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Accuracy of body mass index compared to whole-body dual energy X-ray absorptiometry in diagnosing obesity in adults in the Eastern Province of Saudi Arabia: A cross-sectional study

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Abstract:

BACKGROUND: Obesity is a major health concern that requires accurate diagnosis and management. Body mass index (BMI) commonly used to diagnose obesity, has limitations in accurately assessing body fat. Body fat percentage (BF%) from whole-body dual energy X-ray absorptiometry (DEXA) scans is gaining popularity as a more accurate method in diagnosing obesity.

MATERIALS AND METHODS: This cross-sectional study included 319 adult patients who underwent whole-body DEXA scans in the Eastern Province of Saudi Arabia from May 2016 to December 2021 were recruited from three medical centers, where data for whole-body DEXA were available. Body fat percent was obtained from the whole-body DEXA scan reports and were compared to BMI to evaluate prevalence of obesity. Data was extracted by reviewing patients' records using a structured data collection tool. BMI was defined using WHO criteria, and diagnostic performance was assessed by estimating specificity, sensitivity, likelihood ratios, and predictive values, and by constructing receiver operating characteristic (ROC) curves for BMI to detect obesity by age group.

RESULTS: The gender-specific BF% cutoff points revealed a higher prevalence of obesity than BMI cutoff points. BMI misclassified 40.6% of participants, and optimal cutoff points yielding highest area under the curve were 24 kg/m^2 and 24.3 kg/m^2 for males and females, respectively.

CONCLUSION: The study underscores the importance of using accurate and comprehensive diagnostic tools such as whole-body DEXA scans to assess obesity.

Keywords:

Body mass index, obesity, whole-body dual energy X-ray absorptiometry scan

Introduction

Obesity and overweight are significant worldwide health problems, the prevalence of which is increasing rapidly in both advanced and developing countries.[1-3] The World Health Organization (WHO) has defined obesity as a condition of extreme accumulation of fat in the body. A body mass index (BMI) over 25 is considered overweight, and over 30 is obese.[1] Obesity is linked to a persistent low-grade inflammatory state and immune dysfunction, it is a chronic disease.[4,5] It is known that chronic inflammation disrupts homeostatic mechanisms, which in turn, causes metabolic disorders frequently

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linked to obesity.[5,6] It is a worldwide public health issue linked to significant health complications that could lead to coronary heart disease, stroke, and malignancies, all of which can cause premature death.[7] Obesity now ranks first as a cause of death worldwide.[8] Indeed, it is clear that the impacts of obesity may be physical and psychosocial.[9] It is essential to recognize obesity in patients as an ailment to be treated.[10]

Numerous anthropometric modalities are used to diagnose obesity. Body mass index (BMI) coined by Ancel Keys *et al.*, is measured as the weight of a person in kilograms divided by the height in square meters, and is the most frequently used.[11] Subsequently, some authors have noted that BMI is marginally better than a simple weight-to-height ratio.[12] Owing to its simplicity, BMI has been widely used in epidemiological studies and integrated into clinical settings. One crucial drawback of BMI is that weight as an index numerator fails to differentiate between lean and fat mass (FM).[13-15]

Despite the wide use of BMI for the screening of obesity in clinical practice, there is evidence that current BMI limits for obesity underrate body adiposity. A BMI equivalent to or over 30 can be correctly recognized as excess adiposity only 50% of the time, meaning that 50% of people with an increased body fat fraction will not be considered obese (unrecognized cases will generally be thin).[16] In addition, people with maintained muscle mass are more likely to be considered overweight since BMI calculations use total mass in the denominator. Moreover, BMI does not consider fat distribution. Individuals who have normal weight or are overweight but possess an unhealthy distribution of body fat will not be accurately recognized by BMI. The former individuals may be at higher risk for developing cardiovascular disorders and type 2 diabetes and face high mortality rates.[17]

In contrast, methods that accurately calculate body fat, including plethysmography of air displacement, dual-energy absorptiometry, hydrostatic weighing, isotopic dilution, and analyses of bioelectric impedance, are seldom used in clinical settings. The dual energy X-ray absorptiometry (DEXA) technique can evaluate both regional and overall body composition. The patient lies on a bed during the DEXA test as an X-ray beam runs from posterior to anterior direction to a detector. In comparison to the 4C model, the DEXA estimates of body FM in south Indian men and women had a mean inaccuracy of 1.6 kg.[18] Whole-body DEXA scans are considered a trustworthy and effective measure for the clinical assessment of Total of body fat percentage (%BF) in children and adult populations.[19] Whole-body DEXA scans guarantee an accurate evaluation of the three main body parts (FM, nonbone lean mass [LM], and bone mineral content) at the entire body and local levels and offers assessment of the quantity of visceral adipose tissue.[20, 21]

This study aims to evaluate the diagnostic accuracy of BMI in adult patients who underwent whole-body DEXA scans in the Eastern Province of Saudi Arabia between 2016 and 2021 and determine any age-or gender-specific differences in their diagnostic accuracy.

Materials and Methods

This retrospective cross-sectional study included all 319 patients who underwent whole body DEXA scans in all three medical centers which perform whole body DEXA scan in Eastern Province of Saudi Arabia. Ethical approval was obtained from the Institutional Review Board vide Letter No. IRB2020-01-426 dated 30/12/2020 with a waiver of informed consent since there was no direct relation with human subjects in this study.

Subjects who were at least 18 years old and had undergone whole-body DEXA as part of a screening or follow-up between May 2016 and December 2021 were included in the study. Subjects under 18 years were excluded. The study used body fat percentage (BF%) obtained from the whole-body DEXA scan reports as the gold standard for adiposity assessment, where values over 25% of men and 35% of women were considered obese. These rates were compared with BMI-based measurements of obesity (over 30 kg/m^2) to determine the accuracy of the latter. The subjects' lean body mass, FM, weight, and height were also extracted from the whole-body DEXA scan data reports to assess adiposity. The data were collected from subject records using a prestructured data extraction sheet to avoid data extraction errors and interrupter bias. The collected data included subjects' age, gender, and anthropometric measures (height in meters and weight in kilogram to measure BMI, LM, and FM). The data were presented in Excel worksheets and processed through statistical software for data analysis.

The data were reviewed for any missing values, coded, and analyzed using the Statistical Package for the Social Sciences software (IBM SPSS statistics for Windows, Version 22, IBM Corporation, Armonk, NY, USA). All statistical analyses were completed using two-tailed tests. A value of $P < 0.05$ was considered statistically significant. Descriptive statistics are presented using mean ± standard deviations for scale variables, while numbers and percentages are used to summarize categorical variables. The WHO standards were used to determine the diagnostic accuracy of BMI in identifying obesity using the standardized cutoff points, which defined overweight as a BMI of 25–29.9 kg/m^2 and obesity as a BMI ≥ 30 kg/m^2.[1] Diagnostic performance was assessed by estimating specificity, sensitivity, likelihood ratios, and predictive values, and by constructing receiver operating characteristic (ROC) curves for BMI to detect obesity by age group. A value of $P < 0.05$ was understood as statistically significant.

Results

The sample comprised 319 adult patients. Table 1 presents their age, BMI categories (51.4% were considered obese), and their obesity status as diagnosed by BF% detected by whole-body DEXA scan (92% were considered obese), distributed by gender. There was a significant difference between females and males in the distribution of BMI categories, with a higher prevalence of obesity in females than males (53.6% and 41.4%, respectively). In contrast, according to the whole-body DEXA scan measurements, the difference in the prevalence of obesity between females and males (93.5% and 86.2%, respectively) was not statistically significant.

For males in both age groups, significant positive moderate correlations were found between BMI and both BF% and LM. However, in females, there was a significant positive moderate correlation only in age <60 years. At the age of 60+, no significant correlation between BMI and BF% or LM was found [Table 2].

Table 1: Characteristics of patients undergone whole body dual energy X-ray absorptiometry scan

	Gender			*P*-value
	Male (*n*=58 *N* (%)	**Female (*n*=261 *N* (%)**	**Total *N* (%)**	
Age (years)				
<60	40 (69.0)	171 (65.5)	211 (66.1)	
60+	18 (31.0)	90 (34.5)	108 (33.9)	0.616
BMI (kg/m²)				
Underweight (<18.5)	-	8 (3.1)	8 (2.5)	
Normal (18.5–)	19 (32.8)	27 (10.3)	46 (14.4)	
Overweight (25–)	15 (25.9)	86 (33.0)	101 (31.7)	0.0001
Obese (30+)	24 (41.4)	140 (53.6)	164 (51.4)	
BF%				
Not obese	8 (13.8)	17 (6.5)	25 (7.8)	
Obese	50 (86.2)	244 (93.5)	294 (92.2)	0.062

BMI=Body mass index, BF%=Body fat percentage, LM=Lean mass

Table 2 also shows that with regard to the BF% classification of obesity, BMI diagnosis of obesity at 25+ kg/m^2 had higher sensitivity and accuracy than the use of a BMI of 30+ kg/m^2 for both genders and for

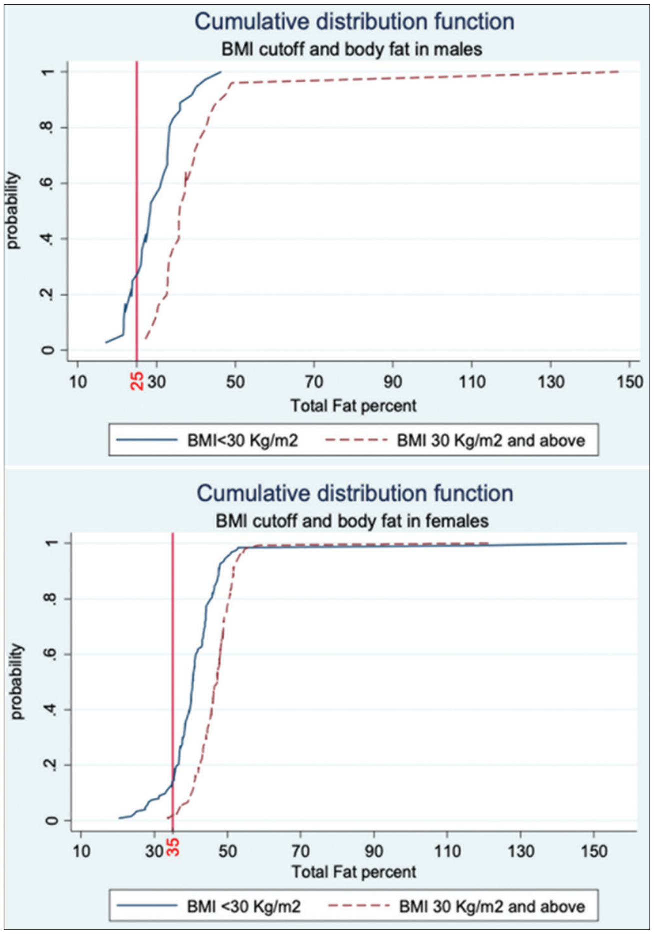

Figure 1: Cumulative distribution functions of percent body fat in males and females with participants of a body mass index ≥30 kg/m^2 and <30 kg/m^2. Vertical lines represent percent body fat cutoffs for males (25%) and females (35%). BMI: Body mass index

Table 2: Correlation of body mass index with body fat percentage and lean mass, and the diagnostic performance of body mass index using cutoffs of ≥25 kg/m² and ≥30 kg/m² by age group and sex

Gender Age (years)	BMI cutoff point for obesity												Correlation of BMI with BF% and LM	
	BMI 30 +kg/m²						BMI 25 +kg/m²						BF%	LM
	Sn	Sp	CC	PPV/PVN	LR+	LR–	Sn	Sp	CC	PPV/PVN	LR+	LR–	*r*, *P*-value	*r*, *P*-value
Male <60	52.9	100	60	100/27.3		0.47	79.4	100	82.5	100/46.2		0.21	0.73, <0.0001	0.628, <0.0001
60+	37.5	100	44.4	100/16.7		0.63	75	100	77.8	100/33.3		0.25	0.626, 0.005	0.491, 0.038
Female <60	53.5	85.7	56.1	97.7/14.1	3.75	0.54	90.4	64.29	88.3	96.6/37.5	2.5	0.15	0.358, <0.0001	0.507, <0.0001
60+	62.1	100	63.3	96.7/100		0.38	90.8	100	91.1	100/27.3		0.092	0.611, 0.122	−0.115, 0.282
Male	48	100	55.17	100/23.5		0.52	78	100	81	100/42.1		0.22	0.697, <0.0001	0.596, <0.0001
Female	56.6	88.24	58.62	98.6/12.4	4.81	0.49	90.57	70.58	89.3	97.79/34.29	3.08	0.134	0.247, <0.0001	0.055, 0.374

r=Pearson correlation coefficient, BMI=Body mass index, BF%=Body fat percentage, LM=Lean mass, Sn=Sensitivity, Sp=Specificity (recall), CC=Correctly classified/accuracy, PPV=Predicted value positive, PVN=Predicted value negative, LR=Likelihood ratio both age groups [detailed values are shown in Table 2]. Cumulative distribution functions are displayed in Figure 1. The distribution of those with a BMI <30 kg/m^2 by body fat is presented in Figure 2 in which the line indicates the standard body fat cutoff for obesity (25% for males and 35% for females). The curve of the cumulative distribution shows a steadier increase in females than in males.

Figure 3 and Table 3 present the diagnostic criteria of different BMI values to identify obesity in males and females. According to ROC, the cutoff point of 24.1 kg/m^2 and above was the value of the highest area under the curve (AUC), which is a measure of accuracy, in both males and females aged <60 years. For older participants, the cutoff points of 23.6 kg/m^2 and 24.3 kg/m^2 were associated with the highest AUC in males and females, respectively. Regardless of age, the optimal cutoff points that yielded the highest AUC were 24 kg/m^2 and 24.3 kg/m^2 for males and females, respectively. Generally, the confidence intervals of AUC were wider in males than in females, which indicates that the variability in BMI accuracy was greater in males than in females.

Discussion

The prevalence of obesity in the participants was 51.4% when a BMI cutoff point of ≥30 kg/m^2 in both genders was used; this rose to 92% when gender-specific BF% cutoff points (>25% in men and >35% in women) were used. The significant difference in obesity prevalence between BMI-and BF%-based assessments could be considered a rough indicator of the suboptimal accuracy of BMI. About 40.6% of the participants were misclassified as nonobese when BMI was used. This discrepancy could be partly explained by the proportion of included females in the sample (82%), as BMI used

Table 3: Body mass index values used to classify obesity in males and females and their diagnostic criteria

Gender Age (years)	AUC 95% CI	Criterion (BMI)	Sn	95% CI	Sp	95% CI	LR+	95% CI	LR–	95% CI
Male <60	0.936 (0.80–0.99)	>24.1©	88.24	72.5–96.7	100	54.1–100			0.12	0.047–0.30
		>24.7	82.35	65.5–93.2	100	54.1–100			0.18	0.085–0.36
		>24.8	79.41	62.1–91.3	100	54.1–100			0.21	0.11–0.40
		>26.1	76.47	58.8–89.3	100	54.1–100			0.24	0.13–0.43
		>27.1	70.59	52.5–84.9	100	54.1–100			0.29	0.17–0.50
60+	1 (0.815–1.0)	>23.6©	93.75	69.8–99.8	100	15.8–100			0.063	0.0094–0.42
		>24	87.5	61.7–98.4	100	15.8–100			0.13	0.034–0.46
		>24.2	81.25	54.4–96.0	100	15.8–100			0.19	0.068–0.52
		>24.6	75	47.6–92.7	100	15.8–100			0.25	0.11–0.58
		>26.2	62.5	35.4–84.8	100	15.8–100			0.38	0.20–0.71
Female <60	0.867 (0.81–0.914)	>24.1©	90.45	84.7–94.6	64.3	35.1–87.2	2.53	1.25–5.1	0.15	0.080–0.28
		>25.2	89.81	84.0–94.1	64.3	35.1–87.2	2.51	1.24–5.1	0.16	0.086–0.29
		>25.6	85.35	78.8–90.5	71.4	41.9–91.6	2.99	1.30–6.8	0.21	0.12–0.34
		>26	83.44	76.7–88.9	71.4	41.9–91.6	2.92	1.27–6.7	0.23	0.14–0.38
		>26.7	80.25	73.2–86.2	78.5	49.2–95.3	3.75	1.37–10.2	0.25	0.17–0.38
60+	0.992 (0.946–1.0)	>24.3©	90.8	82.7–95.9	100	29.2–100			0.092	0.048–0.18
		>25.5	89.66	81.3–95.2	100	29.2–100			0.1	0.056–0.19
		>25.6	87.36	78.5–93.5	100	29.2–100			0.13	0.073–0.22
		>25.9	86.21	77.1–92.7	100	29.2–100			0.14	0.082–0.23
		>26	80.46	70.6–88.2	100	29.2–100			0.2	0.13–0.30
Adult males	0.953 (0.86–0.99)	>24©	88	75.7–95.5	87.5	47.3–99.7	7.04	1.12–44.1	0.14	0.062–0.30
		>24.2	84	70.9–92.8	100	63.1–100			0.16	0.085–0.30
		>24.7	80	66.3–90.0	100	63.1–100			0.2	0.11–0.35
		>24.8	78	64.0–88.5	100	63.1–100			0.22	0.13–0.37
		>26.1	76	61.8–86.9	100	63.1–100			0.24	0.15–0.39
Adult females	0.897 (0.854–0.93)	>24.3©	90.57	86.2–93.9	70.6	44.0–89.7	3.08	1.47–6.4	0.13	0.081–0.22
		>25.2	90.16	85.7–93.6	70.6	44.0–89.7	3.07	1.47–6.4	0.14	0.086–0.23
		>25.5	87.3	82.5–91.2	70.6	44.0–89.7	2.97	1.42–6.2	0.18	0.11–0.28
		>26	82.38	77.0–86.9	76.4	50.1–93.2	3.5	1.48–8.2	0.23	0.16–0.34
		>26.7	80.33	74.8–85.1	82.3	56.6–96.2	4.55	1.63–12.7	0.24	0.17–0.33
		>27	77.87	72.1–82.9	82.3	56.6–96.2	4.41	1.58–12.3	0.27	0.19–0.37

BMI=Body mass index, BF%=Body fat percentage, LM=Lean mass, Sn=Sensitivity, Sp=Specificity (recall), CC=Correctly classified/accuracy, PPV=Predicted value positive, PVN=Predicted value negative, LR=Likelihood ratio, CI=Confidence interval, AUC=Area under the curve, ©BMI value of highest diagnostic accuracy

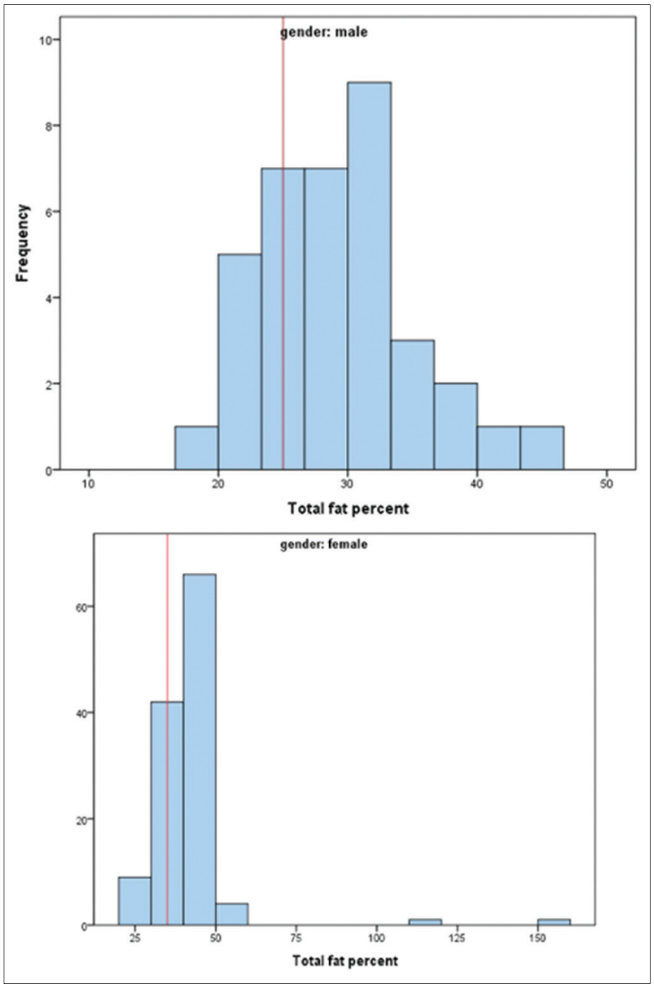

Figure 2: Variations in percent body fat in males and females in subjects with a body mass index < 30 kg/m^2. Line represents body fat cutoffs for each sex (≥25% in males; ≥35% in females)

only one gender-insensitive cutoff point for both males and females (≥30 kg/m^2).

BMI is frequently used to assess obesity in adults because of its simplicity, convenience, and cost-effectiveness. However, its accuracy is not consistent across different ages, genders, and ethnic groups.[22-25] BMI is considered a surrogate measure of adiposity, which can be accurately assessed through the measurement of body fat using such tools as whole-body DEXA scan.[26,27] Hence, in the present study, the diagnostic accuracy of BMI in identifying obesity was assessed using BF% as a reference standard. In a study of American women of reproductive age, 36.9% were identified as obese using a BMI cutoff point of ≥30 kg/m^2.[28] The remaining loss of accuracy could be attributed to the inherent nature of BMI as an overly simplistic assessment method. Despite this inaccuracy, in comparison with BF%, BMI is still considered a routine assessment method for obesity, particularly in primary healthcare settings.[29,30]

In another study of patients at King Faisal Specialist Hospital in Riyadh, 28.7% of males and 53.1% of females were found to be obese according to their BMI (≥30 kg/m^2).[31] In accord with the findings of the present study, the prevalence of obesity according to BF% was higher, at 83.9% and 97.3% in men and women, respectively.[31] In contrast, a cross-sectional study conducted of 530 healthy Saudi adults found a much lower prevalence of obesity, at 33.8% and 60% based on BMI and BF%, respectively.[32]

In a study in which whole-body DEXA scan was used as a routine assessment method for obesity in a female majority sample at a Manhattan clinic, the researchers found a similar percentage of misclassification of 39% when BMI was the basis of classifications.[33]

Although an expected low prevalence of obesity based on either BMI or BF% has been reported in Asian populations, similar correlation patterns between obesity measures have been identified. For instance, in Taiwan, the prevalence of obesity based on BMI was 27.3% and 14.8% in young women and men, respectively.[34] The correlation between BMI and BF% was very strong, with r = 0.91 and 0.87 in males and females, respectively.[34] The recommended BMI cutoff point for Asian population is much lower than for Saudis or Caucasians, at approximately 21 kg/m^2 in some studies.[24,35,36]

Unlike BF%, the present study found a significant difference in the distribution of BMI categories in males and females, with a higher prevalence of obesity in females than males (53.6% vs. 41.4%, respectively). There was also a significant gender difference in obesity prevalence in healthy Saudi adults based on BF% measurement.[32]

For males and females <60, there were significant positive moderate correlations between BMI and both BF% and LM (with r coefficients ranging from 0.49 to 0.73). A higher correlation between BMI and BF%, with r = 0.82, was found in healthy Saudi adults.[32]

Of females younger than 60 included in the study, significant positive moderate correlations were found between BMI and both BF% and LM, with r = 0.36 and 0.51, respectively. Similar results have been found in Syrian women younger than 60, with a significant positive moderate correlation between BMI and BF%.[37] In another study of younger females, however, age was not a significant factor in the prediction of BF%, either as a single predictor or as an interactive term with BMI.[28] Moreover, the BMI cutoff for young males who were physically active was adjusted to address the increased muscular component.[38]

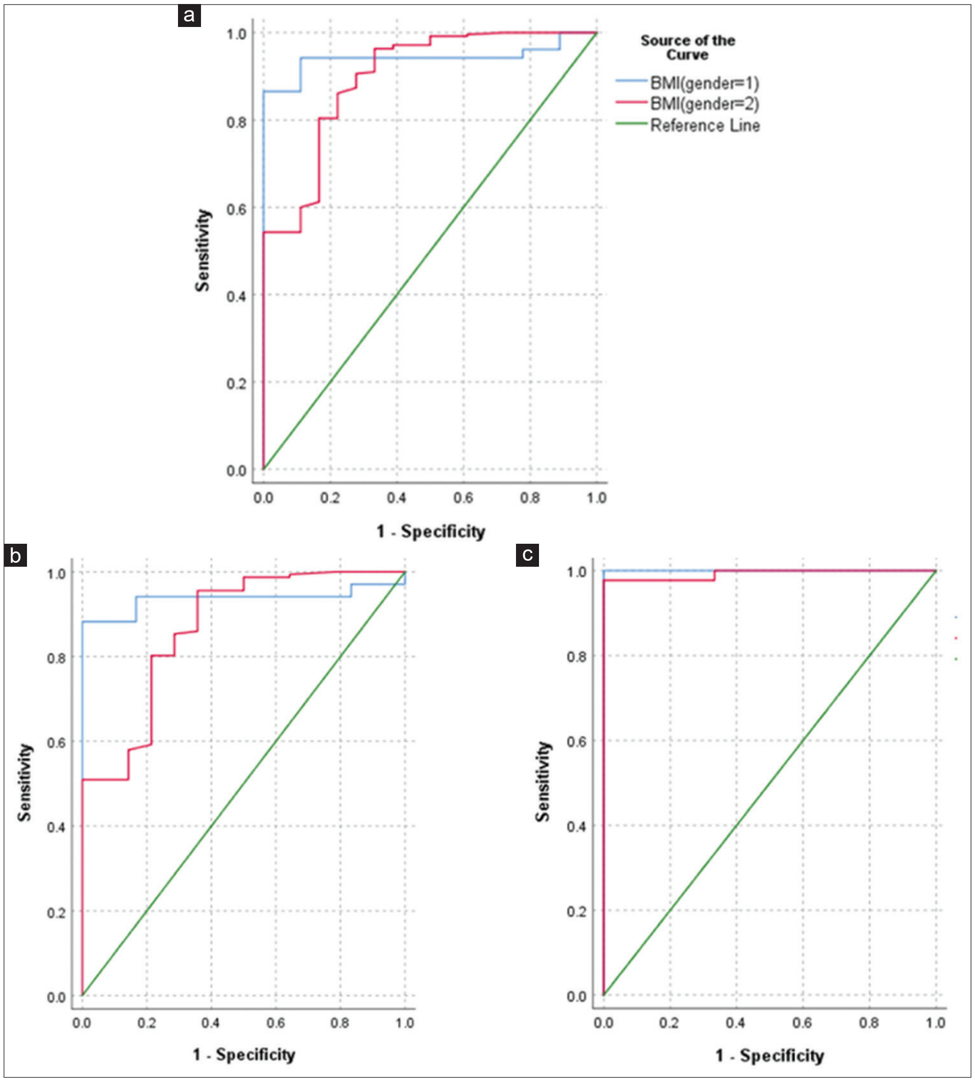

Figure 3: Receiver operating characteristic curves for BMI to detect BF%-defined obesity (≥25% in males; ≥35% in females). (a) all adults p=0.264, (b) adults<60years p=0.285, (c) adults 60+ years *P*=0.411. BMI: Body mass index

In the present study, regardless of age, the optimal cutoff points that yielded the highest AUC were 24 kg/m^2 and 24.3 kg/m^2 for males and females, respectively. Another study of healthy Saudi adults recommended a cutoff point of 26.6 kg/m^2 to obtain the best accuracy metrics.[32] Another study, conducted in King Faisal Hospital in Riyadh, asserts that the maximal BMI cutoff point should not exceed 27 for both sexes.[31] Hence, a lower BMI cutoff than the one recommended by the WHO (≥30 kg/m^2) is consistently indicated in the literature for healthy or diseased Saudi individuals.

In a study of American adults, a large gender difference was found in optimal cutoff points, at 28 kg/m^2 for males and 24 kg/m^2 for females.[33] Moreover, racial differences in optimal BMI cutoff points have been identified in American women of reproductive age, at 25.5, 28.7, and 26.2 kg/m^2 in white, black, and Hispanic females, respectively.[28]

A gender-stratified AUC was 0.953 for males versus 0.897 for females. Generally, the AUC confidence intervals were wider in males than in females, which indicates greater variability in BMI accuracy in males than in females. In contrast, the AUC of a sample of 1393 American adults was found to be higher in females than in males (0.917 vs. 0.872, respectively).[33] In healthy Saudi adults, the AUC has been found to be slightly higher in females than in males.[32] Generally, the accuracy of BMI in obesity classification, presented by AUC was high and sufficient to obtain clinically valid diagnoses.

The study has some limitations. The study population includes only patients from the Eastern Province. Larger scale studies involving patients from the entire country of Saudi Arabia or all gulf countries may be needed to consider ethnic and population differences. The current study could be expanded in future to incorporate additional factors that contribute to obesity and comorbidities into the whole-body DEXA scans findings. By incorporating multiple determinants, a regression analysis-based diagnostic model could be developed. This approach would allow for an assessment of the association between BMI and BF%, while adjusting for other crucial factors. By excluding insignificant determinants from the regression model, the most significant determinants for the estimation of optimal cutoff BMIs for various subgroups could be identified.

Conclusion

The sensitivity of the current cutoff point of BMI to screen for obesity is low, therefore, to improve the diagnostic accuracy of BMI as a screening tool to classify adiposity, a modification of the current cutoff points to make them age and gender specific is required.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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