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Accuracy of anthropometric parameters in predicting prediabetes among adolescents in Eastern Sudan: a community-based cross-sectional study

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Abstract

Introduction The global increase of prediabetes and diabetes in adolescents raises the issue of early prediction of this metabolic disorder via anthropometric parameters, especially in limited resources settings such as Sudan. However, the reliability of these anthropometric predictors is inconclusive. This study aimed to examine the association between anthropometric measures, including body mass index (BMI), hip circumference (HC), waist circumference (WC), waist-to-hip ratio (WHR), body roundness index (BRI), and a body shape index (ABSI), and prediabetes in adolescents in eastern Sudan.

Methods This community-based cross-sectional study was conducted among adolescents in Gadarif City, Eastern Sudan. A questionnaire was used to collect sociodemographic information. Anthropometric and glycated hemoglobin (HbA1c) were performed following the standard procedures. The Receiver Operating Characteristic (ROC) curve was generated. Multivariate binary regression analysis was performed.

Results Among the 401 adolescents, 186 (46.4%) were female, and 215 (53.6%) were male. The median (IQR) age was 14.1 (12.1–16.3) years. There was no correlation between BMI, WC, HC, WHR, BRI, ABSI, and HbA1c levels. Ninety-five (23.7%) adolescents were identified with prediabetes and 10 (2.5%) with diabetes. In univariate analysis, BRI (OR = 1.24, 95.0% CI = 1.01–1.52) and BMI (OR = 1.05, 95.0% CI = 1.01–1.10) were associated with prediabetes. The other anthropometrics and sociodemographic parameters were not associated with prediabetes. In multivariate analysis, BRI and BMI were not associated with prediabetes.

All the tested anthropometric parameters, WHR (AUC = 0.51, cutoff = 0.80, sensitivity = 0.69, specificity = 0.44), BRI (AUC = 0.57, cutoff = 1.77, sensitivity = 0.77, specificity = 0.42), ABSI (AUC = 0.51, cutoff = 0.14, sensitivity = 0.77, specificity = 0.31), BMI (AUC = 0.55, cutoff = 18.30 kg/m^2, sensitivity = 0.45, specificity = 0.67), HC (AUC = 0.54, cutoff = 75.75 cm, sensitivity = 0.73, specificity = 0.36), and WC (AUC = 0.55, cutoff = 66.63 cm, sensitivity = 0.49, specificity = 0.63), had poor reliability in detecting prediabetes in adolescents.

Conclusion This study demonstrated a lack of reliability of anthropometric parameters in predicting prediabetes among adolescents in eastern Sudan. Further extensive research is recommended in various regions of Sudan.

Keywords Anthropometric parameters, Adolescents, Age, Prediabetes, Diabetes, Sudan

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Introduction

The global increase of prediabetes and diabetes in adolescents, including in sub-Saharan Africa [1–5], raises the issue of early prediction of this metabolic disorder, especially in resource settings such as Sudan. Predicting prediabetes and diabetes in adolescents using anthropometric measurements is becoming an important public health issue, especially in countries where lifestyle changes and increasing obesity rates lead to metabolic health problems [6]. Anthropometric measures such as body mass index (BMI), hip circumference (HC), waist circumference (WC), waist-to-hip ratio (WHR), and body roundness index (BRI), are effective indicators of metabolic disorders, including prediabetes and diabetes among adolescents [7–11]. For instance, Pandey et al. reported that estimating BMI and WC can facilitate the early detection of prediabetes in adolescents, allowing for timely diagnostic evaluation and management [7]. On the other hand, other studies reported a lack of accuracy in anthropometrics in predicting prediabetes/diabetes [12]. For example, You et al. [12] reported that none of the assessed anthropometric indicators (BMI and WHR) demonstrated sufficient predictive accuracy for detecting elevated fasting blood glucose (FPG) or glycated hemoglobin (HbA1c) levels in children aged 7–9 years in Shenzhen, China. Consequently, their study does not support anthropometric screening for prediabetes in young children [12]. Although this research was conducted in a different context, it reinforces the notion that specific physical measurements can serve as early indicators of metabolic disorders, which applies to Sudanese adolescents as well. Such studies draw attention to the need for proactive screening measures in vulnerable populations. Furthermore, Elfaki et al.[13]examined the prevalence of metabolic syndrome among early adolescents in Khartoum State, Sudan. Their findings revealed significant correlations between obesity and the components of metabolic syndrome, suggesting that anthropometric measurements could be integral to identifying adolescents at risk for developing type 2 diabetes mellitus. The study highlights the alarming trend of rising obesity rates among adolescents and emphasizes the importance of incorporating regular anthropometric assessments in public health strategies. In summary, the literature indicates an unclear association between anthropometric parameters and predicting prediabetes and diabetes in adolescents. Given the unique health challenges faced in Sudan, further research focusing on these predictive measures is essential for developing effective screening and intervention strategies tailored to this population. Thus, this study aimed to examine the reliability of anthropometric measures, including BMI, HC, WC, WHR, BRI, and A body shape index (ABSI) in detecting prediabetes in adolescents in eastern Sudan.

Methods

Study design and setting

This community-based cross-sectional study included 401 adolescents, conducted in Gadarif city, the capital of Gadarif State in eastern Sudan, from August to October 2023. Gadarif State, located near the border with Ethiopia, had a total population of approximately 1,400,000, according to the 2008 census [14]. Among the 11 localities in Gadarif State, Gadarif locality, home to Gadarif City, is the most populous. The region has extensive agricultural land and hosts Sudan's largest rain-fed agrarian projects. It is also a multiethnic society comprising various tribal groups [15]. Additional details about the study area can be found in our earlier research [16]. This study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [17].

Sampling technique

Gadarif locality was selected from the 11 localities due to its diverse population, representing the entire state. Gadarif City is organized into four squares (Mourabas) containing 13 blocks (hays). Population data for each block were obtained from local authorities. Based on the World Health Organization's estimate that over 20% of the Sudanese population consists of adolescents, a sample of 20% adolescents from the total population in each block was expected [18]. Ultimately, 401 adolescents, including males and females, were included in the study. The number of adolescents sampled from each block was proportional to the estimated adolescent population, meaning blocks with larger populations contributed more to the sample. The designated sample size was selected within each block using a simple random sampling technique (lottery method) from household lists. If the household chosen had no adolescents, or the adolescents refused to participate or met any exclusion criteria, the next household was selected as a replacement. More details were provided in our previous published work [16, 19].

Inclusion and exclusion criteria

The inclusion criteria for the study were apparently healthy adolescents aged 10 to 19 years who resided in Gadarif city. "Healthy" refers to adolescents free from illness or visible disabilities at the time of data collection. Exclusion criteria included participants younger than 10 or older than 19 years, those who did not provide consent to participate, individuals with known diabetes mellitus, those who were unwell, and pregnant or lactating girls.

Sample size calculation

The OpenEpi Menu software was utilized to calculate the required sample size for the study[20]. A total of 401 adolescents were determined as the appropriate sample size for this study. We assumed that 15.0% of the adolescents would have prediabetes, as reported before [21] and anthropometrics measures would have a sensitivity of 90.0% to detect adolescent prediabetes. This sample size would have 80.0% power, a confidence interval (CI) of 95%, and a precision of 5% = 0.05).

Study variables and measures

The questionnaire was designed based on previous similar studies [7, 11, 12]. Sociodemographic data were collected, including age in years and sex (male or female), parent's educational level, and occupational status. The participants' anthropometric measurements were measured, including weight and height (later used to compute BMI), HC in cm, and WC in cm (later used to calculate WHR, BRI, and ABSI). The investigators trained five medical officers from both genders to gather the data. Once the participants and their guardians consented to participate in the study by signing an informed consent form, the medical officers approached the selected adolescents. They provided information about the study's aims and explained essential details, including the voluntary nature of participation, the right to withdraw at any time without giving a reason, and the measures in place to ensure privacy, safety, and confidentiality, such as the exclusion of personal identifiers of the participants during data collection. Anthropometric measurements and HbA1c levels were assessed using standard procedures outlined below. The anthropometric data were defined as secondary outcomes, while prediabetes/diabetes was defined as the primary outcome.

Anthropometric measurements

The weights of the adolescents were measured in kilograms (kg) following standard procedures, using well-calibrated scales that were reset to zero before each measurement. Weight was recorded to the nearest 100 g (g), with the adolescents standing still, arms at their sides, and without shoes or excess clothing. Height was measured to the nearest 0.1 cm while the adolescents stood upright against a wall with their feet together. BMI was computed by dividing weight (in kg) by height (in m^2) [22]. A non-stretchable tape was used to measure WC and HC. WC was measured at the midpoint between the lower edge of the last fixed rib and the upper edge of the iliac crest, while HC was measured at the widest point across the buttocks. Then, ABSI was calculated using the following formula:

$$ABSI = WC/BMI^{0.45} \times Height.^{0.55}$$

BRI was calculated as follows: $BRI = 364.2 - 365.5 \times \sqrt{} (1 - [WC/(2\pi)]^2 / [0.5 \times Height^2)$.

More details are available in our previous study [19].

Blood sample processing

For HbA1c analysis, 3 ml of blood was collected from each adolescent in an EDTA tube under aseptic conditions. The HbA1c levels were measured using an Ichroma machine following the manufacturer's instructions (Republic of Korea), as detailed in our previous study [16]. According to the American Diabetes Association (ADA) criteria, prediabetes was defined as an HbA1c level between 5.7% and 6.4%, while Type 2 Diabetes Mellitus was diagnosed with an HbA1c level of 6.5% or higher. HbA1c has been recognized as an effective diagnostic tool for prediabetes and diabetes in children and adolescents across various studies [23, 24]. Additionally, the ADA criteria for HbA1c measurement are particularly suitable for resource-limited settings like Sudan, where conducting Oral Glucose Tolerance Tests (OGTT) and FBG assessments can be challenging.

Statistical analysis

The data were analyzed using SPSS for Windows, version 22.0 (IBM Corp., NY, USA). The age and the tested anthropometric parameters were assessed for normality using the Shapiro–Wilk test and were found to be non-normally distributed. Consequently, these data were presented as medians with interquartile ranges (IQR) and compared between adolescents with and without prediabetes using the nonparametric Mann–Whitney U test. Spearman's correlation was utilized to examine the relationship between anthropometric parameters and HbA1c level, with the r-value (considered significant if $r > 0.5$) being used to determine correlations rather than the P value. A receiver operating characteristic (ROC) analysis was conducted to evaluate the anthropometric parameters' sensitivity, specificity, and cutoff points in detecting adolescent prediabetes. The area under the curve (AUC) values obtained were classified by their strength: an AUC of 1 indicates a perfectly accurate test, > 0.9 is excellent, 0.8–0.9 is good, 0.7–0.8 is fair, < 0.7 is considered poor, and < 0.5 indicates no discriminatory ability[25]. The optimal ROC parameters were identified based on the highest Youden's index (YI), calculated as YI = sensitivity + specificity − 1. Univariate analysis was performed to evaluate the associations between anthropometric measures, sociodemographic factors, and prediabetes. Variables with $P < 0.020$ in univariate analysis were shifted to the multivariate analysis to assess the confounders. The adjusted odd ratios (aOR) and 95.0 confidence interval were calculated, and $P < 0.05$ was considered statistically significant.

Table 1 The characteristics and anthropometric profile of the adolescents in Eastern Sudan, 2023

Variable		Total ($n = 401$)
Frequency (percentage)		
Sex	Males	186 (46.4)
	Females	215(53.6)
Mothers' education	≥ Secondary	280(69.8)
	< Secondary	121(30.2)
Fathers' education	≥ Secondary	302(75.3)
	< Secondary	99(24.7)
Mothers' occupation	Housewife	328(81.8)
	Employed	73(18.2)
Fathers' occupation	Labourers	242(60.3)
	Skilled workers	159(39.7)
		Median (interquartile range)
Body roundness index		1.94(1.55− 2.44)
Waist-to-hip ratio		0.82(0.77–0.86
Body mass index		16.95(15.27–20.05)
A body shape index		0.14(0.13–0.15)
Hip circumference, cm		80.0 (72.5–88.63)
Waist circumference, cm		65.0(< *spanclass* =′ *convertEndash*′ > 59.87 − 70.75 < /*span* >)

Results

General characteristics

Among the 401 adolescents included in the study, 186 (46.4%) were females, and 215 (53.6%) were males. The median (IQR) age was 14.0 (12.1–16.2) years. Of the 401 adolescents, 280 (69.8%) and 302(75.3%) had educated mothers and fathers (≥ secondary), respectively. Only 73 (18.2%) of the adolescents' mothers were employed. Two hundred forty-two (60.3%) of the adolescents' fathers were laborers, and the rest 159 (39.7%) were skilled workers (Table 1).

There was no correlation between BMI, WC, HC, WHR, BRI, ABSI, and HbA1c levels (Table 2).

Factors associated with prediabetes

Ninety-five (23.7%) adolescents were identified with prediabetes and 10 (2.5%) with diabetes. The median (IQR) of the BRI was significantly higher in adolescents with prediabetes [210 (1.73–2.52) versus 1.90 (1.52–2.43), P = 0.023]. The median values for BMI, WC, HC, WHR, and ABSI did not differ between adolescents with and without prediabetes (Table 3).

Table 2 Spearman correlation between anthropometric measures and HbA1c level in adolescents in eastern Sudan, 2023

Variable	Glycated hemoglobin (HbA1c) level	
	R	P value
Waist-to-hip ratio	0.024	0.638
Body roundness index	0.041	0.409
A body shape index	0.028	0.576
Body mass index, kg/m^2	−0.004	0.932
Hip circumference, cm	0.026	0.607
Waist circumference, cm	0.054	0.285

In univariate analysis, BRI (OR = 1.24, 95.0% CI = 1.01–1.52) and BMI (OR = 1.05, 95.0% CI = 1.01–1.10) were associated with prediabetes. The other anthropometrics and sociodemographic parameters were not associated with prediabetes. In multivariate analysis, BRI and BMI were not associated with prediabetes (Table 4).

Among the tested anthropometric parameters, WHR (AUC = 0.51, cutoff = 0.80, sensitivity = 0.69, specificity = 0.44), BRI (AUC = 0.57, cutoff = 1.77, sensitivity = 0.77, specificity = 0.42), ABSI (AUC = 0.51, cutoff = 0.14, sensitivity = 0.77, specificity = 0.31), BMI (AUC = 0.55, cutoff = 18.30 kg/m^2, sensitivity = 0.45, specificity = 0.67), HC (AUC = 0.54, cutoff = 75.75 cm, sensitivity = 0.73, specificity = 0.36), and WC (AUC = 0.55, cutoff = 66.63 cm, sensitivity = 0.49, specificity = 0.63), the model failed to predict prediabetes in adolescents, (Table 5, Fig. 1).

Discussion

The findings of this study were that the tested anthropometric parameters, including BMI, WC, HC, WHR, BRI, and ABSI, were not reliable predictors of prediabetes in adolescents in eastern Sudan. Several previous studies similar to our study suggest that these anthropometric parameters may not be robust predictors of metabolic health in adolescents, highlighting the need

Table 3 Comparing the characteristics and anthropometric profile of the adolescents with and without prediabetes in Eastern Sudan, 2023

Variable		Adolescents with prediabetes (*n* = 95)	Adolescents without prediabetes/diabetes (*n* = 296)	P value
		Frequency (percentage)		
Sex	Males	46(48.4)	132(44.6)	0.228
	Females	49(51.6)	164(55.4)	
Mothers' education	≥ Secondary	66(69.5)	208(70.3)	0.745
	< Secondary	29(30.5)	88(29.7)	
Fathers' education	≥ Secondary	74(77.9)	221(74.7)	0.613
	< Secondary	21(22.1)	75(25.3)	
Mothers' occupation	Housewife	75(78.9)	245(82.8)	0.396
	Employed	20(21.1)	51(17.2)	
Fathers' occupation	Laborers	51(53.7)	183(61.8)	0.311
	Skilled workers	44(46.3)	113(38.2)	
		Median (interquartile range)		
Body roundness index		210(1.73–2.52)	1.90(1.52–2.43)	0.023
Waist-to-hip ratio		0.82(0.78–0.85)	0.82(0.78–0.86)	0.699
Body mass index		17.61 (15.59–21.24)	16.88(15.23–19.71	0.117
A body shape index		0.14(0.13–0.14)	0.14(0.13–0.15)	0.748
Hip circumference, cm		81.5(74.75–91.25)	79.5(72.5–88.4)	0.187
Waist circumference, cm		66.5(60.37–72.5)	64.0(59.5–70.5)	0.118

Table 4 Univariate and multivariate analysis of the factors associated with prediabetes in adolescents in eastern Sudan, 2023

Variable		Univariate analysis		Multivariate analysis	
		Odds ratio (95% confidence interval)	P value	Adjusted Odds ratio (95% confidence interval)	P value
Waist-to-hip ratio		0.71(0.04–13.45)	0.810		
Body roundness index		1.24 (1.01–1.52)	0.033	1.19 (0.78–1.83)	0.409
A body shape index		6.38(0.01–53.29)	0.847		
Body mass index, kg/m		1.05(1.01–1.10)	0.022	1.03(0.93–1.14)	0.514
Hip circumference, cm		1.01(0.99–1.02)	0.176	1.01(0.99–1.02)	0.296
Waist circumference, cm		1.01(0.99–1.04)	0.159	0.98(0.94–1.02)	0.369
Gender	Males	Reference			
	Females	0.85(0.54–1.36)	0.515		
Mothers' education	≥ Secondary	Reference			
	< Secondary	0.96(0.58–1.59)	0.883		
Fathers' education	≥ Secondary	Reference			
	< Secondary	1.19(0.68–2.07)	0.525		
Mothers' occupation	Employed	Reference			
	Housewife	1.28(0.71–2.28)	0.401		
Fathers' occupation	Skilled workers	Reference			
	Labourers	1.39(0.87–2.22)	0.260		

for more comprehensive assessment methods[12, 26, 27]. Several factors may explain the lack of predictive ability observed in the tested anthropometric measures. Among them, one limitation of anthropometric measures is their inability to accurately reflect body composition and fat distribution, which are critical factors in metabolic health. For instance, a study by Pankiv [28] indicates that while BMI can categorize adolescents into weight classes, it fails to differentiate between lean and fat mass. This limitation is

Table 5 Performance of anthropometric measures to prediabetes in adolescents in Eastern Sudan, 2023

Variable	The Area Under the Curve	95.0% Confidence Interval	Cut-Off Point	Sensitivity	Specificity	Youden's Index
Waist-to-hip ratio	0.51	0.44–0.57	0.80	0.69	0.44	0.13
Body roundness index	0.57	0.51–0.64	1.77	0.73	0.42	0.15
A body shape index	0.51	0.44–0.57	0.14	0.77	0.31	0.08
Body mass index, kg/m	0.55	0.48–0.62	18.30	0.45	0.67	0.12
Hip circumference, cm	0.54	0.47–0.61	75.75	0.73	0.36	0.09
Waist circumference, cm	0.55	0.49–0.61	66.63	0.49	0.63	0.12

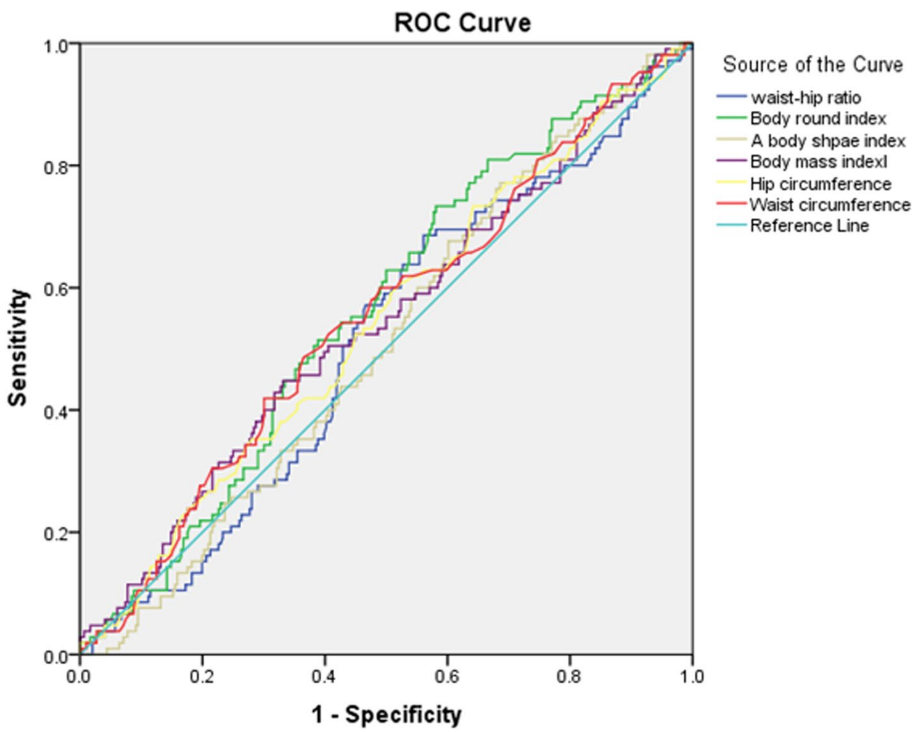

Fig. 1 Receiver operating characteristic of anthropometric measures to detect prediabetes in adolescents in Eastern Sudan, 2023

particularly significant in adolescents, where changes in body composition occur rapidly. For example, a study conducted by Guzmán-de la Garza et al.[26] highlights that anthropometric measurements often misclassify individuals, particularly during rapid growth and development in childhood and adolescence. Researchers suggest that relying solely on BMI may lead to misclassification of metabolic risk, as some adolescents with normal BMI may still exhibit adverse metabolic profiles [27]. Moreover, research conducted by Weiner et al. [27] emphasizes the complexity of predicting diabetes in adolescents based on anthropometric measures alone; their study found that while obesity is a strong risk factor for type 2 diabetes mellitus, the relationship is moderated by other variables such as genetics, lifestyle, and environmental factors; the authors argue that using anthropometric measures without considering these additional factors may overlook individuals at risk, leading to delayed diagnosis and intervention. Additionally, a previous study has demonstrated a limited correlation between anthropometric measurements and key glycemic markers such as FPG and HbA1c levels[29]. This weak association raises concerns about the utility of these anthropometric measures as reliable predictors of prediabetes. For instance, research conducted by Kim et al. [30] showed that while obesity is a known risk factor, traditional anthropometric indicators failed to capture the complexity of metabolic risk in adolescents; their findings revealed that traditional anthropometric indicators did not correlate well with glycemic status in adolescents.

The effectiveness of anthropometric measures varies across ethnic and cultural groups [31]. Certain populations may have distinct body composition profiles that do not align with existing BMI and WC thresholds. This variability can lead to underestimating or overestimating diabetes risk in diverse populations. Kim et al. [31] reported that the correlation between anthropometric measures and metabolic parameters was weaker in specific ethnic groups, indicating that reliance on these measures could overlook at-risk individuals. Xie et al. [11] found that the predictive value of anthropometric measures, such as WHR, WC, and BMI, varied by race and ethnicity for cardiometabolic conditions, including hyperglycemia. This underscores the need for tailored risk assessment strategies. This suggests that ethnic and cultural differences may influence the effectiveness of anthropometric measures as predictors of prediabetes and diabetes, further complicating their use as universal screening tools. Therefore, while anthropometric measures like BMI and WC are commonly used to assess the risk of prediabetes and diabetes in adolescents, they have notable limitations. These measures often fail to account for variations in body composition and do not adequately consider the multifaceted nature of diabetes risk. As such, there is a growing consensus that more comprehensive assessment strategies, including advanced imaging techniques and metabolic profiling, are needed to better identify adolescents at risk for prediabetes and diabetes [32].

Such contradictory results concerning the reliability of anthropometric parameters to predict the risk of prediabetes and diabetes in adolescents prompt researchers to evaluate the reliability of these measures within the local context to develop more accurate predictive tools. Additionally, the variability of these anthropometric measures and glycemic status across different ethnicities and cultural factors cannot be overlooked, even in the studied region [31, 33].

In contrast, other studies have reported that anthropometric parameters are reliable predictors of prediabetes and diabetes in adolescents [7, 11].

Strengths and limitations

To the best of our knowledge, this is the first comprehensive study to examine the predictive value of anthropometric measures for prediabetes among adolescents in Sudan. However, this study had some limitations that need to be noted. As this study was a cross-sectional study, it cannot establish causality. Therefore, a longitudinal study is necessary to evaluate the temporal relationship between anthropometric measures and the development of prediabetes. This study was conducted in only one region of Sudan (eastern Sudan); the findings may not be generalizable to other areas of Sudan with different ethnicities, cultural practices, and lifestyles. Also, there is a lack of longitudinal follow-up, as without longitudinal data, the study cannot assess changes in anthropometric measures or the progression of prediabetes over time. For example, DeLacey and Josefson recommended that more studies be conducted in longitudinal and diverse cohorts to determine which pediatric anthropometric measures most effectively predict adult insulin resistance [6]. Therefore, a large longitudinal study involving different regions of Sudan is recommended. A large study will provide the opportunity to analyze both diabetes and prediabetes; hence, subgroup analyses for each outcome (diabetes and prediabetes) will be conducted. This separate analysis for each group could yield more specific and clinically relevant insights.

Conclusions

Consistent with previous studies, this research demonstrated the lack of reliability of anthropometric parameters in predicting prediabetes among adolescents in eastern Sudan. Additionally, further extensive research is recommended in various regions of Sudan.

Clinical trial number

Not applicable.

Abbreviations

AOR	Adjusted odds ratio
BMI	Body mass index
WC	Waist circumference
WHtR	Waist-height ratio
HC	Hip circumference
WHR	Waist–hip ratio
RAAS	The renin–angiotensin–aldosterone system
CI	Confidence interval
SD	Standard deviation
IQR	Interquartile range
AUC	Area under the curve
ROC	Receiver-operating characteristic curve

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Authors' contributions

OAE and IA conceived the study; WMA, KAA, and IA supervised the work, guided the analysis, and critically reviewed the manuscript; OAE, WMA, AAH, and IA prepared the analysis plan, performed the data analysis, and wrote the first draft of the manuscript. All authors reviewed and approved the final manuscript

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Data availability

The datasets generated and/or analyzed during the current study are not publicly available (because the manuscript is still under peer review) but are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and Consent to Participate
This study was conducted following the principles outlined in the Declaration of Helsinki and adhered to good clinical research practices. Ethical approval was granted by the ethical research committee of the Faculty of Medicine at the University of Gadarif in Gadarif, eastern Sudan (Ref. #2023, 14). Written informed consent was obtained from all adolescents and their guardians.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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