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Clinical Research Article

Association Between Anthropometric Indices and Nonanthropometric Components of Metabolic Syndrome in Saudi Adults

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Abstract

Context: Waist circumference (WC) is used in screening for metabolic syndrome (MetS) based on its association with cardiometabolic risk. This might apply differently in ethnically different populations. Associations with other measures are also unclear.

Objective: This work aimed to investigate the association between neck circumference (NC), WC, WC:hip circumference, WC:height (WC:Ht), NC:Ht, fat percentage, body mass index (BMI), conicity index, abdominal volume index, and weight-adjusted waist index with nonanthropometric components of MetS in nondiabetic Saudi adults.

Methods: This cross-sectional study took place in public health centers in Jeddah, comprising 1365 Saudi adults (772 men and 593 women) aged 18 years or older not previously diagnosed with diabetes. Main outcome measures included the presence of 2 or more nonanthropometric components of the MetS were used to define clinical metabolic abnormality (CMA). The predictive ability of studied anthropometric indices for CMA was determined using the area under receiver operating characteristics (AUC) curve and binary logistic regression.

Results: A total of 157 men and 83 women had CMA. NC and NC:Ht had the highest predictive ability for CMA in men (odds ratio $[OR]_{NC} = 1.79$, $P < .001$ and $OR_{NC:Ht} = 1.68$, $P < .001$; $AUC_{NC} = 0.69$ [95% CI, 0.64-0.74] and $AUC_{NC:Ht} = 0.69$ [95% CI, 0.64-0.73]). In women, WC had the highest predictive ability $OR_{WC} = 1.81$, $P < .001$; $AUC_{WC} = 0.75$ [95% CI, 0.69-0.80]).

Conclusion: Upper-body anthropometric indicators that were associated with subcutaneous fat had the highest predictive ability for CMA in men whereas abdominal obesity indictors had the best predictive ability in women, suggesting that fat distribution might contribute to CMA in a sex-specific manner.

Key Words: metabolic syndrome, anthropometry, blood pressure, blood glucose, cholesterol, HDL

Abbreviations: AUC, area under receiver operating characteristic curve; AVI, abdominal volume index; BMI, body mass index; BP, blood pressure; C index; conicity index; CMA, clinical metabolic abnormality; CVD, cardiovascular disease; FPG, fasting plasma glucose; HbA_{1c}, glycated hemoglobin A_{1c}; HC, hip circumference; HDL-C, high-density lipoprotein cholesterol; Ht, height; KSA, kingdom of Saudi Arabia; MetS, metabolic syndrome; NC, neck circumference; OR, odds ratio; ROC, receiver operating characteristic; T2DM, type 2 diabetes mellitus; TGs, triglycerides; WC, waist circumference.

Metabolic syndrome (MetS), defined as a combination of any 3 risk factors, including abdominal obesity, dysglycemia, elevated blood pressure (BP), serum triglycerides (TGs), and low high-density lipoprotein cholesterol (HDL-C), is reported to increase the probability of developing cardiovascular diseases (CVDs) and type 2 diabetes mellitus (T2DM) [1-3]. The prevalence of MetS has been increasing globally, and it varies between 12% and 37% in Asian populations and 12% and 26% in European populations [4-6]. MetS is highly prevalent in the kingdom of Saudi Arabia (KSA) [7, 8]. Furthermore, there is an increasing prevalence of T2DM and CVD worldwide [9-11], and in the KSA in particular [12]. CVD is the number one cause of death both globally [11] and in the KSA [11, 13]. Therefore, it is imperative to identify individuals

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with metabolic abnormalities for the implementation of preventive strategies and to reduce the burden both of CVD and T2DM in the community.

The diagnosis of MetS requires invasive laboratory measurements to determine the plasma lipid profile and glycemic status. These measurements are difficult to standardize and costly, hence challenging to include in large-scale population screening. The beneficial effect of weight loss on the different components of MetS [14] has been shown to reduce all-cause and CVD mortality. In view of such various reports, the use of anthropometric indices as an important noninvasive method for diagnosing MetS has been suggested, and novel anthropometric measures have been introduced and compared with traditional ones [15-22].

Anthropometric indices such as waist circumference (WC) reflecting abdominal visceral adiposity are usually used by clinicians in the screening for MetS. The selection of WC as a tool to determine MetS was based on its association with cardiometabolic risk in the United States and Western European populations, who generally have a higher stature than, for instance, the Saudi population [2]. Using WC to screen for MetS in the Saudi population might have limitations since people with similar WC do not necessarily share similar health risks that may also depend on their height (Ht) [23]. For example, in a Japanese population, short men showed higher health risks than tall men who had similar WC in the moderately large WC group, suggesting that other metabolic indices such as WC:Ht might better reflect cardiometabolic health [23, 24]. In addition, subcutaneous adipose tissue mass has been showed to contribute both in an independent and synergistic way with visceral fat to the pathology of CVD in longitudinal studies [25, 26]. Thus, the simple measurement of WC to indicate visceral adiposity is not reflective of all risk predictions for CVD associated with anthropometric factors.

Therefore, we aimed to investigate the association between several anthropometric indices, traditional and novel, and the metabolic components of MetS, alone and combined, in a Saudi population. Since cutoff values for risk of metabolic dysregulation may vary according to sex and ethnicity [2, 27, 28], we also aimed at estimating cutoff values that best predict metabolic abnormalities for each measurement investigated.

Materials and Methods

Study Design and Data Collection

Saudi adults (aged ≥ 18 years) living in the city of Jeddah, not previously diagnosed with T2DM, were included in the study following a detailed protocol outlined earlier [29]. Individuals with previously diagnosed T2DM, cancer, renal or liver disease, CVD, gastrointestinal diseases requiring a special diet, physical or mental disabilities, and pregnant women were excluded. The Committee on Ethics of Human Research at the Faculty of Medicine, King Abdulaziz University, and the Committee on Research Ethics at the Ministry of Health, KSA, approved the study.

In brief, a cross-sectional design was used aiming to recruit 1500 participants (750 men and 750 women) from randomly selected public health care centers by employing a stratified, 2-stage cluster sampling method [30]. A consent form was signed by recruited participants. Demographics, lifestyle variables, dietary habits, and personal medical and family history were obtained using a predesigned questionnaire based on factors associated with dysglycemia and other metabolic abnormalities found in other populations [31-42].

Participants were instructed to fast overnight for 10 to 14 hours, and fasting blood samples were collected to measure fasting plasma glucose (FPG), as well as serum TGs and HDL-C.

Anthropometric Indices

Anthropometric indices, (height, weight, WC, hip circumference [HC], and NC), and fat percentage [fat %]) as well as BP were measured using standardized equipment and techniques as outlined earlier [29]. Ht was measured bare footed to the nearest 0.5 cm using a stationary stadiometer. Weight was measured to the nearest 0.5 kg while wearing light street clothing using a portable calibrated scale (Omron BF511; OMRON Healthcare). WC was measured midway between the lowest rib and iliac crest to the nearest 0.5 cm. Weight and Ht measurements were used to calculate body mass index (BMI). Conicity index (C index), abdominal volume index (AVI), and weight-adjusted-waist index (WWI) were measured as follows [43-45]:

$$C-Index=\frac{WC\ (m)}{0.109\sqrt{\frac{body\ weight\ (kg)}{height\ (m)}}}$$

$$AVI=\frac{2\times(WC)^2+0.7\ \times\ (WC-HC)^2}{1000}$$

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

Biochemical Assays

All samples (whole blood, serum, and plasma) were analyzed at the Clinical Chemistry Laboratory at National Guard Hospital in Jeddah. Total cholesterol, serum HDL-C, TG levels, and plasma glucose were measured by spectrophotometric methods according to the manufacturer's instructions using an Architect c8000 auto-analyzer (Abbott). Glycated hemoglobin A_{1c} (HbA_{1c}) was measured with HbA_{1c} analyzer G8 (TOSOH Corporation). Another sample was collected 1 hour after ingestion of 50-g glucose solution (CASCO NERL Diagnostics) for estimating plasma glucose (1-hour oral glucose tolerance test) [46, 47].

Definition of Clinical Metabolic Abnormality (Nonanthropometric Components of Metabolic Syndrome)

Participants were considered to have a CMA in the presence of 2 or more of the following abnormalities: high TGs defined as TGs greater than or equal to 1.7 mmol/L (150 mg/dL) or taking drugs for hyperlipidemia; low HDL-C defined as HDL-C less than 1.0 mmol/L (40 mg/dL) for men, less than 1.3 mmol/L (50 mg/dL) for women, or taking drugs for hyperlipidemia; high BP defined as systolic BP greater than or equal to 130 and/or diastolic BP greater than or equal to 85 mm Hg and/or taking BP-lowering drugs; and high FPG defined as FPG greater than or equal to 5.5 mmol/L (100 mg/dL) [2].

Statistical Analysis

Data analysis was performed using IBM SPSS statistics version 24.0 for Windows. Baseline characteristics were expressed as mean ± SDs. Demographic, clinical, anthropometric, and lifestyle variables of people with CMA were analyzed in comparison to those without CMA. An independent *t* test was used to compare factors with continuous variables between the 2 groups, while chi-square test or Fisher exact test, as appropriate, was used to compare categorical variables. After adjusting for age, partial correlation analysis was performed to evaluate the correlation between various anthropometric indicators and metabolic variables. Following adjustment for age, binary logistic regression was used for assessing association between anthropometric indicators and metabolic variables where *z* scores of anthropometric indicators were used. The receiver operating characteristic (ROC) curve and the area under the ROC curve (AUC) were used to assess the ability of anthropometric indicators to identify CMA and its components. Pairwise comparison of AUCs was used to assess AUC differences in association with CMA among anthropometric indicators. The optimal cutoff values for the identification of CMA and its 5 components were determined based on the nearest distance to corner in the ROC curve. A *P* value less than .05 (2-sided test) was accepted as statistically significant.

Results

A total of 1477 adults were recruited for the study. Complete data were obtained for 1365 people. Following biochemical measurements, 1125 people (615 men and 510 women) were found to have no CMA and 240 (157 men and 83 women) had CMA. The prevalence of CMA was 17.6% (95% CI, 15.6-19.7), 20.3% (95% CI, 17.6-23.3) in men and 14.0% (95% CI, 11.4-17.0) in women (Table 1). The most common CMA component in men was high BP (33.5%; 95% CI, 30.3-36.9) followed by high TGs (27.2%; 95% CI, 24.2-30.4), low HDL-C (15.5%; 95% CI, 13.1-18.2), and high FPG (8.5%; 95% CI, 6.7-10.6) (Fig. 1). In women, the most common component of CMA was low HDL-C (27.0%; 95% CI, 23.5-30.7) followed by high BP (21.2%; 95% CI, 18.1-24.7), high TGs (14.3%; 95% CI, 11.4-17.0), and high FPG (5.7%; 95% CI, 4.1-7.8) (see Fig. 1). Men had a significantly higher prevalence of CMA ($P < .01$), high TGs ($P < .001$), and high BP ($P < .001$) than women, who had a significantly lower prevalence of low HDL-C ($P < .001$) (see Fig. 1).

Association Between Clinical Metabolic Abnormality and Anthropometric Indices, Clinical, and Biochemical Characteristics

There were significant differences in the means of demographic and anthropometric indices between people with and without CMA. As expected, people with CMA had significantly higher means of age, BMI, weight, fat percentage, WC, and NC and HC, WC:HC, WC:Ht and NC:Ht ratios, C index, AVI, and WWI (all $P < .001$; see Table 1).

Partial Correlation and Regression Between Different Anthropometric Indices and Indices and Metabolic Variables

After adjusting for age, most anthropometric measures were significantly correlated with the metabolic components of CMA. The correlations of WC, NC, WC:Ht, NC:Ht, fat percentage, BMI, and AVI with metabolic abnormalities were stronger than those of WC:HC, C index, and WWI (Table 2).

Binary Logistic Regression Analysis of Anthropometric Indicators and Clinical Metabolic Abnormality

The binary logistic regression analysis with each anthropometric indicator and CMA showed that WC, NC, WC:HC, WC:Ht, NC:Ht, fat percentage, BMI, and AVI were independently correlated with CMA in men and WC, NC, WC:Ht, NC:Ht, fat percentage, BMI, C index, AVI, and WWI were independently correlated with CMA in women (Table 3). NC and NC:Ht had the highest odds ratio (OR) for CMA in men (NC OR = 1.79, $P < .001$ and NC:Ht OR = 1.68, $P < .001$; see Table 3), whereas in women, WC and BMI had the highest OR for CMA (WC OR = 1.81, $P < .001$ and BMI OR = 1.79, $P < .001$; see Table 3).

As for each of the CMA components, all measured anthropometric indices were associated with high BP both in men and women. WC, WC:Ht, and AVI had the highest OR for high BP in men (OR = 1.68, 1.64, and 1.66, respectively, $P < .001$ at least; see Table 3), whereas in women, WC and NC had the highest OR for high BP (OR = 1.72 and 1.76, respectively, $P < .001$ at least; see Table 3). WC, WC:Ht, and fat percentage had the highest OR for high FPG in men (OR = 1.5, 1.5, and 1.51, respectively, $P < .01$) (see Table 3), whereas in women, fat percentage and BMI had the highest OR for high FPG (OR = 2.3 and 1.8, respectively, $P < .01$). NC and NC:Ht had the highest OR for high TGs in men (OR = 1.63 and 1.45, respectively, $P < .001$), whereas in women, WC and fat percentage had the highest OR for high TGs (OR = 1.46 and 1.53, respectively, $P < .01$). Fat percentage was the only anthropometric parameter associated with low HDL-C in men (OR = 1.4, $P < .01$), whereas in women, NC and BMI had the highest OR for low HDL-C (OR = 1.53 and 1.51, respectively, $P < .001$).

Diagnostic Ability of Anthropometric Indices for Clinical Metabolic Abnormality and its Components

NC and NC:Ht had the highest AUC to identify CMA in men (AUC_{NC}: 0.69 [95% CI, 0.64-0.74] and $AUC_{NC:Ht}$: 0.69 [95% CI, 0.64-0.73] (Table 4 and Fig. 2). However, these AUCs in identifying CMA were not significantly different from those of other measured anthropometric indicators (Table 5). WC, WC:Ht, and AVI had the best abilities to identify CMA in women (AUC_{WC}: 0.75 [95% CI, 0.69-0.80], $AUC_{WC:Ht}$ 0.75 [95% CI, 0.70-0.80], and AUC_{AVI} 0.75 [95% CI, 0.64-0.80] (see Table 4). WC:HC, fat percentage, C index, and WWI had the lowest AUCs in identifying CMA in women; however, only WC:HC and WWI had a significantly lower AUC compared with WC (WC – WC:HC AUC difference: 0.09 [95% CI, 0.036-0.143], $P < .001$ and WC – WWI AUC difference: 0.059 [95% CI, 0.014-0.105], $P < .001$) (Table 5).

WC, WC:Ht, and AVI had the highest AUC to identify high BP in both sexes; in men, AUC_{WC}: 0.66 (95% CI, 0.62-0.71), $AUC_{WC:Ht}$: 0.67 (95% CI, 0.63-0.71), and (AVI AUC: 0.66 (95% CI, 0.62-0.70) and in women, AUC_{WC}: 0.71 (95% CI, 0.66-0.76), $AUC_{WC:Ht}$: 0.70 (95% CI, 0.65-0.76), and AUC_{AVI}: 0.71 (95% CI, 0.66-0.76) (see Table 4 and Fig. 2). However, these AUCs in identifying high BP were not significantly different from those of other measured anthropometric indicators (data not shown).

Table 1. Demographic, anthropometric, clinical, and biochemical characteristics of people with and without clinical metabolic abnormality

	Men		Women	
	CMA absent n = 615	CMA present n = 157	CMA absent n = 510	CMA present n = 83
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Age, y	30 ± 10	37 ± 12[b]	32 ± 11	43 ± 13[b]
Height, cm	172 ± 6.8	172 ± 7.4	158 ± 6.5	157 ± 6.8
Weight, kg	79.5 ± 17.9	89.3 ± 18.7[b]	66.8 ± 15.5	79.8 ± 18.1[b]
WC, cm	95.2 ± 15.2	104.2 ± 14.7[b]	86.4 ± 15.5	100.1 ± 14.4[b]
HC, cm	106.1 ± 13.6	111.5 ± 12.9[b]	104.0 ± 13.3	114.3 ± 14.0[b]
NC, cm	39.1 ± 3.61	41.4 ± 3.7[b]	33.3 ± 3.5	35.8 ± 3.3[b]
WC:HC	0.90 ± 0.08	0.93 ± 0.07[b]	0.83 ± 0.09	0.88 ± 0.08[b]
WC:Ht	0.56 ± 0.09	0.61 ± 0.08[b]	0.55 ± 0.10	0.64 ± 0.09[b]
NC:Ht	0.228 ± 0.022	0.241 ± 0.021[b]	0.212 ± 0.023	0.228 ± 0.022[b]
Fat, %	26.2 ± 8.5	31.0 ± 7.3[b]	39.09 ± 10.02	45.6 ± 8.35[b]
BMI	27.0 ± 5.8	30.2 ± 5.5[b]	26.6 ± 6.1	32.1 ± 6.5[b]
C index	1.29 ± 0.11	1.33 ± 0.1[b]	1.22 ± 0.12	1.3 ± 0.11[b]
AVI	18.7 ± 6.1	22.2 ± 6.3[b]	15.7 ± 5.6	20.7 ± 5.9[b]
WWI	10.7 ± 0.9	11.1 ± 0.88[b]	10.6 ± 1.11	11.3 ± 0.96[b]
HbA_{1c}, %	5.2 ± 0.4	5.7 ± 1.1[b]	5.3 ± 0.4	5.5 ± 1.1[b]
TC mmol/L	4.8 ± 0.9	5.1 ± 1.0[b]	4.8 ± 0.9	5.2 ± 1.1[a]
LDL-C, mmol/L	3.2 ± 0.9	3.5 ± 0.9[b]	3.1 ± 0.8	3.4 ± 0.9[b]

Data are presented as mean ± SD. Differences in measurements between individuals with and without CMA was analyzed using the *t* test.
Abbreviations: AVI, abdominal volume index; BMI, body mass index; C index, conicity index; CMA, clinical metabolic abnormality; HbA_{1c}, glycated hemoglobin A_{1c}; HC, hip circumference; LDL-C, low-density lipoprotein cholesterol; NC, neck circumference; TC, total cholesterol; WC, waist circumference; WWI, weight-adjusted waist index.
[a]Significantly different between CMA groups ($P \leq .01$).
[b]Significantly different between CMA groups ($P \leq .001$).

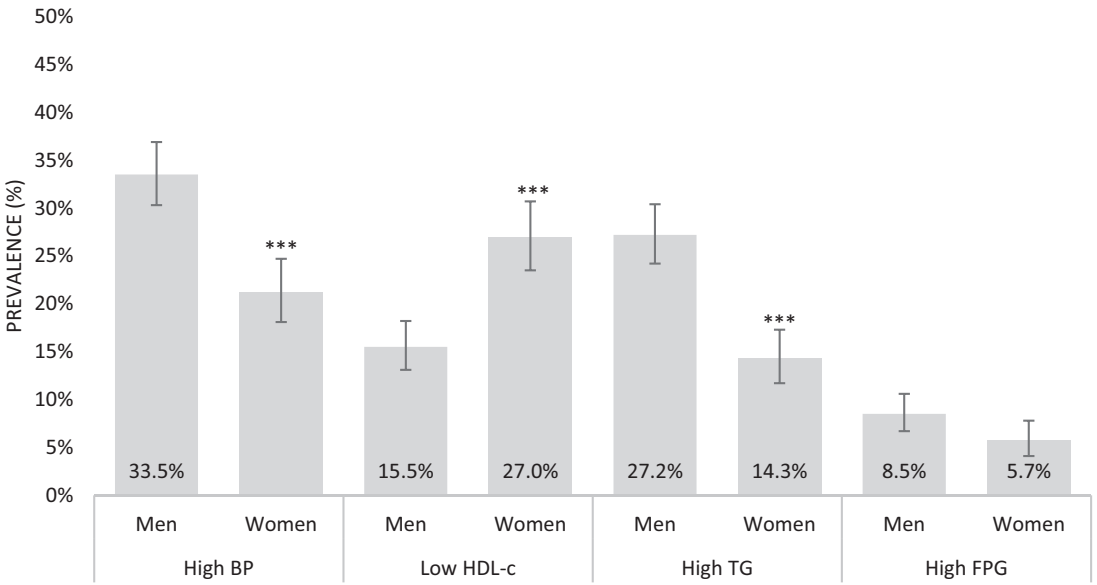

Figure 1. The prevalence of nonanthropometric components of metabolic syndrome (MetS) in men and women in Saudi Arabia. Error bars indicate 95% CIs. Difference in prevalence between men and women was analyzed using the chi-square test. **Significant difference in prevalence between sexes ($P \leq .01$) and *** ($P \leq .001$). BP, blood pressure; FPG, fasting plasma glucose; HDL-c, high-density lipoprotein cholesterol; TG, triglycerides.

WC:HC and WC:Ht had the highest AUC to identify high FPG in men; $AUC_{WC:HC}$: 0.72 (95% CI, 0.66-0.77) and $AUC_{WC:Ht}$: 0.72 (95% CI, 0.66- 0.77) (see Table 4 and Fig. 2). In women, WC:Ht and fat percentage had the highest AUC to identify high FPG; $AUC_{WC:Ht}$: 0.75 (95% CI, 0.68-0.82) and $AUC_{fat\ \%}$: 0.74 (95% CI, 0.66- 0.81). These AUCs in identifying high FPG were not significantly different from those of other measured anthropometric indicators (data not shown).

NC and NC:Ht had the highest AUC to identify high TGs in men: AUC_{NC}: 0.67 (95% CI, 0.62-0.71) and $AUC_{NC:Ht}$: 0.644

Table 2. Partial correlations between anthropometric indices with nonanthropometric components of metabolic syndrome

	Men					Women				
	SBP	DBP	HDL-C	TGs	FPG	SBP	DBP	HDL-C	TGs	FPG
WC	0.294[c]	0.182[c]	**–0.135**[c]	0.107[b]	0.089[a]	0.228[c]	**0.193**[c]	–0.102[a]	0.147[b]	0.105[a]
NC	**0.296**[c]	**0.219**[c]	–0.074[a]	**0.214**[c]	–0.078[a]	**0.243**[c]	**0.21**[c]	**–0.158**[c]	**0.161**[c]	0.036
WC:HC	0.19[c]	0.141[c]	–0.099[b]	0.093[a]	0.032	0.125[b]	0.146[b]	–0.037	0.101[a]	0.082
WC:Ht	0.293[c]	0.164[c]	–0.121[b]	0.088[a]	**0.098**[b]	0.234[c]	0.178[c]	–0.09[a]	0.156[c]	**0.128**[b]
NC:Ht	0.289[c]	**0.189**[c]	–0.051	**0.183**[c]	–0.06	**0.25**[c]	0.191[c]	–0.137[b]	**0.174**[c]	0.071
Fat, %	0.238[c]	0.128[c]	**–0.188**[c]	0.074[a]	**0.203**[c]	0.139[b]	0.099[a]	–0.095[a]	0.104[a]	**0.145**[b]
BMI	0.295[c]	0.165[c]	–0.124[b]	0.092[a]	0.087[a]	0.199[c]	0.15[c]	**–0.138**[b]	0.113[b]	0.111[b]
C index	0.174[c]	0.119[b]	–0.093[a]	0.066	0.064	0.153[c]	0.136[b]	–0.007	0.12[b]	0.082
AVI	**0.297**[c]	0.174[c]	–0.128[c]	0.094[a]	0.094[a]	0.229[c]	0.191[c]	–0.098[a]	0.13[b]	0.101[a]
WWI	0.169[c]	0.101[b]	–0.079[a]	0.047	0.073[a]	0.154[c]	0.122[b]	0.003	0.124[b]	0.099[a]

The partial correlation is adjusted for age. Bold indicates the strongest related anthropometric indices for different metabolic variables.
Abbreviations: AVI, abdominal volume index; BMI, body mass index; C index, conicity index; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HC, hip circumference; HDL-C, high-density lipoprotein cholesterol; NC, neck circumference; SBP, systolic blood pressure; TGs, triglycerides; WC, waist circumference; WWI, weight-adjusted waist index.
[a]Significant correlation ($P \leq .05$).
[b]Significant correlation ($P \leq .01$).
[c]Significant correlation ($P \leq .001$).

Table 3. Binary logistic regression analysis of anthropometric indices with clinical metabolic abnormality and nonanthropometric components of metabolic syndrome

	CMA	High BP	High FPG	High TGs	Low HDL-C
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Men					
WC	1.55 (1.28-1.87)[c]	**1.68 (1.41-1.99)**[c]	**1.5 (1.15-1.95)**[b]	1.35 (1.14-1.6)[c]	1.18 (0.96-1.45)
NC	**1.79 (1.47-2.18)**[c]	1.54 (1.31-1.81)[c]	1.49 (1.13-1.96)[b]	**1.63 (1.37-1.94)**[c]	1.1 (0.9-1.35)
WC:HC	1.33 (1.09-1.64)[b]	1.43 (1.2-1.71)[c]	1.42 (1.07-1.88)[a]	1.24 (1.03-1.49)[a]	1.24 (0.99-1.54)
WC:Ht	1.48 (1.23-1.8)[c]	1.64 (1.38-1.95)[c]	**1.5 (1.15-1.95)**[b]	1.25 (1.05-1.49)[a]	1.17 (0.95-1.44)
NC:Ht	**1.68 (1.38-2.05)**[c]	1.48 (1.26-1.75)[c]	1.48 (1.13-1.94)[b]	**1.45 (1.22-1.72)**[c]	1.09 (0.89-1.34)
Fat, %	1.65 (1.35-2.02)[c]	1.56 (1.32-1.85)[c]	**1.51 (1.14-2.02)**[b]	1.23 (1.03-1.46)[a]	**1.4 (1.13-1.73)**[b]
BMI	1.57 (1.31-1.88)[c]	1.61 (1.37-1.9)[c]	1.47 (1.15-1.89)[b]	1.25 (1.06-1.47)[b]	1.18 (0.97-1.44)
C index	1.22 (0.99-1.49)	1.35 (1.14-1.61)[c]	1.33 (1-1.78)	1.24 (1.04-1.49)[a]	1.07 (0.86-1.33)
AVI	1.47 (1.23-1.77)[c]	**1.66 (1.4-1.96)**[c]	1.4 (1.1-1.78)[b]	1.3 (1.1-1.53)[b]	1.15 (0.94-1.4)
WWI	1.16 (0.95-1.42)	1.32 (1.11-1.57)[b]	1.32 (0.99-1.76)	1.14 (0.95-1.37)	1.06 (0.85-1.32)
Women					
WC	**1.81 (1.38-2.38)**[c]	**1.72 (1.36, 2.17)**[c]	1.75 (1.21-2.52)[b]	**1.46 (1.12-1.9)**[b]	1.47 (1.19-1.81)[c]
NC	1.59 (1.25-2.02)[c]	**1.76 (1.42-2.17)**[c]	1.39 (1-1.94)	1.24 (0.97-1.57)	**1.53 (1.26-1.85)**[c]
WC:HC	1.27 (0.99-1.64)	1.32 (1.07-1.64)[a]	1.38 (0.98-1.95)	1.31 (1.02-1.68)[a]	1.19 (0.98-1.45)
WC:Ht	**1.75 (1.34-2.28)**[c]	1.64 (1.3-2.06)[c]	1.77 (1.23-2.54)[b]	1.43 (1.1-1.85)[b]	1.41 (1.14-1.73)[b]
NC:Ht	1.58 (1.24-2.01)[c]	1.68 (1.36-2.07)[c]	1.48 (1.06-2.06)[a]	1.23 (0.96-1.57)	1.45 (1.19-1.76)[c]
Fat, %	1.72 (1.26-2.34)[b]	1.31 (1.03-1.67)[a]	**2.3 (1.39-3.79)**[b]	**1.53 (1.14-2.05)**[b]	1.44 (1.16-1.79)[c]
BMI	**1.79 (1.39-2.31)**[c]	1.63 (1.31-2.02)[c]	**1.8 (1.29-2.5)**[c]	1.38 (1.08-1.77)[a]	**1.51 (1.24-1.85)**[c]
C index	1.38 (1.06-1.8)[a]	1.37 (1.1-1.71)[b]	1.38 (0.96-1.99)	1.27 (0.98-1.63)	1.12 (0.92-1.37)
AVI	1.67 (1.3-2.14)[c]	1.64 (1.32-2.04)[c]	1.6 (1.15-2.21)[b]	1.39 (1.09-1.77)[b]	1.43 (1.17-1.75)[c]
WWI	1.36 (1.04-1.77)[a]	1.32 (1.06-1.65)[a]	1.41 (0.98-2.03)	1.25 (0.96-1.61)	1.09 (0.89-1.33)

The binary logistic regression is adjusted for age. Bold indicates the strongest related anthropometric indices for different metabolic variables based on its calculated OR.
Abbreviations: AVI, abdominal volume index; BMI, body mass index; BP, blood pressure; C index, conicity index; CMA, clinical metabolic abnormality; FPG, fasting plasma glucose; HC, hip circumference; HDL-C, high-density lipoprotein cholesterol; NC, neck circumference; OR, odds ratio; TGs, triglycerides; WC, waist circumference; WWI, weight-adjusted waist index.
[a]Significant correlation ($P \leq .05$).
[b]Significant correlation ($P \leq .01$).
[c]Significant correlation ($P \leq .001$).

Table 4. Area under the receiver operating characteristic curve and its 95% CI for anthropometric indices with clinical metabolic abnormality and nonanthropometric components of metabolic syndrome

	CMA	High BP	High FPG	High TGs	Low HDL-C
	AUC (95% CI)	AUC (95% CI)	AUC (95% CI)	AUC (95% CI)	AUC (95% CI)
Men					
WC, cm	0.684 (0.639-0.73)[c]	**0.663 (0.621-0.705)**[c]	0.708 (0.651-0.766)[c]	0.64 (0.596-0.683)[c]	0.614 (0.559-0.668)[c]
NC, cm	**0.687 (0.64-0.735)**[c]	0.637 (0.595-0.679)[c]	0.643 (0.57-0.716)[c]	**0.665 (0.62-0.709)**[c]	0.568 (0.511-0.625)[a]
WC:HC	0.669 (0.623-0.716)[c]	0.643 (0.602-0.685)[c]	**0.717 (0.661-0.773)**[c]	0.638 (0.596-0.681)[c]	**0.631 (0.579-0.683)**[c]
WC:Ht	0.685 (0.64-0.73)[c]	**0.668 (0.627-0.71)**[c]	**0.719 (0.663-0.774)**[c]	0.63 (0.587-0.673)[c]	**0.623 (0.57-0.676)**[c]
NC:Ht	**0.686 (0.639-0.732)**[c]	0.644 (0.602-0.686)[c]	0.657 (0.585-0.729)[c]	**0.644 (0.6-0.689)**[c]	0.578 (0.523-0.632)[b]
Fat, %	0.666 (0.62-0.711)[c]	0.643 (0.601-0.685)[c]	0.651 (0.589-0.712)[c]	0.587 (0.543-0.631)[c]	0.621 (0.569-0.674)[c]
BMI	0.674 (0.629-0.718)[c]	0.654 (0.612,0.695)[c]	0.666 (0.606-0.726)[c]	0.605 (0.562-0.649)[c]	0.604 (0.55-0.657)[c]
C index	0.637 (0.589-0.686)[c]	0.629 (0.585-0.672)[c]	0.699 (0.642-0.757)[c]	0.622 (0.579-0.666)[c]	0.597 (0.542-0.651)[b]
AVI	0.683 (0.637-0.728)[c]	0.662 (0.621-0.704)[c]	0.705 (0.648-0.763)[c]	0.638 (0.595-0.681)[c]	0.612 (0.558-0.667)[c]
WWI	0.632 (0.584-0.679)[c]	0.627 (0.584-0.671)[c]	0.703 (0.644-0.762)[c]	0.604 (0.56-0.647)[c]	0.602 (0.548-0.656)[c]
Women					
WC, cm	**0.746 (0.694-0.799)**[c]	**0.711 (0.658-0.764)**[c]	0.732 (0.656-0.809)[c]	0.697 (0.642-0.752)[c]	0.611 (0.559-0.664)[c]
NC, cm	0.712 (0.655-0.769)[c]	0.695 (0.64-0.751)[c]	0.672 (0.579-0.765)[b]	0.649 (0.59-0.708)[c]	**0.634 (0.58-0.687)**[c]
WC:HC	0.657 (0.598-0.716)[c]	0.665 (0.613-0.718)[c]	0.683 (0.606-0.759)[c]	0.611 (0.548-0.673)[b]	0.563 (0.51-0.616)[a]
WC:Ht	**0.75 (0.698-0.802)**[c]	0.704 (0.65-0.758)[c]	**0.747 (0.676-0.819)**[c]	**0.702 (0.648-0.755)**[c]	0.606 (0.554-0.658)[c]
NC:Ht	0.708 (0.653-0.764)[c]	0.688 (0.633-0.744)[c]	0.69 (0.606-0.774)[c]	0.642 (0.582-0.701)[c]	**0.618 (0.565-0.672)**[c]
Fat, %	0.694 (0.634-0.755)[c]	0.63 (0.571-0.688)[c]	**0.735 (0.658-0.813)**[c]	0.674 (0.614-0.734)[c]	0.612 (0.558-0.665)[c]
BMI	0.729 (0.674-0.783)[c]	0.673 (0.617-0.729)[c]	0.73 (0.652-0.807)[c]	0.689 (0.631-0.746)[c]	0.63 (0.579-0.68)[a]
C index	0.689 (0.63-0.747)[c]	0.672 (0.619-0.725)[c]	0.673 (0.584-0.762)[b]	0.628 (0.567-0.689)[c]	0.56 (0.506-0.614)[c]
AVI	**0.746 (0.693-0.799)**[c]	**0.708 (0.655-0.761)**[c]	0.73 (0.652-0.807)[c]	**0.698 (0.643-0.753)**[c]	0.611 (0.559-0.664)[c]
WWI	0.687 (0.628-0.746)[c]	0.664 (0.61-0.717)[c]	0.675 (0.583-0.767)[c]	0.629 (0.567-0.691)[c]	0.554 (0.5-0.608)

The AUC and 95% CI were analyzed using anthropometric *Z* scores after controlling for age. Bold indicates the largest AUC for related anthropometric indices for different metabolic variables; however, this does not mean its value is significantly different from that of other anthropometric indices.
Abbreviations: AUC, area under receiver operating characteristic curve; AVI, abdominal volume index; BMI, body mass index; BP, blood pressure; C index, conicity index; CMA, clinical metabolic abnormality; FPG, fasting plasma glucose; HC, hip circumference; HDL-C, high-density lipoprotein cholesterol; NC, neck circumference; TGs, triglycerides; WC, waist circumference; WWI, weight-adjusted waist index.
[a]Significant correlation ($P \le .05$).
[b]Significant correlation ($P \le .01$).
[c]Significant correlation ($P \le .001$).

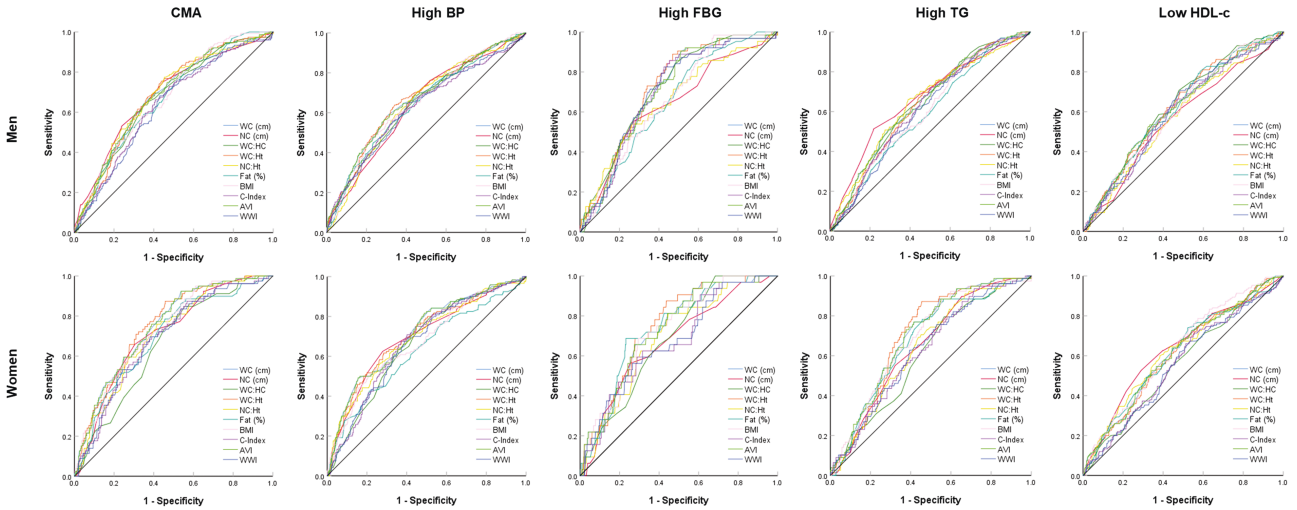

Figure 2. The discriminative power of the anthropometric indices and indices for clinical metabolic abnormality (CMA) and its components using the receiver operating characteristic curve. AVI, abdominal volume index; BMI, body mass index; BP, blood pressure; C-Index, conicity index; FPG, fasting plasma glucose; HC, hip circumference; HDL-c, high-density lipoprotein cholesterol; Ht, height; NC, neck circumference; TG, triglycerides; WC, waist circumference; WWI, weight-adjusted waist index.

(95% CI, 0.60-0.69) (see Table 4 and Fig. 2). In women, WC, WC:Ht, and AVI had the highest AUC to identify high TGs: AUC_{WC}: 0.70 (95% CI, 0.64-0.75), $AUC_{WC:Ht}$: 0.70 (95% CI, 0.65, 0.76), and AUC_{AVI}: 0.70 (95% CI, 0.64, 0.75). These AUCs in identifying high TGs were not significantly different from those of other measured anthropometric indicators (data not shown).

Table 5. Pairwise comparison for the using receiver operating characteristic curves for the identification of clinical metabolic abnormality

	Male		Female	
	AUC difference (CI)	*P*	AUC difference (CI)	*P*
WC – NC	–0.003 (–0.045 to 0.039)	.89	0.035 (–0.023 to 0.092)	.24
WC – WC:HC	0.015 (–0.028 to 0.057)	.49	0.09 (0.036 to 0.143)	.001
WC – WC:Ht	0.001 (–0.013 to 0.015)	.92	–0.004 (–0.02 to 0.012)	.66
WC – NC:Ht	–0.001 (–0.046 to 0.044)	.96	0.037 (–0.021 to 0.096)	.21
WC – Fat %	0.019 (–0.014 to 0.052)	.27	0.052 (0.004 to 0.1)	.03
WC – BMI	0.011 (–0.017 to 0.038)	.45	0.018 (–0.017 to 0.052)	.31
WC – C–Index	0.046 (0.014 to 0.078)	.005	0.058 (0.017 to 0.099)	.005
WC – AVI	0.002 (0 to 0.003)	.02	0.001 (–0.001 to 0.003)	.53
WC – WWI	0.053 (0.016 to 0.089)	.004	0.059 (0.014 to 0.105)	.01
NC – WC:HC	0.018 (–0.038 to 0.073)	.53	0.055 (–0.016 to 0.126)	.13
NC – WC:Ht	0.004 (–0.042 to 0.049)	.88	–0.038 (–0.098 to 0.022)	.21
NC – NC:Ht	0.002 (–0.02 to 0.024)	.88	0.003 (–0.022 to 0.028)	.82
NC – Fat %	0.022 (–0.031 to 0.074)	.42	0.017 (–0.057 to 0.092)	.65
NC – BMI	0.014 (–0.034 to 0.062)	.58	–0.017 (–0.073 to 0.04)	.56
NC – C–Index	0.049 (–0.001 to 0.1)	.06	0.024 (–0.049 to 0.097)	.52
NC – AVI	0.005 (–0.038 to 0.047)	.83	–0.034 (–0.092 to 0.024)	.25
NC – WWI	0.056 (0.002 to 0.11)	.04	0.025 (–0.051 to 0.1)	.52
WC:HC – WC:Ht	–0.014 (–0.054 to 0.026)	.49	–0.093 (–0.144 to –0.042)[a]	<.001
WC:HC – NC:Ht	–0.016 (–0.069 to 0.037)	.55	–0.052 (–0.118 to 0.014)	.12
WC:HC– Fat %	0.004 (–0.049 to 0.056)	.89	–0.038 (–0.109 to 0.034)	.30
WC:HC – BMI	–0.004 (–0.057 to 0.049)	.88	–0.072 (–0.138 to –0.006)	.03
WC:HC – C index	0.031 (–0.006 to 0.069)	.10	–0.031 (–0.078 to 0.016)	.19
WC:HC – AVI	–0.013 (–0.057 to 0.03)	.56	–0.089 (–0.144 to –0.033)	.002
WC:HC – WWI	0.038 (0.001 to 0.075)	.05	–0.03 (–0.077 to 0.017)	.21
WC:Ht – NC:Ht	–0.002 (–0.044 to 0.04)	.93	0.041 (–0.014 to 0.096)	.15
WC:Ht– Fat %	0.018 (–0.015 to 0.051)	.28	0.056 (0.009 to 0.102)	.02
WC:Ht – BMI	0.01 (–0.018 to 0.038)	.48	0.021 (–0.014 to 0.056)	.24
WC:Ht – C index	0.045 (0.014 to 0.077)	.005	0.062 (0.023 to 0.101)	.002
WC:Ht – AVI	0.001 (–0.013 to 0.015)	.88	0.004 (–0.012 to 0.021)	.61
WC:Ht – WWI	0.052 (0.021 to 0.083)	.001	0.063 (0.024 to 0.102)[a]	.001
NC:Ht – Fat %	0.02 (–0.032 to 0.072)	.45	0.014 (–0.059 to 0.088)	.7
NC:Ht – BMI	0.012 (–0.036 to 0.06)	.62	–0.02 (–0.075 to 0.036)	.49
NC:Ht – C index	0.047 (–0.002 to 0.097)	.06	0.021 (–0.049 to 0.091)	.56
NC:Ht – AVI	0.003 (–0.042 to 0.048)	.9	–0.037 (–0.096 to 0.022)	.22
NC:Ht – WWI	0.054 (0.006 to 0.102)	.03	0.022 (–0.046 to 0.09)	.53
Fat % – BMI	–0.008 (–0.036 to 0.02)	.58	–0.034 (–0.077 to 0.008)	.12
Fat % – C index	0.027 (–0.024 to 0.079)	.3	0.006 (–0.064 to 0.077)	.86
Fat % – AVI	–0.017 (–0.05 to 0.016)	.31	–0.051 (–0.099 to –0.004)	.04
Fat % – WWI	0.034 (–0.018 to 0.086)	.2	0.007 (–0.064 to 0.079)	.84
BMI – C index	0.035 (–0.018 to 0.089)	.19	0.041 (–0.028 to 0.109)	.25
BMI – AVI	–0.009 (–0.036 to 0.018)	.52	–0.017 (–0.051 to 0.017)	.33
BMI – WWI	0.042 (–0.012 to 0.096)	.13	0.042 (–0.028 to 0.111)	.24
C index – AVI	–0.044 (–0.077 to –0.012)	.008	–0.058 (–0.099 to –0.016)	.007
C index – WWI	0.007 (–0.007 to 0.02)	.33	0.001 (–0.013 to 0.015)	.89
AVI – WWI	0.051 (0.014 to 0.088)	.007	0.059 (0.012 to 0.105)	.01

Abbreviations: AUC, area under receiver operating characteristic curve; AVI, abdominal volume index; BMI, body mass index; C index, conicity index; HC, hip circumference; Ht, height; NC, neck circumference; WC, waist circumference; WWI, weight-adjusted waist index.
[a]Significantly different after Bonferroni correction of *P* value for multiple comparisons ($P < .001$).

WC:HC and WC:Ht had the highest AUC to identify low HDL-C in men: $AUC_{WC:HC}$: 0.63 (95% CI, 0.58-0.68) and $AUC_{WC:Ht}$: 0.62 (95% CI, 0.57, 0.68) (see Table 4 and Fig. 2). In women, NC and NC:Ht had the highest AUC to identify low HDL-C; AUC_{NC}: 0.63 (95% CI, 0.58-0.69) and $AUC_{NC:Ht}$: 0.62 (95% CI, 0.57-0.67). These AUCs in identifying low

HDL-C were not significantly different from those of other measured anthropometric indicators (data not shown).

Optimal Cutoff Value of Anthropometric Indicators for the Identification of Clinical Metabolic Abnormality

To detect a CMA, the optimal cutoff value of each anthropometric indicator was for WC (97.5 for men and 89.5 for women), NC (39.8 for men and 33.8 for women), WC:HC (0.93 for men and 0.84 for women), WC:Ht (0.58 for men and 0.59 for women), NC:Ht (0.23 for men and 0.21 for women), fat percentage (29.1 for men and 42.1 for women), BMI (27.9 for men and 28.3 for women), C index (1.31 for men and 1.26 for women), AVI (19.1 for men and 16.3 for women), and WWI (10.8 for men and 10.9 for women) (Table 6). The sensitivity, specificity, positive and negative predictive values, and positive and negative likelihood ratios are presented in Table 6.

Discussion

In this cross-sectional study among people older than 18 years from Jeddah, Saudi Arabia, who were not previously diagnosed with T2DM, the prevalence of CMA was 17.6% with a sex difference: 20.3% in men and 14% in women. Several anthropometric measurements and indices including WC, NC, WC:HC, WC:Ht, NC:Ht, fat percentage, BMI, C index, AVI, and WWI were investigated for their predictive abilities of CMA. These anthropometric indices were significantly associated with elevated FPG, BP, TGs, and low HDL-C in both sexes, similar to findings from previous studies [48, 49]; however, with such a high number of people participating in the study, these correlations are not considered particularly strong, as expected from correlations between biological parameters. After adjusting for age, NC and NC:Ht had the best abilities to identify CMA in men, whereas WC, WC:Ht, and AVI had the best abilities to identify CMA in women. This may suggest that fat distribution might contribute to CMA in a sex-specific manner. The difference in body fat distribution between men and women is well known. Nevertheless, the diagnostic abilities of WC, NC, WC:Ht, NC:Ht, BMI, and AVI for CMA were similar both in men and women.

Previous studies investigating the prediction of MetS with anthropometric indices and markers in the Saudi population included markers such as BMI for general obesity and WC for abdominal obesity, but did not include markers of upper-body subcutaneous adiposity or body shape [50]. Our study explored and compared the predictive ability of several anthropometric parameters and indices for the association with CMA including parameters that are reflective both of abdominal and upper-body subcutaneous adiposity and body shape.

NC has been accepted as a marker for subcutaneous fat adiposity [25, 26]. Its utility as a screening tool for MetS or CMA has been explored in different populations [21, 22, 26, 51, 52]. A previous study in an Asian Indian population indicated that NC and NC:Ht are good predictors of MetS and CVD risk factors after adjustment for age, and that NC:Ht was a better predictor of cardiometabolic risk than NC [51]. In our study, NC and NC:Ht were the best predictors of CMA in men. A previous study in an elderly Chinese population reported that WC and NC were independent predictors of MetS; NC was a stronger predictor of MetS than WC in both sexes [22]. Furthermore, a recent meta-analysis indicated that NC is a good predictor of MetS with a sensitivity and specificity greater than 65% [53]. This meta-analysis reported that both race and sex contributed to the association between NC and cardiometabolic risk; NC had a stronger association with FPG in Asians compared with other populations, and had a stronger correlation with LDL-C levels in men compared with women [53]. In the Framingham Heart Study, NC was associated with CVD risk factors irrespective of BMI [26]. It was specifically associated with systolic BP and diastolic BP in men only, and with TGs and FPG in women only, and with insulin, proinsulin, and homeostasis model assessment of insulin resistance and inversely associated with HDL-C both in men and women after adjustment for accumulation of visceral adipose tissue.

In the present study, the strong association between NC and CMA was mainly attributed to lipids with its association with high TGs in men and low HDL-C in women. Similarly, NC has been shown to correlate directly with TGs and inversely with HDL-C independently of BMI, WC, and sex in a White population [54]. It has been proposed that upper-body subcutaneous fat has a reduced capability to take up and deposit circulating TGs, which might explain the association between high NC and elevated TGs in men [54-56].

It is well established that WC contributes to the risk of CMA through elevating hepatic free fatty acid delivery that results from the lipolysis of visceral adipose tissue [55-57]. However, unlike abdominal obesity, the mechanisms by which neck adiposity contributes to cardiometabolic risk is not well identified. Upper-body subcutaneous fat has a higher rate of lipolysis and its contribution to released systemic free fatty acid exceeds that of visceral fat, especially in obese people. This might explain the stronger ability of NC in predicting CMA and MetS compared with WC in some populations [55] and in men in our study. The elevated plasma free fatty acid level might contribute to CMA as it can increase insulin resistance and the production of very-low-density lipoprotein and TGs [58, 59]. This suggests that both upper-body subcutaneous and visceral fat contribute to the pathology of MetS and that more emphasis needs to be placed on upper-body obesity in addition to central obesity in screening for risk of CMA, especially in men. This will be better quantified by imaging modality, which was not an option in our study.

Our study demonstrated that among Saudi individuals, an NC of 39.8 cm in men and 33.8 cm in women were the best predictors for identifying CMA, with a sensitivity of 75.5% and 73.4% and a specificity of 55.0% and 58.5%, respectively. These are close to the 39 cm and 35 cm cutoffs for MetS suggested by findings in a Turkish population [52]. The optimal cutoff points of NC for MetS in a Chinese population were 37 to 38 cm in men and 33 to 35 cm in women [22, 60] and in South Asian Indians 35 cm in men and 31.3 cm in women [51]. The sensitivity and specificity in the previous studies for NC cutoff values were in keeping with our findings. The difference in NC cutoff points between our study and previous studies might be due to the difference in mean NC among populations as a result of variations in body composition or differences in the criteria of determining MetS and CMA [22, 51, 52, 60].

Among other obesity- and visceral adiposity–related anthropometric indicators, the markers for visceral adiposity WC:Ht, WC, and AVI were the best CMA predictors, particularly in women followed by BMI, NC, and NC:Ht. Fat percentage, WC:HC, C index, and WWI had the lowest

Table 6. Optimal cutoff values and sensitivity and specificity for the identification of clinical metabolic abnormality

CMA	Male							Female						
	Cutoff point	Sensitivity	Specificity	PPV	NPV	PLR	NLR	Cutoff point	Sensitivity	Specificity	PPV	NPV	PLR	NLR
WC	**97.5**	0.669	0.624	0.312	0.881	1.779	0.562	**89.5**	0.747	0.606	0.243	0.934	1.896	0.527
NC	**39.8**	0.755	0.550	0.299	0.898	1.678	0.596	**33.8**	0.734	0.585	0.230	0.929	1.769	0.565
WC:HC	**0.93**	0.642	0.649	0.318	0.877	1.829	0.547	**0.84**	0.734	0.548	0.216	0.924	1.624	0.616
WC:Ht	**0.58**	0.662	0.639	0.318	0.881	1.834	0.545	**0.59**	0.696	0.690	0.275	0.931	2.245	0.445
NC:Ht	**0.23**	0.682	0.609	0.308	0.883	1.744	0.573	**0.21**	0.722	0.604	0.236	0.928	1.823	0.548
Fat, %	**29.1**	0.589	0.651	0.301	0.862	1.688	0.593	**42.1**	0.722	0.582	0.226	0.925	1.727	0.579
BMI	**27.9**	0.623	0.607	0.288	0.863	1.585	0.631	**28.3**	0.658	0.675	0.255	0.921	2.025	0.494
C index	**1.31**	0.662	0.592	0.292	0.873	1.623	0.616	**1.26**	0.671	0.627	0.233	0.918	1.799	0.556
AVI	**19.1**	0.669	0.621	0.310	0.880	1.765	0.567	**16.3**	0.759	0.610	0.248	0.937	1.946	0.514
WWI	**10.8**	0.682	0.570	0.288	0.876	1.586	0.630	**10.9**	0.671	0.636	0.238	0.920	1.843	0.542
BP														
WC	**98.5**	0.590	0.689	0.488	0.770	1.897	0.527	**87.5**	0.733	0.568	0.323	0.883	1.697	0.589
NC	**39.3**	0.679	0.570	0.443	0.779	1.579	0.633	**34.5**	0.625	0.721	0.387	0.872	2.240	0.446
WC:HC	**0.91**	0.663	0.562	0.432	0.768	1.514	0.661	**0.86**	0.617	0.638	0.324	0.855	1.704	0.587
WC:Ht	**0.58**	0.614	0.675	0.487	0.777	1.889	0.529	**0.59**	0.617	0.704	0.370	0.867	2.084	0.480
NC:Ht	**0.23**	0.643	0.596	0.445	0.768	1.592	0.628	**0.22**	0.617	0.685	0.356	0.864	1.959	0.511
Fat, %	**29.1**	0.546	0.677	0.460	0.748	1.690	0.592	**42.1**	0.608	0.580	0.290	0.840	1.448	0.691
BMI	**28.3**	0.562	0.693	0.479	0.759	1.831	0.546	**28.3**	0.583	0.692	0.348	0.855	1.893	0.528
C index	**1.31**	0.602	0.612	0.438	0.754	1.552	0.645	**1.26**	0.642	0.648	0.339	0.865	1.824	0.548
AVI	**19.2**	0.610	0.661	0.475	0.771	1.799	0.556	**15.2**	0.767	0.545	0.322	0.893	1.686	0.593
WWI	**10.8**	0.647	0.598	0.447	0.771	1.609	0.621	**10.8**	0.675	0.610	0.328	0.870	1.731	0.578
FPG														
WC	**97.5**	0.746	0.591	0.145	0.962	1.824	0.548	**95.5**	0.656	0.719	0.127	0.971	2.335	0.428
NC	**41.8**	0.556	0.727	0.159	0.946	2.037	0.491	**35.5**	0.563	0.747	0.122	0.965	2.225	0.449
WC:HC	**0.93**	0.730	0.619	0.151	0.961	1.916	0.522	**0.86**	0.656	0.598	0.092	0.965	1.632	0.613
WC:Ht	**0.59**	0.714	0.665	0.166	0.962	2.131	0.469	**0.60**	0.688	0.694	0.123	0.973	2.248	0.445
NC:Ht	**0.24**	0.540	0.731	0.157	0.945	2.007	0.498	**0.22**	0.719	0.604	0.102	0.972	1.816	0.551
Fat, %	**29.4**	0.587	0.622	0.126	0.942	1.553	0.644	**47.1**	0.688	0.768	0.156	0.975	2.966	0.337
BMI	**27.7**	0.651	0.575	0.125	0.947	1.532	0.653	**29.6**	0.688	0.704	0.127	0.973	2.324	0.430
C index	**1.31**	0.825	0.572	0.152	0.972	1.928	0.519	**1.28**	0.625	0.674	0.107	0.966	1.917	0.522
AVI	**19.16**	0.746	0.588	0.144	0.961	1.811	0.552	**18. 5**	0.656	0.721	0.128	0.971	2.351	0.425
WWI	**11.0**	0.714	0.644	0.157	0.960	2.006	0.499	**11.3**	0.563	0.735	0.117	0.964	2.125	0.471
TGs														
WC	**97.5**	0.582	0.619	0.361	0.800	1.528	0.655	**88.8**	0.769	0.581	0.234	0.938	1.835	0.545
NC	**40.8**	0.572	0.681	0.399	0.811	1.793	0.558	**34.5**	0.551	0.677	0.221	0.900	1.706	0.586
WC:HC	**0.93**	0.572	0.650	0.377	0.804	1.634	0.612	**0.84**	0.641	0.532	0.186	0.899	1.370	0.730
WC:Ht	**0.56**	0.682	0.545	0.357	0.822	1.499	0.667	**0.57**	0.744	0.618	0.245	0.935	1.948	0.513
NC:Ht	**0.23**	0.662	0.602	0.381	0.828	1.663	0.601	**0.21**	0.705	0.547	0.206	0.918	1.556	0.643
Fat, %	**29.4**	0.483	0.639	0.331	0.770	1.338	0.747	**42.1**	0.731	0.583	0.226	0.929	1.753	0.570
BMI	**26.2**	0.667	0.477	0.321	0.795	1.275	0.784	**28.3**	0.628	0.665	0.238	0.915	1.875	0.533
C index	**1.29**	0.682	0.525	0.347	0.817	1.436	0.696	**1.26**	0.564	0.609	0.194	0.893	1.442	0.693
AVI	**19.1**	0.587	0.617	0.362	0.801	1.533	0.652	**16.5**	0.731	0.622	0.244	0.933	1.934	0.517
WWI	**10.8**	0.612	0.567	0.343	0.798	1.413	0.708	**10.8**	0.628	0.605	0.209	0.907	1.590	0.629
HDL-C														
WC	**98.5**	0.560	0.624	0.216	0.885	1.489	0.671	**87.5**	0.633	0.553	0.349	0.799	1.416	0.706
NC	**40.8**	0.500	0.634	0.201	0.873	1.366	0.732	**33.8**	0.627	0.601	0.373	0.810	1.571	0.636
WC:HC	**0.93**	0.586	0.623	0.223	0.891	1.554	0.643	**0.85**	0.540	0.566	0.320	0.765	1.244	0.804
WC:Ht	**0.56**	0.698	0.518	0.211	0.903	1.448	0.691	**0.55**	0.653	0.525	0.342	0.800	1.375	0.727
NC:Ht	**0.23**	0.638	0.510	0.194	0.884	1.302	0.768	**0.21**	0.600	0.616	0.372	0.803	1.563	0.640

Table 6. Continued

CMA	Male							Female						
	Cutoff point	Sensitivity	Specificity	PPV	NPV	PLR	NLR	Cutoff point	Sensitivity	Specificity	PPV	NPV	PLR	NLR
Fat, %	**29.1**	0.543	0.629	0.213	0.882	1.464	0.683	**41.7**	0.640	0.548	0.349	0.801	1.416	0.706
BMI	**26.1**	0.716	0.465	0.198	0.899	1.338	0.747	**26.5**	0.653	0.540	0.350	0.804	1.420	0.704
C index	**1.31**	0.621	0.570	0.211	0.891	1.444	0.692	**1.20**	0.707	0.444	0.325	0.800	1.272	0.786
AVI	**20.1**	0.534	0.667	0.229	0.886	1.604	0.624	**15.6**	0.640	0.556	0.353	0.803	1.441	0.694
WWI	**10.7**	0.698	0.522	0.212	0.903	1.460	0.685	**10.6**	0.620	0.518	0.328	0.783	1.286	0.777

Bold values are the cutoff points determined by ROC curve.
Abbreviations: AVI, abdominal volume index; BMI, body mass index; BP, blood pressure; C index, conicity index; CMA, clinical metabolic abnormality; FPG, fasting plasma glucose; HC, hip circumference; HDL-C, high-density lipoprotein cholesterol; NC, neck circumference; NLR, negative likelihood ratio; NPV, negative predictive value; PLR, positive likelihood ratio; PPV, positive predictive value; ROC, receiver operating characteristic; TGs, triglycerides; WC, waist circumference; WWI, weight-adjusted waist index.

predictive ability in both sexes. A previous study that compared the discriminative ability of WC, BMI, and WC:HC in identifying MetS reported that WC:HC was the weakest compared with WC and BMI in both sexes in people of different ages and ethnicities [61].

The optimal cutoff points for WC, WC:Ht, and BMI were 97.5 cm, 0.58, and 27.9 for men and 89.5 cm, 0.59, and 28.3 for women, respectively. These cutoff points are higher than the previously suggested WC and BMI cutoff points for CMA in the Saudi population, which were 92 cm and 25 for men and 87 cm and 28 for women, respectively [50], probably due to differences in study inclusion criteria. In the previous Saudi study, nondiabetic and diabetic people were included, which resulted in a high prevalence of more than 40% of MetS. The population included in our study, in which the CMA prevalence was 17.6%, had not previously been diagnosed with T2DM.

The optimal cutoff points for explored anthropometric indices had a relatively high sensitivity and negative predictive value in predicting CMA; however, they had a low positive predictive value and positive likelihood ratio, which is typical in cross-sectional studies. Therefore, they cannot be used solely to select individuals for further testing. Combinations of 2 or more anthropometric indices might improve the accuracy of the prediction of the CMA. This will require further analysis using more sophisticated statistical approaches such as artificial intelligence and machine learning to illustrate the complicated relations between predicting anthropometric factors for MetS that we plan to conduct in the future.

The limitation of our study was its cross-sectional design, which does not allow determining causality. However, this is the first study in a Saudi population to investigate the predictive ability of traditional as well as several novel anthropometric indices of CMA and to determine their cutoff points.

In conclusion, anthropometric indices that had the best ability to identify a CMA after adjusting for age were NC and NC:Ht in men and WC, WC:Ht, and AVI in women, with no significant difference between these indices. Thus, body fat distribution might contribute to CMA in a sex-specific manner. WC:HC, C index, and WWI had the lowest abilities to predict a CMA.

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Disclosures

The authors have nothing to disclose.

Data Availability

The data sets analyzed for this study can be found at the King Abdulaziz University repository at http://www.kau.edu.sa/GetFile.aspx?id=310042&fn=AnthropometricandMetSdataavailabilitycheck.rar.

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