

Metabolic syndrome severity scoring using confirmatory factor analysis in Jordanian adults

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Abstract. *Background and aim:* Metabolic syndrome (MetS) is a significant health concern with specified diagnostic criteria. Determining the severity of MetS and screening individuals with pre-MetS pose challenges. MetS severity score (MetSSS) is a new assessment method developed to better manage and diagnose MetS. The study aimed to design a MetS severity score (MetSSS) equation specific to Jordanian adults based on sex and age. *Methods:* 428 participants were recruited for MetSSS calculations in this cross-sectional study. A confirmatory factor analysis (CFA) of a single MetS factor allowed differential loadings across groups to generate sex- and age-specific, continuous MetSSS was performed. *Results:* Systolic blood pressure (SBP) exhibited the highest factor loading contributing factors in MetSSS, followed by high-density lipoprotein (HDL). In contrast, fasting blood glucose (FBG) and triglycerides (TG) had the lowest factor loadings across the MetS components for the total population. Results showed a strongly positive correlation between MetSSS and body mass index (BMI) ($r=0.617$, $p<0.001$), demonstrating the link between MetS and obesity. MetSSS effectively predicted traditional MetS and its components, as validated by receiver operating characteristic (ROC) analysis. Notably, there was a progressive increase in mean MetSSS with the accumulation of MetS components, highlighting its ability to reflect disease severity. *Conclusion:* The MetSSS offers a promising tool for clinicians to screen at-risk individuals and is more sensitive than traditional MetS diagnosis methods. Its potential for clinical application in identifying high-risk patients, determining main factors, motivating life-style change, and tracking treatment progress is significant. (www.actabiomedica.it)

Key words: metabolic syndrome, severity score, confirmatory factor analysis, adult, Jordanian population

Introduction

Metabolic syndrome (MetS) is a cluster of metabolic abnormalities and a significant health concern. It includes central obesity, elevated blood pressure, insulin resistance, and atherogenic dyslipidemia (1). Different institutions have established different diagnostic criteria for MetS. The National Cholesterol Education Program Adult Treatment Panel (NCEP ATP-III) and the International Diabetes Federation (IDF) have diagnostic criteria. The IDF's criteria consider specific waist circumference cut-points for different ethnic

groups and two or more other components of MetS (2). NCEP ATP-III criteria include the presence of three or more of the following five MetS components: WC ≥ 90 cm in men and ≥ 80 cm in women, fasting blood glucose (FBG) ≥ 100 mg/dL (5.55 mmol/L), or use of anti-diabetic medication, blood pressure (BP); SBP ≥ 130 mmHg, diastolic blood pressure (DBP) ≥ 85 mmHg, use of antihypertensive medication, TG ≥ 150 mg/dL, and HDL cholesterol < 40 mg/dL in men and < 50 mg/dL in women (3). Gurka and colleagues (2012) developed a new assessment method called the MetS severity score (MetSSS) to better manage

and diagnose MetS. This score can be automatically calculated and inserted into the computerized medical record, aiding physicians in patient follow-up and evaluation of their progress (4). The variation between the most prevalent and lowest prevalence of MetS components within the same population may affect the variation in MetSSS equations in different ethnic groups (5). The Current definitions of MetS, such as those by the NCEP ATP-III and IDF, have limitations. They tend to provide a binary diagnosis, categorizing patients as having MetS or not. This approach can be problematic when dealing with borderline values, as it may fail to estimate risk accurately. Additionally, minor variations in the criteria values can lead to misclassifying individuals as having or not having MetS. These limitations underscore the need for a new assessment method, such as the MetSSS, that can provide a more nuanced and accurate diagnosis. The MetSSS equations came to solve the problem of binary classification as to whether the syndrome is present or not; it also did not restrict itself to the IDF and NCEP ATP- III organization's standards (6-8). The prevalence of MetS and its associated conditions has significantly increased among the Jordanian population. According to the IDF criteria, the crude prevalence of MetS was 48.2%, with 52.9% among males and 46.2% among females. Using the ATP III criteria, the prevalence was 44.1%, with 51.4% among males and 41% among females (9). Also, the prevalence of obesity was 60.4% among men and 75.6% among women, while approximately three-quarters of men and women were overweight or obese as defined by BMI (10). In addition, the high cholesterol, high triglycerides, high LDL, and low HDL rates were 44.3%, 41.9%, 75.9%, and 59.5%, respectively. The prevalence of high cholesterol in Jordan nearly doubled from 23.0% in 1994 to 44.3% in 2017, and the prevalence of high triglycerides increased from 23.8% in 1994 to 41.9% in 2017 (11). Almost one-third of Jordanian adults had hypertension; the prevalence was 33.8% among men and 29.4% among women (12). For the previously mentioned scenario, it is crucial to determine the specific MetSSS for the Jordanian population. Notably, all available MetSSS formulas are based on data from the US and Asian populations (7). The absence of specific criteria

that can minimize the likelihood of MetS diagnosis to a numerical value for each individual based on ethnicity, sex, and age underscores the need for creating specialized equations that integrate these MetS components. Therefore, this study aimed to develop a specific equation for predicting MetSSS for Jordanian adults based on sex and age.

Methods

Study design

A cross-sectional study was performed between April 2023 and March 2024. It included demographic data, medical data from participants, and demographic information. Medical data was obtained from the Hakeim system, and anthropometric measurements were taken at Al-Basher Hospital clinics. Participants were informed about the study's objectives before undergoing anthropometric measurements.

Sampling procedure

Based on the recommended approach by Pourhoseingholi and colleagues (2013), the calculated sample size is 424 (13). The total sample recruited was 540 individuals. However, due to missing some biochemical data values, only 428 participants were recruited for MetSSS calculations. Randomization in sample selection was used to mitigate the selection bias.

Study population

The inclusion criteria were apparently healthy adults aged 19-64 years. The exclusion criteria included being pregnant or having known diabetes or unknown diabetes (fasting plasma glucose >125mg/dL), taking antihyperlipidemic or anti-diabetic medications, all of which were situations likely to change lipid and insulin levels, a history of cardiovascular or cerebrovascular accidents, traumatic, degenerative, or inflammatory diseases of the nervous system; epilepsy, and other endocrine disorders, according to these studies (6-8).

Ethical consideration and consent to participate

The research protocol underwent a thorough review and obtained Institutional Review Board (IRB) approval from the ethics committees of the Jordanian governmental hospital, Al-Basher, with IRB number (MBA, IRB, 20219-1/12/2022), and The University institutional review board (HU-IRB) (No.19/1/2022/2023). Before the data collection process, informed written consent was obtained from each participant. Participants were interviewed face-to-face, and the researcher completed anthropometric measurements. Additionally, medical history, BP measurement, and biochemical data were gathered from their medical records in the Hakim auto-record system.

Anthropometric and biochemical measurements

Height was measured to the nearest centimeter, with participants standing in light clothing and barefoot, using a portable wall stadiometer. Additionally, a digital balance measured body weight to the nearest tenth of a kilogram in the same conditions (Omron). BMI was calculated as weight divided by the square of their height in meters to determine their (BMI kg/m^2). The WC and hip circumference were measured (cm) at the spot where the lower rib and upper iliac crest were the narrowest. However, the fully automatic serum analysis was completed according to the hospital protocol, and the full laboratory analysis was recorded in the Hakim medical system. As part of quality control procedures in the hospital, all lab tests were repeated two times. Data about FBG (mg/dL), HDL (mg/dL), TG (mg/dL), total cholesterol (mg/dL), SBP (mmHg), and DBP (mmHg) were gathered.

Formulating equation

Based on the five MetS components, the MetSSS was developed using a confirmatory factor analysis (CFA) method with a weighted contribution to a latent MetS factor (4). Each component's MetS loading factors were calculated based on specific age ranges and gender. In the equation, SBP was inserted instead of DBP (7). Additionally, log-transformed TG values

were due to the TG levels of the collected data (8). At the same time, the inverse value of high-density lipoprotein HDL cholesterol was used to be interpretable similarly to the other metrics involved in the model. The factor loading was crucial in MetSSS since it illustrated the strength of the correlation coefficient between each related component and the underlying MetS factors (6). The used model allowed the factor loading of MetS components to vary among the groups for structural equation modeling using AMOS (14). The resulting MetSSS was modulated using a z-score, representing the relative MetS severity for each gender and age category, extending from theoretically negative to positive infinity (7).

Statistical analysis

To perform CFA, SBP, the inverse of HDL value, and the log-transformed values of TG, WC, and FBG were used (15). All five MetS components in the models were standardized at mean = 0 and SD = 1 over the entire sample. The factor loadings indicated the magnitude of the association between each component and the unobserved latent variable of MetS. Factor loadings > 0.3 were considered to show a moderate correlation. Factor scores were produced using proper linear combinations of the variables. Factor scores and MetSSS were calculated using linear regression analysis (8). The standardized factor coefficients in the final models were applied to estimate the MetSSS for each individual. The performance of the overall and age- and sex-specific models was compared with various fit indices. To evaluate the model fitness, the chi-squared test, the root mean square error of approximation (RMSEA; a good fit < 0.05), standardized root mean square residual (SRMR; good fit < 0.08), comparative fit index (CFI, good fit > 0.90), the goodness of fit index (GFI, good fit > 0.90), Bentler-Bonett normed fit index (NFI, good fit > 0.90), and Akaike's information criterion (AIC, smaller values indicates a better fit) were used. Receiver operating characteristic (ROC) analysis was used to assess the participants' external validation to assess the MetSSS's overall predictive performance for the ATP-III MetS criteria (8, 15). The area under the curve (AUC) between 0.9 and 1.0 has excellent

discrimination ability; AUC from 0.80 to 0.90, 0.70 to 0.80, 0.60 to 0.70, and 0.50 to 0.60 indicates good, fair, poor, and fail discrimination ability, respectively (Hosmer & Lemeshow, 2000). MedCalc (22.023) software was also used to determine the Youden Index, sensitivity, and specificity. Data was analyzed using SPSS software (IBM SPSS Statistics for Windows, Version 25.0, Armonk, NY: IBM Corp). The chi-square test (χ^2) was used to assess differences between categorical variables, and the results were presented as percentages. In contrast, continuous variables were analyzed using an independent t-test or one-way Analysis of Variance (ANOVA) and were described using means $\pm$ standard deviation (SD). A p -value <0.05 was considered statistically significant.

Results

Table 1 shows the general characteristics of the study sample. Participants exhibited an average weight of 81.81 ± 17.79 kg and an average height of 162.27 ± 7.24 cm. The mean BMI was 31.07 ± 6.46 kg/m², classified as obesity. The mean WC is 98.15 ± 13.34 cm, while the mean HC is 113.92 ± 13.36 cm. The study's findings revealed that the mean SBP and DBP were 124.72 ± 21.38 and 82.70 ± 13.20 mmHg, respectively. Furthermore, the mean FBG, HDL, LDL, and TG were 105.78 ± 25.23 mg/dL, 51.85 ± 22.78 mg/dL, 128.66 ± 38.30 mg/dL, and 163.66 ± 83.72 mg/dL; respectively. Hence, FBG and TG values are considered abnormal according to the MetS ATP and IDF standards. About half of them (54.2%) were classified as obese based on BMI classification. The majority of the participants were aged 19–45 years (60.1%), predominantly female (85.9%), and primarily educated up to high school (39.8%). Most participants were married (71.5%) and nonsmokers (77.6%).

The sample of participants for the CFA series consisted of 428 individuals aged 19–64, with complete data for MetS components presented in Table 2. The mean values of age, waist circumference, SBP, TG, HDL, and FBG differed notably across age and sex groups. The model fit indices in the developed models, including RMSEA, SRMR, GFI, NFI, and CFI, were

Table 1. General characteristics of the participants and biochemical data (n=428)

Variables	Mean $\pm$ SD
Weight (kg)	81.81 ± 17.79
Height (cm)	162.27 ± 7.24
Body mass index (kg/m ²)	31.07 ± 6.46
Waist circumference (cm)	98.15 ± 13.34
Hip circumference (cm)	113.92 ± 13.36
SBP (mmHg)	124.72 ± 21.38
DBP (mmHg)	82.70 ± 13.20
FBG (mg/dL)	105.78 ± 25.23
HDL (mg/dL)	51.85 ± 22.78
LDL (mg/dL)	128.66 ± 38.30
TG (mg/dL)	163.66 ± 83.72
Variables	n (%)
Body Mass Index categories	
Underweight	6 (1.1)
Normal weight	88 (16.4)
Overweight	151 (28.2)
Obese	290 (54.2)
Age groups	
19–45 years	323 (60.1)
46–64 years	214 (39.9)
Sex	
Females	464 (85.9)
Males	76 (14.1)
Educational level	
Primary, secondary, and High school	377 (69.8)
Community college	31 (5.7)
B.Sc. degree and Higher education (master's/Ph. D.)	132 (24.4)
Marital status	
Married	386 (71.5)
Single	95 (17.6)
Divorced	37 (6.9)
Widow	22 (4.1)
Smoking status	
Nonsmoker	419 (77.6)
Smoker (Cigarette and/or hookah)	116 (21.5)

Abbreviations: SBP: systolic blood pressure; DBP: diastolic blood pressure; FBG: fasting blood glucose; HDL: high-density lipoprotein; LDL: low-density lipoprotein; TG: triglycerides.

Table 2. Model fit indices and factor loadings in sex and age subgroups

	Total			Males			Females		
	19-64 years	19-45 years	46-64 years	19-45 years	46-64 years	19-64 years	19-45 years	46-64 years	19-64 years
No of participants	428	258	170	29	29	58	229	141	370
WC (cm)	98.62±13.45	95.55±13.5	103.28±11.92	108.69±12.3	106.52±10.6	107.60±11.5	93.89±12.77	102.62±12.09	97.22±13.20
SBP (mmHg)	124.65±21.8	119.9±16.2	131.84±26.62	126.31±12.5	131.10±10.9	128.71±11.9	119.10±16.5	131.99±28.83	124.01±22.9
HDL (mg/dL)	51.88±22.89	50.49±21.1	53.97±25.28	41.26±10.12	47.14±13.25	44.19±12.06	51.67±21.8	55.37±26.92	53.08±23.94
ln TG (mg/dL)	4.98±0.45	4.96±0.48	5.03±0.39	5.08±0.51	4.94±0.39	5.01±0.46	4.9431±0.48	5.05±0.39	4.98±0.46
FBG (mg/dL)	105.90±25.4	101.6±18.7	112.41±31.96	109.11±28.6	120.71±38.6	114.91±34.1	100.65±16.9	110.71±30.31	104.49±23.4
Model fit indices									
Chi-square	10.8	4.45	18.76	1.97	3.99	3.73	1.60	22.07	14.44
AIC	30.83	24.45	38.76	21.97	24.00	23.73	21.60	42.074	34.44
RMSEA (90% CI)	0.052 (0.000- 0.095)	0.000 (0.000- 0.082)	0.128 (0.069- 0.192)	0.000 (0.000, 0.143)	0.000 (0.000 -0.234)	0.000 (0.000 -0.158)	0.000 (0.00-0.039)	0.156 (0.093- 0.225)	0.072 (0.030- 0.116)
SRMR	0.038	0.029	N/A	0.07	N/A	N/A	0.018	N/A	0.047
GFI	0.99	0.993	0.958	0.97	0.944	0.97	0.99	0.938	0.984
NFI	0.904	0.948	0.5	0.93	0.784	0.89	0.97	0.408	0.833
CFI	0.943	1	0.5	1	1	1	1	0.375	0.876
Factor loadings									
WC	0.635	0.552	0.008	0.839	0.324	0.788	0.468	0.037	0.546
SBP	0.718	0.343	0.438	0.209	0.017	0.126	0.354	0.428	0.243
HDL	0.642	0.369	0.654	0.079	0.177	0.118	0.401	0.624	0.117
ln TG	0.284	0.224	0.122	0.397	0.239	0.337	0.196	0.146	0.31
FBG	0.382	0.258	0.198	0.399	0.757	0.279	0.216	0.254	0.293

Abbreviations: MetSS: metabolic syndrome severity score; WC: waist circumference; HDL: high-density lipoprotein; SBP: systolic blood pressure; TG: triglycerides; FBG: fasting blood glucose; AIC: Akaike information criterion; RMSEA: root mean squared error of approximation; CI: confidence interval; SRMR: standard root mean square; residual; GFI: the goodness of fit index; NFI: Bentler-Bonett normed fit index; CFI: comparative fit index.

0.00–0.156, 0.018–0.047, 0.938–0.993, 0.408–0.904, and 0.375–1, respectively (Table 2). Due to the small sample size in some age-gender groups, it wasn't easy to calculate the SRMR value by AMOS. The factor loadings of the MetS components varied by age and sex groups. Among the MetS components for the total sample, SBP had the highest factor loading (0.718). Followed by HDL (0.642) and waist circumference (0.635), TG had the lowest factor loading among the MetS components (0.382 and 0.284, respectively). Based on gender, waist circumference exhibited higher factor loadings in the total samples of males and females. The factor loading of fasting plasma glucose was consistent between men aged 20–39 years and those aged 40–60. However, the factor loading values of other MetS components varied among age groups in different genders. In terms of WC, the total population (19–64 years) shows a mean WC of 98.62 ± 13.45 cm, with younger individuals (19–45 years) demonstrating a slightly lower mean WC at 95.55 ± 13.5 cm, while older individuals (46–64 years) exhibit a higher mean WC of 103.28 ± 11.92 cm. The overall mean WC for males aged 19–64 was $107.60 \text{ cm} \pm 11.5$. According to ATP and IDF, the WC in men for all age groups exceeds the normal cut-point. On the other hand, the overall mean WC for females aged 19–64 was 97.22 ± 13.20 cm. As for SBP levels indicate a mean of $124.65 (\pm 21.8)$ mmHg for the total population, with the younger age group showing a lower mean SBP of 119.9 ± 16.2 mmHg versus the older age group, which

shows a higher mean SBP of 131.84 ± 26.62 mmHg this observed that SBP be likely to increase with age in the whole population. For males aged 19–45, the mean SBP was 126.31 ± 12.5 mmHg, which increased to 131.10 ± 10.9 mmHg for those aged 46–64. The overall mean SBP for males aged 19–64 was 128.71 ± 11.9 mmHg. For females aged 19–45, the mean SBP was 119.10 ± 16.5 mmHg, which increased to 131.99 ± 28.83 mmHg for those aged 46–64. The overall mean SBP for females aged 19–64 was 124.01 ± 22.9 mmHg. Regarding HDL levels, the mean was 51.88 ± 22.89 mg/dL for the total population, 50.49 ± 21.1 mg/dL for the younger age group, and 53.97 ± 25.28 mg/dL for the older age group. However, for males aged 19–45, the mean HDL level was 41.26 ± 10.12 mg/dL, which increased to 47.14 ± 13.25 mg/dL for those aged 46–64.

The overall mean HDL level for males aged 19–64 was 44.19 ± 12.06 mg/dL. By illustrating this mean value using ATP criteria, we concluded that the average for men does not indicate a problem in HDL level. However, this may not clearly define a small sample size. For females aged 19–45, the mean HDL level was 51.67 ± 21.8 mg/dL, which increased to $55.37 \text{ mg/dL} \pm 26.92$ for those aged 46–64. The overall mean HDL level for females aged 19–64 years was 53.08 ± 23.94 mg/dL, which in all age groups showed an average value according to ATP and IDF standards. As age increases, regardless of gender, the major loading factors (SBP, WC, and HDL levels) increase. Table 3 shows the final age and sex-specific MetSSS

Table 3. Age and sex-specific MetSSS equations derived from the confirmatory factor analysis

Groups	Age (years)	Equations for MetSSS
Males	19–45	$-10.491 + 0.039 \cdot \text{WC} + 0.019 \cdot \text{SBP} - 0.014 \cdot \text{HDL} + 0.638 \cdot \ln(\text{TG}) + 0.012 \cdot \text{FBG}$
	46–64	$-1.465 + 0.035 \cdot \text{WC} - 0.008 \cdot \text{SBP} + 0.021 \cdot \text{HDL} - 0.82 \cdot \ln(\text{TG}) + 0.015 \cdot \text{FBG}$
	19–64	$-11.536 + 0.047 \cdot \text{WC} + 0.018 \cdot \text{SBP} - 0.017 \cdot \text{HDL} + 0.766 \cdot \ln(\text{TG}) + 0.009 \cdot \text{FBG}$
Females	19–45	$-9.275 + 0.033 \cdot \text{WC} + 0.022 \cdot \text{SBP} - 0.018 \cdot \text{HDL} + 0.564 \cdot \ln(\text{TG}) + 0.017 \cdot \text{FBG}$
	46–64	$0.326 + 0.011 \cdot \text{WC} + 0.015 \cdot \text{SBP} + 0.02 \cdot \text{HDL} - 0.65 \cdot \ln(\text{TG}) - 0.011 \cdot \text{FBG}$
	19–64	$-10.545 + 0.037 \cdot \text{WC} + 0.014 \cdot \text{SBP} - 0.009 \cdot \text{HDL} + 0.817 \cdot \ln(\text{TG}) + 0.015 \cdot \text{FBG}$
Total	19–45	$-9.006 + 0.031 \cdot \text{WC} + 0.021 \cdot \text{SBP} - 0.016 \cdot \text{HDL} + 0.56 \cdot \ln(\text{TG}) + 0.016 \cdot \text{FBG}$
	46–64	$0.177 + 0.005 \cdot \text{WC} + 0.018 \cdot \text{SBP} + 0.023 \cdot \text{HDL} - 0.622 \cdot \ln(\text{TG}) - 0.01 \cdot \text{FBG}$
	19–64	$-10.067 + 0.037 \cdot \text{WC} + 0.014 \cdot \text{SBP} - 0.01 \cdot \text{HDL} + 0.737 \cdot \ln(\text{TG}) + 0.014 \cdot \text{FBG}$

Abbreviations: MetSSS: metabolic syndrome severity score; WC: waist circumference; HDL: high-density lipoprotein; SBP: systolic blood pressure; TG: triglycerides; FBG: fasting blood glucose.

Table 4. The range of MetSSS values in the study population by sex-age category and based on the number of MetS components

Variables	N	Mean $\pm$ SD	Minimum	Maximum
MetSSS total	428	-0.0347 $\pm$ 0.99	-4.90	3.30
MetSSS for MetS components				
None	10	-1.358$\pm$0.30	-1.87	-1.03
One component	56	-0.996$\pm$0.64	-2.33	0.04
Two-components	99	-0.412$\pm$0.83	-4.90	1.65
Three components	138	0.086$\pm$0.82	-2.05	2.47
Four components	106	0.585$\pm$0.88	-2.07	3.30
Five components	20	1.066$\pm$0.59	-0.07	2.23
Females				
19-45 years	229	-0.390 $\pm$ 0.89	-4.90	2.68
46-64 years	141	0.298 $\pm$ 0.93	-2.07	2.87
Total	370	-0.128 $\pm$ 0.96	-4.90	2.87
Males				
19-45 years	29	0.584 $\pm$ 1.02	-2.06	2.47
46-64 years	29	0.566 $\pm$ 0.88	-1.04	3.30
Total	58	0.575 $\pm$ 0.95	-2.06	3.30

Abbreviations: MetSSS: Metabolic syndrome severity score; MetS: metabolic syndrome.

equations derived from the CFA. Nine equations were developed in sex and age subgroups of 19-45 and 46-64 years. The resulting equations can continuously show traditional MetS criteria while representing the MetS severity. Since MetS components contribute to MetS differently according to age groups and sex, the age—and sex-specific equations are recommended for further studies. Due to the small sample size for subgroups based on age and sex-specific, we used the MetSSS for the total population regardless of sex specifications.

Table 4 presents the range of MetSSS values in the study population by age and sex-specific category and based on the number of MetS components. The total MetSSS value ranged from -4.9 to 3.4. The mean MetSSS for total females is -0.128 $\pm$ 0.96, ranging from -0.90 to 2.84. At the same time, the mean for total males is 0.575 $\pm$ 0.95, ranging from -2.06 to 3.30. MetSSS increases with a positive value, indicating an increase in MetS severity; negative values mean a low severity. The mean of MetSSS for MetS components increased gradually as the number of MetS components increased from none to five components

(-1.358, -0.996, -0.412, 0.086, 0.585, and 1.066, respectively).

The ROC analysis was performed to validate MetSSS for MetS and MetS components. AUC results are presented in Table 5 and Figure 1. The AUC of MetSSS for MetS and each component of MetS is between 0.648 and 0.903. The AUC for total MetSSS in predicting MetS is 0.729, which indicates fair discriminatory ability in distinguishing individuals with and without MetS. Among the MetS components, the AUC of MetSSS shows an excellent discriminatory ability for WC (0.903), a fair discriminatory ability for TG (0.764 and 0.740, respectively), followed by poor discriminatory ability for SBP (0.689) and HDL (0.648). Differential predictive performances of total MetSSS across MetS components, with WC demonstrating a notably higher sensitivity of 81% compared to the overall MetS prediction. HDL exhibited a poor sensitivity of 49.8% and specificity of 77.4%, while SBP demonstrated a balanced performance, with a sensitivity of 60.9% and a specificity of 69.3%. These statistical analyses led to determining the cut-off point of MetS, WC, HDL, SBP, TG, and FBG, which

Table 5. The AUCs of total MetSSS for MetS and MetS components

Variables	AUC	<i>p</i> -value	95%CI	Sensitivity	Specificity	Cut-Off Points	Youden Index
MetS	0.729	<0.001	0.682-0.776	58.8%	76.2%	>0.140	0.349
WC	0.903	<0.001	0.871-0.936	81.0%	86.4%	>-0.440	0.674
HDL	0.648	<0.001	0.600-0.693	49.8%	77.4%	≤-0.410	0.271
SBP	0.689	<0.001	0.639-0.739	60.9%	69.3%	>-0.021	0.302
TG	0.764	<0.001	0.719-0.808	38.4%	82.0%	>0.220	0.404
FBG	0.740	<0.00	0.693-0.787	58.5%	81.6%	>0.160	0.401

Abbreviations: AUC: area under the curve; MetS: metabolic syndrome; WC: waist circumference; HDL: high-density lipoprotein; SBP: systolic blood pressure; TG: triglycerides; FBG: fasting blood glucose.

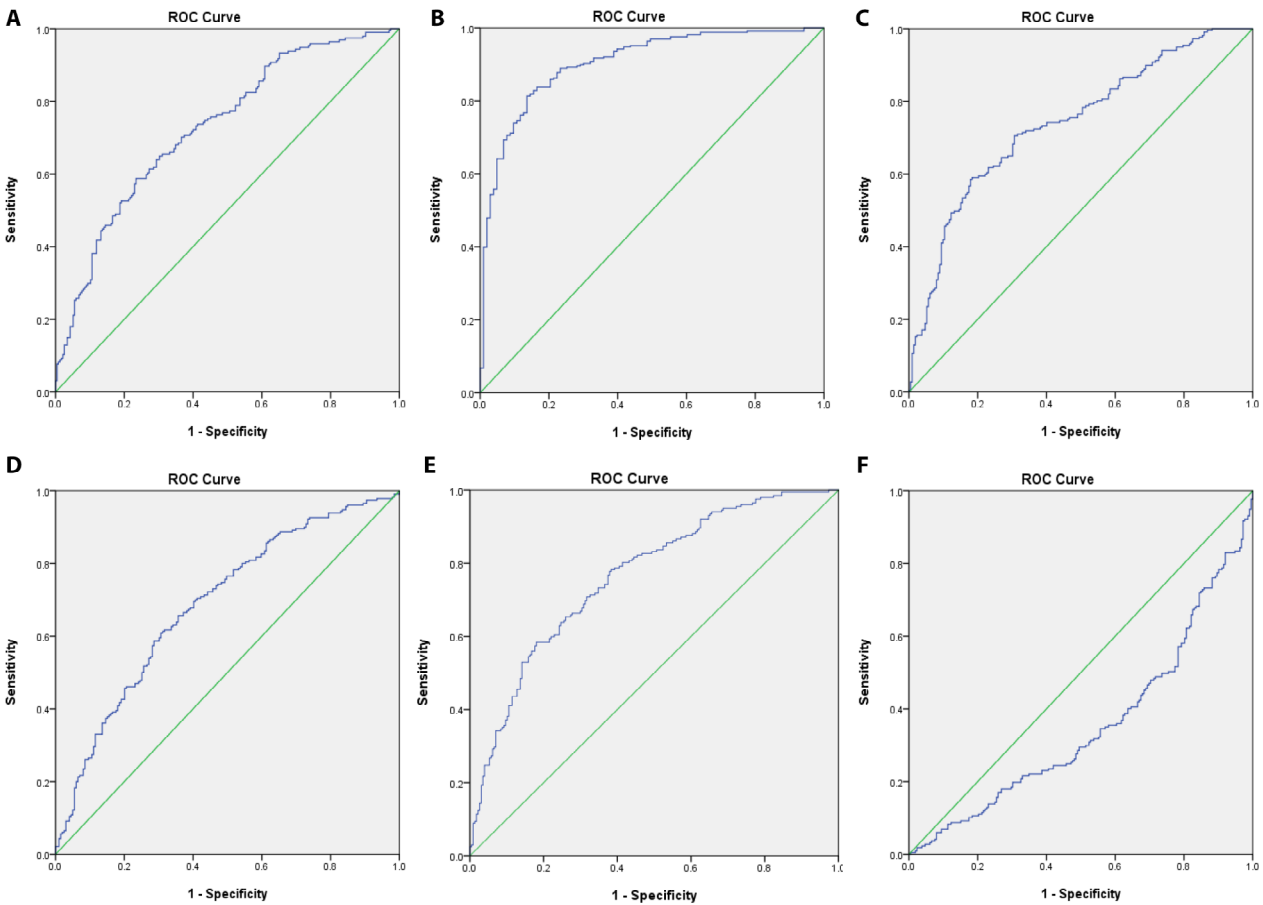


Figure 1. ROC curve of MetSSS for predicting metabolic syndrome (MetS) and its components: (a) MetS, (b) waist circumference, (c) fasting blood glucose, (d) systolic blood pressure, (e) triglycerides, and (f) high-density lipoprotein.

were found to be (>0.140, >-0.440, ≤-0.410, >-0.021, >0.220, and >0.160, respectively). These thresholds serve as markers for classifying individuals as positive or negative for MetSSS.

Discussion

In the present study, we derived valuable findings by examining each component of MetS to construct

MetSSS equations. We have considered the varying impact of MetS across different age-sex groups. Our results show that factor loadings of the MetS components varied by age and sex groups. The variation observed can be explained as follows: SBP exhibited the highest factor loading, with HDL ranking as the second highest contributing factor to the MetS. While FBG and TG had the lowest factor loadings across the MetS components for the total population, based on sex, WC exhibited higher factor loadings across males and females. However, the WC had a higher correlation with MetS in males than in women. The factor loading of FBG was consistent between men aged 20–39 years and those aged 40–60. Furthermore, the contribution of WC to MetS tends to decline with age in women and men. Thus, both the correlation and value of MetS components about MetS varied by sex and age, justifying the importance of employing age- and sex-specific MetSSS, but in this study, we only designed the model of age-sex-specific MetSSS but did not approve it; we only relied on the total population-specific MetSSS. Regarding higher loading coefficients of SBP, HDL, and WC, it is better to discuss that CFA indicates a variation in the degree of influence each MetS component had on MetS. This suggests that the weighting of the MetS components should be considered individually rather than evenly distributed by previous methods (15). To our knowledge, the present study is regarded as the first to develop a Middle East-specific MetSSS. It applied the ROC analysis to assess the ability of MetSSS to predict MetS and MetS components, which showed a high ability to distinguish individuals with and without MetS among the MetS components. The AUC analysis of MetSSS shows an excellent discriminatory ability for WC and a fair discriminatory ability for TG and FBG. The Korean study also applied the ROC analysis to measure internal validity and found an excellent ability to predict traditional MetS classification (8). The Iranian study demonstrated the excellent predictive ability of the ROC analysis on the resulting risk score for predicting the Iranian NCEP MetS classification (15). In line with the current findings, the Korean study (8) and the Iranian study (15) were distinguished by establishing MetSSS equations for the total population and age- and sex-specific models utilizing CFA. Here, it should

be emphasized that the age-sex model is not fully supported because of the small sample size. It was only developed for potential future research. With data regarding age, sex, and the measurements for the five MetS components, these formulas can be used to determine the MetSSS of each individual. In all of these steps to constitute the scores of MetS severity on a continuous scale, we consider a range from -5 to 5, according to Gurka and colleagues (2024) (6). The current findings provide clear insights into the age-related changes in the correlation of MetS components with MetS. Moreover, according to our results, SBP showed the highest factor loading (0.343–0.718) among the total population, exhibiting the highest association with MetS; also, we could say that SBP accounts for 11.77% – 51.55% of the variation of the MetS latent variable in the Jordanian population. The current study displays the range of MetSSS values across different age-sex groups and MetS profiles. MetSSS values ranged from -4.9 to 3.4, indicating a wide variation in MetS within the study population. Mean MetSSS differed between sexes, with females exhibiting a slightly lower mean score than males. There was a progressive increase in mean MetSSS according to the number of components present in MetS, showing a worsening of MetS as more components accumulate. The Iranian study was considered the only study to discuss the association of MetSSS value to MetS components across age-sex groups; the study delved into the mean values of the MetSSS across subgroups classified via the number of MetS components within the total population (15). Furthermore, the study observed that individuals with fewer than two MetS components showed a mean MetSSS value below zero, indicative of a less severe MetS, consistent with the current findings. It was observed that the Chinese, Malaysian, and Singaporean men and older women in the current study exhibited the highest coefficients in quantity for HDL (15–17). In contrast, the white women in the US, Taiwanese, young Korean women, and black US and total men in the current study showed the highest coefficients for WC (15, 16), the white women in the US, Taiwanese, young Korean women, and black US and in total men in the present study showed the highest coefficients for WC (6–8). In contrast, the Indian, Iranian, Korean, Hispanic US, and Singaporean

women and white American men population revealed the highest coefficients for TG (6, 8, 15, 16). In the Korean and Iranian studies, TG was the highest-correlated component to MetS except for women aged 20–39 in Korea (8, 15), as shown in Table S1, which reviews the factor loadings of the MetS components only in studies that formulated MetSSS for the total population and age–sex specific equation using CFA in the adult population from different ethnicities/regions. Among the MetS components, TG had the highest correlation with MetS as a latent variable in Iranian, Korean (8, 15), Hispanic populations, white American men, and Singaporean women (6, 16, 18). WC in White women, young Korean women, the Black population, and HDL in Singaporean men had the most significant correlation with MetS (8, 16, 19). In most studies, SBP had a minor contribution to MetS, showing that the high rate of essential hypertension is independent of MetS. The correlation with MetS varied by ethnicity, with black and Hispanic women having the highest and Iranian middle-aged women having the lowest factor loadings (15, 19). Although not all studies were precisely similar in age and the corresponding subgroups, the weighted contribution of components to MetS showed variation by sex and ethnicity/region. This finding aligns with the previous epidemiologic reports showing sex, ethnic, and regional disparities in the prevalence of MetS components and their contribution to MetS. The variation in patterns of fat accumulation among males and females, lipid metabolism, and sex hormones are the primary differences and possible explanations for the differences in the contribution of MetS components to MetS (18). When correlating with age factors, the prevalence of MetS components and their contribution to MetS change may be due to menopause in women and the decline in androgen levels in men. These findings correspond with previous prevalence studies (19, 20). Various methods have been used in the last 20 years, such as counting and clustering the traits or summing z-scores of the MetS components. These strategies aim to address the limitations of the conventional criteria in determining the severity of MetS (19). However, efforts to assess the severity of each MetS component and its weighted contribution to MetS were limited until researchers decided to use the CFA approach. To understand the

mechanism of MetSSS deeply, we should note that relying solely on prevalence rates or incidence numbers of MetS may not provide a complete picture of the impact of MetS on population health.

Strengths and limitations

This study is strengthened for several reasons: Firstly, it marks the debut of the Metabolic Syndrome Severity Score (MetSSS) in the Middle East, utilizing a total population model established through CFA and stratified across different age subgroups. Additionally, it designed age–sex MetSSS subgroups. Such considerations offer a more concrete quantitative assessment of MetS, which enables clinicians to accurately predict the prevalence of type 2 diabetes (T2D) and cardiovascular diseases (CVD), screen and detect individuals at risk, and evaluate the metabolic shift and effectiveness of any medical interventions. One significant challenge was the small sample size and uneven sex distribution of participants, with more females than males within our sample because of the lower level of cooperation. Also, the study has a cross-sectional design, which lacks a causal relationship. Moreover, data cannot be generalized for Jordanians or other Middle Eastern countries that share the ethnicity due to the small, unrepresentative sample size.

Conclusions

To bring everything together, the present study benefited from a contribution–effect approach, utilizing CFA to deal with each MetS component. Interestingly, there is no intention of displacing the role of traditional MetS diagnosis. So, we have formulated total population equations for the Jordanian population; the current methodological approach involved excluding individuals taking medication for MetS, ensuring a focus on the natural progression and severity of the condition. While the SBP exhibited the highest factor loading, with HDL ranking as the second highest contributing factor to the MetS, FBG and TG had the lowest factor loadings across the MetS components for the total population. Thus, knowing that MetSSS is more sensitive than traditional MetS

diagnosis, we pass through two methods to prove our claim; firstly, we perform internal validation by ROC analysis, showing that MetSSS effectively predicted traditional MetS and its components; the analysis revealed differential predictive performances of total MetSSS across MetS components, with WC exhibiting notably higher sensitivity and specificity compared to the overall MetS prediction. HDL showed poor sensitivity. Moreover, the determined cut-off points for MetS, HDL, SBP, TG, and FBG serve as valuable markers for classifying individuals as positive or negative for MetSSS. Secondly, we observed a progressive increase in mean MetSSS with the accumulation of MetS components, indicating worsening MetS severity. The present study exhibits a strongly positive correlation between MetSSS and BMI, demonstrating the link between MetS and obesity. The current MetS scoring systems, unlike binary MetS criteria, can be utilized to track changes over time in a population from a clinical standpoint. These systems allow for the assessment of potential impacts of MetS severity over time, comparison of differences among sex and racial groups, and evaluation of changes in clinical status, such as those occurring over the menopausal transition. However, as mentioned earlier, the clinical application of these scores would benefit from established cutoffs that identify patients at particularly high risk. It is important that continuous MetS scores were developed alongside traditional MetS criteria, partly due to the arbitrary nature of cutoffs in the individual MetS components and binary risk categorization. Nonetheless, in practical terms, the MetS scores are likely more easily used as risk indicators and patient motivators if they have established cutoffs. These cutoffs could provide specific guidance when counseling patients about their MetS-related risks. Further studies with larger sample sizes and male participants are required.

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Conflict of Interest: Each author declares that they have no commercial associations (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangement, etc.) that might pose a conflict of interest in connection with the submitted article.

Authors' Contribution: AA: Concept, Design, Resources, Materials, Data Collection and Processing, Interpretation, Literature Search, Writing Manuscript; BA: Supervision, Analysis, Interpretation, Literature Search, Critical Review; LA: Supervision, Analysis, Interpretation, Critical Review, Writing Manuscript.

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ANNEX

Table S1. Reviews the factor loadings of the MetS components in studies that formulated MetSSS for the total population and an age-sex-specific equation using CFA in the adult population from different ethnicities/regions.

Studies/ Ethnicity country	Age-sex group		Factor loading
The present study (Jordan Middle East) (15)	Men	(19-45) years	①WC (0.839) ②FPG (0.399) ③TG (0.397) ④SBP (0.209) ⑤HDL (0.079)
		(46-64) years	①FPG (0.757) ② WC (0.324) ③ TG (0.239) ④ HDL (0.177) ⑤ SBP (0.017)
		Total	①WC (0.788) ② TG (0.337) ③ FPG (0.279) ④ SBP (0.126) ⑤ HDL (0.118)
	Women	(19-45) years	①WC (0.468) ② HDL (0.401) ③ SBP (0.354) ④ FPG (0.216) ⑤ TG (0.196)
		(46-64) years	①HDL (0.624) ② SBP (0.428) ③FPG (0.254) ④TG (0.146) ⑤ WC (0.037)
		Total	①WC (0.546) ② TG (0.31) ③ FPG (0.293) ④ SBP (0.243) ⑤ HDL (0.117)
	Total population	(19-64) years	①SBP (0.718) ② HDL (0.642) ③ WC (0.635) ④ FPG (0.382) ⑤ TG (0.284)
		(19-45) years	①WC (0.552) ② HDL (0.369) ③ SBP (0.343) ④ FPG (0.258) ⑤ TG (0.224)
		(46-64) years	①HDL (0.654) ② SBP (0.438) ③ FPG (0.198) ④ TG (0.122) ⑤ WC (0.008)
Iran West Asia Honarvar et al., 2023	Men	(20-39) years	①TG (0.79) ② WC (0.57) ③HDL (0.48) ④SBP (0.30) ⑤FPG (0.27)
		(40-60) years	①TG (0.74) ②WC (0.48) ③HDL (0.47) ④FPG (0.26) ⑤SBP (0.22)
	Women	(20-39) years	①TG (0.73) ②WC (0.59) ③HDL (0.45) ④SBP (0.39) ⑤FPG (0.35)
		(40-60) years	①TG (0.84) ②HDL (0.46) ③WC (0.30) ④SBP (0.25) ⑤FPG (0.23)
	Total population	Total population	①TG (0.73) ②WC (0.63) ③SBP (0.44) ④HDL (0.42) ⑤FPG (0.39)
Korea Asia-Pacific Huh et al., 2019) (8)	Men	(20-39) years	①TG (0.68) ②WC (0.66) ③HDL (0.47) ④FPG (0.40) ⑤SBP (0.37)
		(40-60) years	①TG (0.67) ②WC (0.57) ③HDL (0.47) ④FPG (0.30) ⑤SBP (0.24)
		(20-39) years	①WC (0.67) ②TG (0.57) ③HDL (0.44) ④FPG (0.43) ⑤SBP (0.33)
	Women	(40-60) years	①TG (0.69) ②WC (0.51) ③HDL (0.51) ④FPG (0.34) ⑤SBP (0.28)
	Total population	(20-60) years	①WC (0.70) ②TG (0.69) ③HDL(0.52) SBP with FPG(0.43)

TG: triglycerides; WC: waist circumference; FPG: fasting plasma glucose; HDL: high-density lipoprotein; SBP: systolic blood pressure