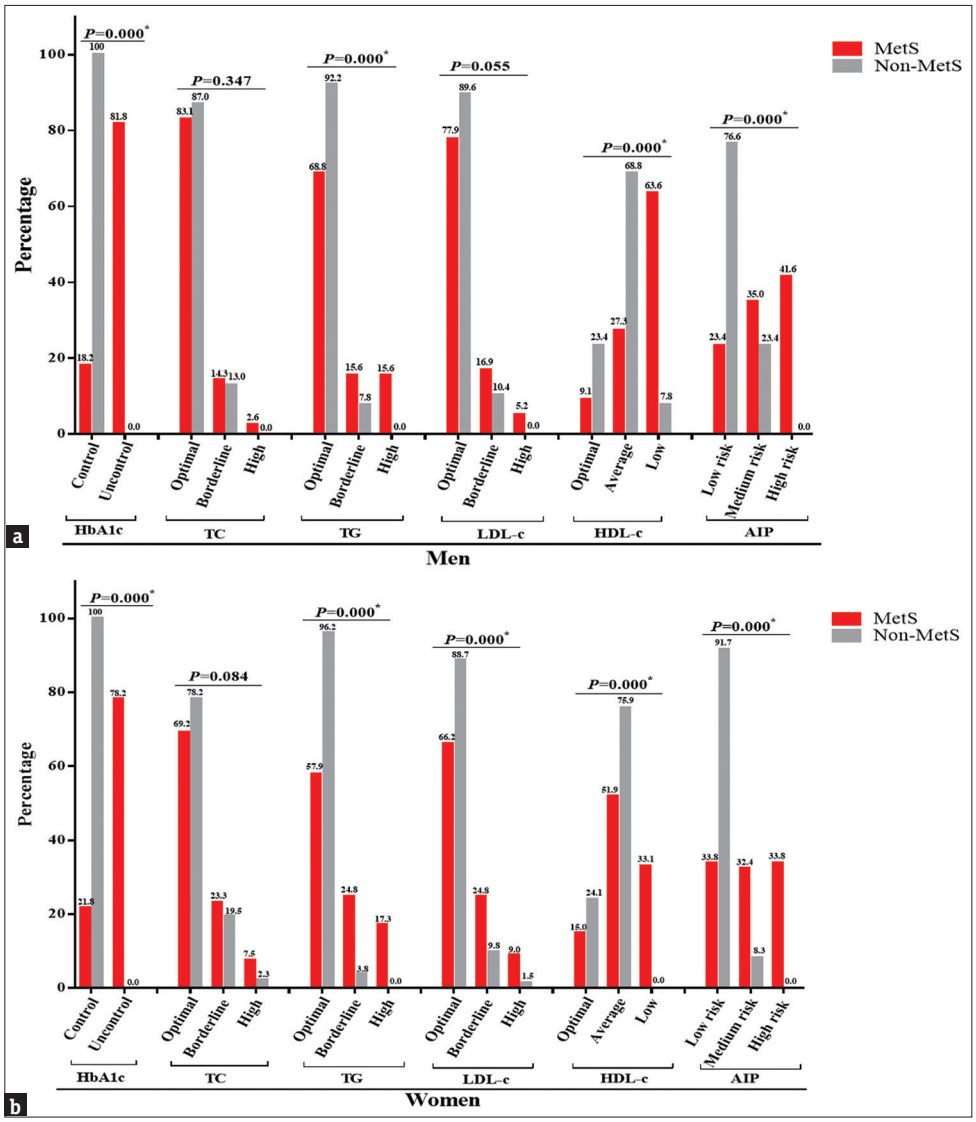

Figure 1: Comparison of biochemical measurements between MetS and Non-MetS group among both men (a) and women (b)

HDL-C measurements and an EDTA container (whole blood) for HbA1c measurements. Biosystem reagents and an automated spectrophotometer analyzer were used to measure TG, TC, LDL-C, and HDL-C. Ichroma was used to measure HbA1c.

BMI was computed as body weight (kg) divided by height^2 (m), and according to WHO, BMI was classified into underweight group of (<18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25–29.9 kg/m^2), obese (≥30 kg/m^2).[16] WC (cm)/height (cm) was used to calculate WHtR and the normal value is < 0.5.[17] The ratio of TG to HDL-C was computed as TG (mmol/L) divided by HDL-C (mmol/L). The gender-specific mathematical model formula was used to determine LAP and VAI; LAP = [WC (cm) - 65] ×TG (mmol/L) for males and [WC (cm) - 58] ×TG (mmol/L) for females. VAI = [WC (cm)/[39.68 + (1.88 × BMI)]] × [TG (mmol/L)/1.03] × [1.31/HDL-C (mmol/L)] for males, and [WC (cm)/[36.58 + (1.89 × BMI)]] ×[TG (mmol/L)/0.81] × [1.52/HDL-C (mmol/L)] for females. AIP = log (TG/HDL-C)[1,9,18] and according to previous studies, AIP was classified into three groups: low risk (<0.11), intermediate risk (0.11–0.24), and increased risk (>0.24).[12,18]

According to the third report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (ATP III), TC is classified into three groups: Optimal (<200 mg/dL), Borderline (200-239 mg/dL), and High (≥240 mgldL), TG is classified into, Optimal (<150 mg/dL), Borderline (150-199 mg/dL), and High (≥200 mgldL), LDL-C is classified into, Optimal (<130 mg/dL), Borderline (130-159 mg/dL), and High (≥160 mgldL), HDL-C is classified into, Optimal (≥60 mg/dL), Average (40-59 mg/dL), and Low (<40 mgldL).[19]

Statistical analyses

SPSS version 20.0 was used for all statistical analyses (SPSS; Chicago, USA). We generated all of the descriptive statistics for all of the variables. Continuous variables were compared using two-sided *t*-tests and were represented as mean and standard deviation. The Chi-square test was used to compare between the

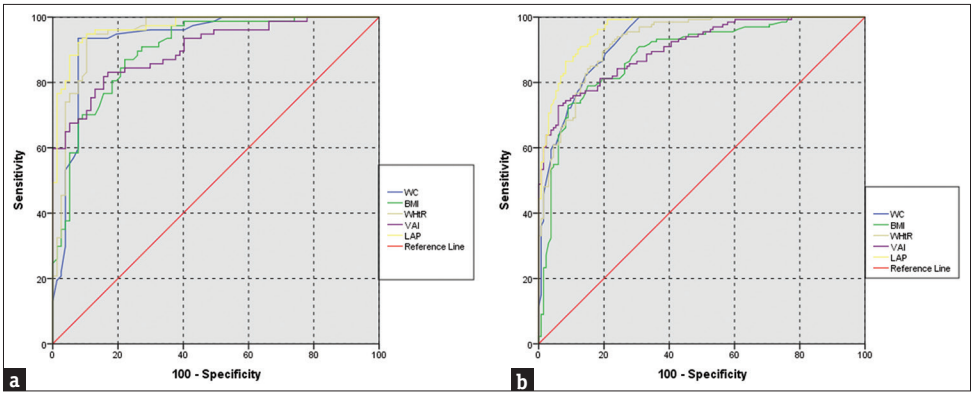

Figure 2: ROC curves for obesity and lipid-related factors in males (a) and females (b) to predict MetS

Table 2: Comparison of biochemical measurements between MetS and non-MetS groups

Variable	Men (*n*=154)			Women (*n*=266)		
	MetS	Non-MetS	*P*	MetS	Non-MetS	*P*
	Mean (SD)#			Mean (SD)#		
HbA1c (%)	8.7 (2.0)	5.6 (0.5)	0.000*	8.8±2.3	5.8±0.4	0.000*
TC (mg/dL)	174.1 (31)	171.0 (26)	0.499	189.1 (32)	177.9 (28)	0.003*
TG (mg/dL)	154.3 (46)	109.2 (32)	0.000*	167.5 (56)	110.0 (26)	0.000*
LDL-C (mg/dL)	102.8 (31.3)	94.2 (24.8)	0.061	116.0 (32.4)	92.8 (29.1)	0.000*
HDL-C (mg/dL)	41.0 (14.8)	52.0 (10.5)	0.000*	47.2 (12.9)	56.0 (8.2)	0.000*
TG/HDL-C Ratio	4.2 (2.4)	2.1 (0.7)	0.000*	4.0 (2.8)	2.0 (0.5)	0.000*
LAP	80.3 (29.2)	28.8 (17.6)	0.000*	96.9 (46.0)	32.8 (17.9)	0.000*
VAI	2.6 (1.5)	1.2 (0.5)	0.000*	3.7 (2.7)	1.6 (0.5)	0.000*
AIP	0.22 (0.1)	-0.05 (0.1)	0.000*	0.19 (0.1)	-0.07 (0.1)	0.000*

#Mean=Geometric mean; SD=standard deviation; *P* value is obtained using independent *t*-test. TC: total cholesterol, TG: triglyceride, LDL-C: low-density lipoprotein cholesterol, HDL-C: high-density lipoprotein cholesterol, LAP: lipid accumulation product, VAI: visceral adiposity index, AIP: atherogenic index of plasma. *P*≤0.05 was considered statistically significant

Table 3: Correlations between the obesity markers (BMI, WC, WHtR, LAP, VAI), lipid profile, AIP, and HbA1c in the MetS group

Variables	BMI *r*	WC *r*	WHtR *r*	LAP *r*	VAI *r*
Male					
BMI	-	0.400*	0.531*	0.420*	-0.017
WC	0.400*	-	0.820*	0.588*	0.178
WHtR	0.531*	0.820*	-	0.520*	0.080
TC	0.080	-0.287*	-0.237*	0.092	-0.235*
TG	0.266*	-0.089	0.040	0.671*	0.346*
LDL-C	-0.283*	-0.221	-0.247*	-0.065	0.048
HDL-C	-0.049	-0.191	-0.142	-0.018	-0.754*
TG/HDL-C Ratio	0.197	0.046	0.044	0.405*	0.927*
LAP	0.420*	0.588*	0.520*	-	0.448*
VAI	-0.017	0.178	0.080	0.448*	-
AIP	0.197	0.046	0.044	0.405*	0.927*
HbA1c	-0.222	-0.057	-0.121	0.149	0.281*
Female					
BMI	-	0.546*	0.578*	0.438*	0.018
WC	0.546*	-	0.947*	0.742*	0.362*
WHtR	0.578*	0.947*	-	0.721*	0.324*
TC	0.020	-0.049	-0.025	0.199*	0.056
TG	0.140	0.151	0.163	0.733*	0.718*
LDL-C	-0.078	0.024	0.015	0.225*	0.307*
HDL-C	-0.015	-0.238*	-0.187*	-0.239*	-0.726*
TG/HDL-C Ratio	0.119	0.265*	0.243*	0.664*	0.967*
LAP	0.438*	0.742*	0.721*	-	0.702*
VAI	0.018	0.362*	0.324*	0.702*	-
AIP	0.119	0.265*	0.243*	0.664*	0.967*
HbA1c	-0.134	-0.068	-0.078	0.027	0.104

BMI: body mass index, WC: waist circumference, WHtR: waist-to-height ratio, LAP: lipid accumulation product, VAI: visceral adiposity index, TC: total cholesterol, TG: triglyceride, LDL-C: low-density lipoprotein cholesterol, HDL-C: high-density lipoprotein cholesterol, AIP: atherogenic index of plasma. Spearman correlation was used. $P \leq 0.05$ was considered statistically significant. *$P<0.05$

frequencies. Spearman correlation was done to correlate different parameters. Receiver operating characteristic curve analysis was done to examine the predictive ability of the parameters and establish the best cutoff values for predicting MetS. The areas under the receiver operating characteristic curves (AUCs) were determined to identify the optimum parameters, and the ideal cutoff values were selected using the greatest Youden index (sensitivity plus specificity-1). Logistic regression was done to predict risk factors for MetS. All statistical analyses were carried out separately for males and females because of the considerable gender variations in body fat distribution and MetS.[9](Gu, 2018 #307) For all of the statistical tests for bilateral comparisons, *P* values less than 0.05 were considered significant.

Results

A total of 420 Sudanese adults were enrolled. Their mean age was 54.0 (7.6) years, range from 40 to 64 years. Two hundred and ten (50%) of the participants had MetS (men = 77 (36.7%); women = 133; (63.3%). Based on gender, there was a significant increase in the means of BMI, WC, and WHtR ratio in the MetS group compared to the non-MetS group. Overall, 122 (56%) MetS patients suffer from general obesity and 205 (96.8%) suffer from central obesity as defined by their BMI and WC. Also, MetS patients had high WHtR and were associated with increased CVD risk, as shown in Table 1.

Participants with MetS had higher means of HbA1c, TC, TG, LDL-C, TG/HDL-C ratio, LAP, VAI, and AIP, and lower mean of HDL-C compared with participants without MetS, Table 2. Overall, 80% of the participant with MetS had high HbA1c values (n = 167),

Table 4: AUC, optimal cutoff values, sensitivity, specificity, and Youden index of the obesity and lipid-related parameters for predicting MetS in the adult Sudanese population.

Variable	AUC (95%CI)	Cut-off value	Sensitivity (%)	Specificity (%)	Youden index (%)
Male					
WC	0.934 (0.891 –0.976)*	101.5	93.5	92.2	85.7
BMI	0.899 (0.851 –0.947)*	25.45	87.0	77.9	64.9
WHtR	0.952 (0.918 – 0.986)*	0.59	94.8	89.6	84.4
LAP	0.970 (0.948 – 0.993)*	49.42	93.5	90.9	84.4
VAI	0.900 (0.853 – 0.947)*	1.81	82.4	83.7	66.2
Female					
WC	0.932 (0.903 –0.960)*	89.0	98.5	70.7	69.2
BMI	0.884 (0.844 – 0.925)*	28.05	75.9	88.0	63.9
WHtR	0.927 (0.898 – 0.956)*	0.57	91.8	78.1	69.9
LAP	0.964 (0.945 – 0.982)*	52.23	92.8	85.3	78.2
VAI	0.905 (0.870 – 0.939)*	2.51	72.9	94.0	66.9

AUC: area under curve, CI: confidence interval, WC: waist circumference, BMI: body mass index, WHtR: waist-to-height ratio, LAP: lipid accumulation product, VAI: visceral adiposity index. *P=0.000

Table 5: Multiple linear regression with the AIP values being dependent variable. Independent variable WC, LDL-C, DBP, HbA1c, LAP, VAI, and WHtR

Variable	Unstandardized coefficients		Standardized coefficients	*t*	Sig.	95.0% confidence interval for B	
	B	Std. Error	Beta			Lower bound	Upper bound
WC	-0.003	0.005	-0.119	-0.659	0.510	-0.013	0.007
LDL-C	0.002	0.001	0.163	3.479	0.001	0.001	0.004
DBP	0.012	0.004	0.150	3.132	0.002	0.004	0.019
HbA1c	0.029	0.011	0.141	2.646	0.009	0.008	0.051
LAP	0.004	0.001	0.395	4.373	0.000	0.002	0.006
VAI	0.046	0.012	0.219	3.682	0.000	0.021	0.070
WHtR	0.130	0.778	0.030	0.168	0.867	-1.401	1.662

R=0.73; R^2=0.533; adjusted R^2=0.521; R^2 change=0.533; F change=42.138; sum of Square=58.545; Sig.F=0.000

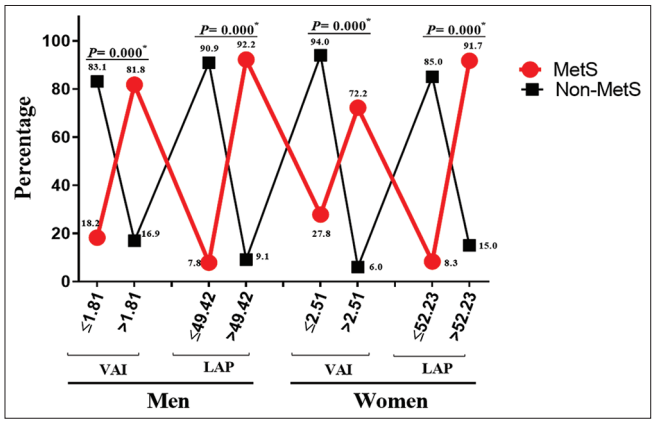

Figure 3: Optimal cutoff points for VAI and LAP as grouped by gender. *P value was obtained using Chi-square; the cutoff points for VAI and LAP were obtained from ROC analysis.

with (n = 54) 24% and (n = 80) 37% having high TC and high TG values, respectively. (n = 93) 45% however had low HDL-C values.

In Table 3, LAP had a significant correlation with BMI, WC, WHtR, TG, TG/HDL-C, VAI, AIP, and inversely with HDL-C in the MetS group [Figure 1].

Based on ROC analysis, the AUCs of all the anthropometric indices were more prominent than 0.5 ($p < 0.05$), suggesting their diagnostic significance for MetS [Table 4]. Furthermore, LAP had the largest AUC for both genders, 0.970 (0.948–0.993) for men and 0.964 (0.945 – 0.982) for women, followed by WC, and VAI, while BMI showed the lowest AUCs for men and women [Figure 2].

In addition, the optimal cutoff points for VAI and LAP were different for men and women based on ROC analysis and both were significant when compared with the non-MetS group. Many men (63/77) suffered from visceral adiposity dysfunction as assessed by their VAI compared to women (96/133) in the MetS group. Moreover, ≥92.0% of the MetS group had visceral adiposity based on the LAP value, Figure 3.

Findings revealed that AIP values increased significantly with LDL-C, DBP, HbA1c, LAP, and VAI Table 5.

Discussion

Given the rise in life expectancy and the high frequency of MetS among adults, the morbidity and mortality of middle-aged people have increased.[2] Simple and accurate clinical indicators to detect metabolic abnormalities might be helpful for early management and lowering the risk of future consequences like CVD and T2DM.[2] VAI and LAP, two novel visceral obesity markers, have been proposed as reliable, straightforward clinical markers, and indications of MetS in the elderly.[9] Identifying those at high cardiometabolic risk may aid in implementing early lifestyle adjustments and treatment strategies to reduce future CVD risks. Obesity and lipid-related indicators such as WC, BMI, WHtR, LAP, and VAI were explored for their predictive capacity and cutoff in detecting MetS in Sudanese individuals in their middle age. The findings revealed that LAP outperformed the other measures in predicting MetS in male and female subjects. To our knowledge, this is the first comprehensive study to assess the prognostic capacity of these obesity and lipid-related indicators in middle-aged Sudanese people with MetS. Our findings indicated that LAP had the best power to predict MetS in both men and women, consistent with several studies.[1,9] In the current study, the AUC of LAP and VAI was (0.900 ≤ AUC < 0.980), which was higher than the AUC of LAP and VAI reported by Chiu *et al.*[1] and Gu *et al.*[9] which was (0.850 ≤ AUC < 0.900) in older persons.[1,9] In our study, the cutoff values for LAP and VAI to predict MetS were 49.4, 1.81 in men and 52.2, 2.5 in women, which were higher than the cutoff values reported by Gu *et al.*[9] in middle-aged and elderly Chinese populations, where 26.35, 1.63 and 31.04, 2.05 were reported in men and women, respectively. This disparity may be explained by dietary and cultural variations because diet affects adiposity.

In the present study, we found significantly higher BMI, WC, HbA1c, TG, TG/HDL-C, WHtR, LAP, VAI, and AIP in MetS. In addition, LAP, VAI, AIP, TG/HDL-C, and WHtR were positively correlated with BMI, WC, and TG and negatively correlated with HDL-C. In the present investigation, however, LAP and VAI were equally capable of detecting MetS, which includes WC, a critical marker of central obesity. Therefore, it should be included in lipid profile reports to provide doctors with a more accurate picture of their patients' cardiometabolic condition, allowing for early MetS diagnosis and treatment.

Our findings confirmed the prognostic significance of LAP in the Sudanese adult population. LAP was also a powerful predictor of metabolic and associated illnesses, including diabetes and insulin resistance.[20] Indeed, LAP is a straightforward and rapid parameter that just requires WC and serum TG testing. As a result, in clinical practice, LAP is predicted to be a potent tool and the best indicator among many obese and lipid-related markers for identifying Sudanese adult people at high risk of MetS. Additionally, the LAP was also strongly correlated with WC and TG and was suggested as a surrogate index of MetS. For a long time, WC, WHtR, and BMI have been used to detect cardiometabolic risk. Yang *et al*.[21] discovered that WHtR was a superior screening strategy for MetS than BMI and WC.[21] WHtR and WC were both shown to be acceptable predictors of MetS in our study. In the present study, the significant association between AIP and MetS was consistent with previous studies.[14,18] The biological mechanisms for higher AIP causing an increased risk for MetS might be explained through dyslipidemia. As a well-known risk factor for CVD, dyslipidemia also plays a vital role in MetS for both TG and HDL-C, serving as its relevant diagnostic criteria.[18]

Our study, as is well known, focused on the middle-aged people in Khartoum State, and discrepancies in the findings with other findings might be related to age and geographical distributional variances. One of the main drawbacks of this study is that the participants were limited to Khartoum. Therefore, the sample may not fully represent all middle-aged Sudanese people. Further research involving more sites and large sample size is needed. In addition, although LAP was found to be an essential indicator for MetS, more research is needed to utilize this marker in clinical practice to define an acceptable cutoff value for middle-aged people.

Conclusion

The LAP was considerably higher in middle-aged people with MetS in both gender and was considered the best diagnostic performance followed by WC and VAI.

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Conflicts of interest

There are no conflicts of interest.

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