Body Mass Index Versus Bioelectric Impedance Analysis for the Assessment of Obesity and Excess Body Fat among Adolescents in Abia State, Nigeria

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ABSTRACT

Background: *The body mass index (BMI) Z- score is widely used in children and adolescents to assess overweight/obesity, but does not determine the body fat percentage (BF%). The bioelectric impedance analysis (BIA) can be used to determine body fat, because it provides information on body mass composition.*

Objective: *To evaluate the ability of the BMI Z-scores to predict BF% in adolescents.*

Methods: *This cross sectional survey included 277 randomly selected adolescent (10-19 years) boys and girls in Umuahia Metropolis, Abia State, Nigeria. Height and weight were measured and BMI-for-age Z-scores calculated using WHO standards, while BF% was estimated using BIA. Sensitivity and specificity of BMI Z-score ≥+1.00 were calculated and Receiver Operating Characteristic (ROC) analysis and Area Under the Curve (AUC) were used to determine the diagnostic ability of BMI Z-score to predict BF%. Inferential statistics was performed with the Student's t - test, Pearson's correlation and Chi Square test.*

Results: *Overall, 4.7% of participants have excess BF% and 9% were obese using BIA and BMI Z-score, respectively. Mean BMI-Z score and BF% were -0.36±1.08 and 16.08±6.83%, respectively. Percent BF was significantly correlated with BMI Z-score (r= 0.626). The AUC was > 0.89 and >0.75 in girls and boys, respectively. Sensitivity was high (80% and 84%) and specificity was moderate (65% and 60%) in boys and girls, respectively.*

Conclusion: *The high sensitivity but moderate specificity in detecting excess BF% underscores the need for more direct measurement of body fat, to improve the diagnostic accuracy of overweight and obesity.*

Keyword: *Body fat percentage, body mass index, BIA, ROC, adolescents*

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INTRODUCTION

Adolescence is the phase of life between childhood and adulthood, from ages 10 to 19 (1). It is a critical position in the life cycle of human beings, characterized by an exceptionally rapid rate of growth (2). It is a unique stage of human development and an important time for laying the foundations of good health.

Obesity is a major risk factor for non-communicable diseases (3). Accurate, precise and reliable indicators are needed for proper assessment of excess adiposity and obesity. Anthropometric measurements are widely used, as they are inexpensive, rapid and non-invasive, however, these techniques have limited precision and/or specificity. The BMI, calculated as body weight (in kg) divided by the square of the height (in meters) is a commonly used indicator to assess overweight and obesity. However, its inherent limitation is the inability to adequately distinguish between fat mass (FM) and fat-free mass (FFM), both of which contribute to the BMI (4). BMI is regarded as a measure of excess weight rather that excess body fat, and changes with age, gender, and maturation in children (10). For the classification of weight status, different BMI criteria have been developed such as the World Health Organization (WHO) reference (5), the Centres for Disease Control and Prevention (CDC) (6), and the International Obesity Taskforce (IOTF) (7).

Currently, there is an increasing need for body composition analysis to monitor weight status and general health status of children and adolescents (8). Body composition can be estimated using a number of available techniques including under water weighing, dual-energy X-ray absorptiometry (DXA), total body potassium, air displacement plethysmography, bioelectrical impedance, and isotope dilution method (9). These techniques are however expensive, limited to laboratory settings, costly, and technically demanding especially when used at the population level (10). In the absence of a "gold standard" to measure body fat content especially in low and middle-income countries, other indirect methods (e.g. bioelectric impedance analysis, skinfold thickness, waist circumference measurements) have been used to define a proportion of participants as excessively fat on the basis of these measurements (11).

In the case of children, the interpretation of BMI is very difficult due to the rapid growth and development of the body (12). In order to compare a BMI value with the norm, it is recommended that BMI standard deviation Z-score, age, and gender be considered (13), thus other indicators have been recommended for comparison.

The BIA has been used to assess excess body fat. It is a safe and non-invasive technique that can be used in different population groups, making its use increasingly useful in nutrition research (14). BIA gives estimates of total body water (TBW), determined by impedance from which prediction models are used to estimate fat free mass (FFM). There is a great variety of BIA devices, which may be single or multi-frequency, or spectroscopic, and includes hand-to-hand, foot-to-foot and hand-to-foot systems (15). The principle of BIA is to determine the electric impedance of an electric current passing through the body (16). Hence, lean body mass and Fat Mass (FM) can be calculated from the difference in conductivity (16).

Receiver operating characteristic (ROC) are graphs used to assist with data interpretation. The ROC curve is used to assess the overall diagnostic performance of a test and to compare the performance of two or more diagnostic tests (17). It is also used to select an optimal cut off value for determining the presence or absence of a disease. Receiver operating characteristic (ROC) curve analysis have been used to assess the validity of anthropometric indicators (18).

In Africa, the prevalence of overweight in adolescence ranged from 7.7% in Western Africa to 16.1% in Eastern Africa, while obesity estimates ranged from 4.1% in Southern Africa to 9.6% in Eastern Africa (19). A study carried out among adolescents in Enugu State Nigeria using anthropometry reported 9.8% and 2.8% prevalence of overweight and obesity, in urban areas and 5.2% and 1.1% overweight and obesity prevalence in rural areas, respectively. While 5.6% and 1.8% overweight and obesity prevalence, respectively in urban setting and 4.3% overweight and 1.1% obesity prevalence in the rural area were reported using BIA (20).

Some studies have used BMI-based criteria to estimate overweight and obesity among children and adolescents in Africa (21). However, in

Nigeria, the diagnostic accuracy of the BMI Z-score to detect excess BF% among adolescents is sparse. Thus, the present study aimed to evaluate the diagnostic accuracy of the BMI Z-score in defining overweight and obesity using BIA as a criterion in a sample of Nigerian adolescents.

METHODS

Study design

Multistage random sampling method was used to select three urban public secondary schools in Umuahia Metropolis. A list of students in the selected schools formed the sampling frame for the target age group and sex. Adolescents that met the inclusion criteria were recruited to participate in the study after an informed oral consent was obtained from the guardian/parents.

Data Collection

Data collection was conducted during the school year between October, 2022 to February, 2023. The school Principal and adolescent's parents/guardians received verbal descriptions of the study and gave oral consent for their wards to participate in the study. Ten research assistants involving nutrition students were trained to assist in data collection. The research assistants were trained on how to measure weight, height, and how to use BIA device to assess body fat, as well as administer questionnaires.

Eligibility Criteria

Adolescents aged 10 to 19 years, attending government owned public secondary schools, and gave informed oral consent or assent for participation were included in the study, while those with ill health or were absent at two consecutive visits were excluded.

Ethical Approval

Research ethics committee of the Federal Medical Centre, Umuahia, Abia State gave ethical approval for the study (FMC/QEH/G.596/Vol.10/643)

Socio-demographic Questionnaire

Socio-demographic information, including data on personal information and family (i.e. education of the parents, employment), were collected by means of structured questionnaires.

Anthropometry and body composition measurement

The height of the adolescents was measured to the nearest 0.1 cm using a portable stadiometer, and weight to 0.1 kg in light clothing using a OMRON BF511 body composition scale (OMRON, Japan). From the height and weight measures, BMI was calculated for each adolescent as weight divided by square of height (kg/m^2) and then computed based on age- and sex-specific Z-score relative to the WHO BMI-for-age reference using the WHO Anthro Plus package (Stata Corp., College Station, United States of America). Obesity was defined as BMI z-score $\geq +2.00$ SD and overweight as BMI z-score $\geq +1.00$ SD (22).

The OMRON BF511 body composition scale (OMRON, Japan) was used to measure BF% based on the BIA, which, according to the technical specifications of the device, gives results with a precision of 0.1%. Before measurements, the previously obtained body height data, age and sex of the subjects were entered into the device using the device key. When the subject stands on the hand-to-foot BIA BF511 device, it sends an extremely weak electrical current of 50 kHz and less than 500 μA through the body to determine the amount of fat tissue. This weak electrical impedance, along with the height, weight, age and gender information generates results based on OMRON's data of body composition. The measurement was performed by the same study team members on the same respondents. Excessive BF% was classified using the McCarthy cut-offs as low, normal and high/very high for the target age group and sex (23).

Statistical Analysis

Data were analyzed using Statistical Package for Social Sciences (SPSS) version 20 package. The Student *t*-test was used to compare means of continuous variables, while the Chi-square test was used to compare categorical variables. Agreement between the results obtained with BIA and BMI-for-age Z-score was explored by Pearson correlation analysis. Receiver operating characteristic (ROC) analysis was carried out to evaluate the general performance of BMI Z-score in detecting excess BF%. ROC curve is a plot of the true positive rate (sensitivity) against the false positive rate (1-specificity) across a range of values from the diagnostic test. The decision threshold is the criterion value with the highest accuracy that maximizes the sum of the sensitivity and specificity (24). The areas under each ROC curve (AUC) and their 95% confidence intervals (CI) were estimated to compare the relative ability of BMI to estimate high percentage fat mass. AUC values range between 1 (one) is regarded as a perfect test and 0.5 as an inadequate test. BMI Z score was calculated using WHO Anthro plus software for each age and sex group.

RESULTS

Anthropometric and Body Composition Characteristics of Study Participants

Table I presents the mean anthropometric and body composition characteristics of the adolescents according to age and gender. The mean BF% (p=0.001), skeletal muscle (p=0.001) and height (p=0.007) were statistically significantly different (p<0.05) between boys and girls. In addition BMI Z-score (p=0.036), BF% (p=0.000), visceral fat (p=0.031), weight (p=0.001) and height (p=0.001) were statistically significantly different (P<0.05) between the ages (10-12, 13-15, >16 years).

In the general population of adolescents, the prevalence of excess %BF and obesity (BMI Z score) was 4.7%, and 9% as shown in Table 2. There was no significant difference in the BMI Z score and %body fat between boys and girls (p>0.05).

Table 3 represents the correlation between anthropometric and body composition variables. There was significant positive association (r=0.626) (p=<0.01) between BMI Z-score and BF% among the participants studied (boys; r=0.555 and girls; r=0.737).

Sensitivity and specificity of BMI Z score to identify the excess BF%

Table 3 shows that the sensitivity of BMI to identify the excess BF% was high (80% and 84% for boys and girls, respectively), but specificity was moderate (65% and 60%) in boys and girls, respectively.

Receiver Operating Characteristics for participants

Figs 1, 2 and 3 represents the ROC analysis for boys and girls. The AUC for prediction of excess % body fat was 0.82 (0.757–0.891) and 0.846 (0.781-0.910) for boys and girls, respectively. The AUC was similar in the overall sample 0.822 (0.774-0.870).

DISCUSSION

This study aimed to determine obesity and excess BF% prevalence in adolescent boys and girls using the WHO BMI for age Z-score and excess BF from BIA technique, respectively and determine the diagnostic accuracy of BMI Z score to detect excess BF. Percent BF values reported in this study is lower than reported among Indian boys (38.5%) and girls (54%) (6–17 years) (25) using McCarthy's cut-off, suggesting that adolescents in this study have lower BF% than their counterparts in India. The prevalence of excess BF was also lower than reported among Ghanaian children (8-11 years) (19). The significant positive correlation between the BMI Z-scores and BF% was similar to that reported in a Ghanaian study of 8-11 year old children (19) and those among Moroccan adolescents (22). Similarly, a Swiss study of school children aged 8–11 years showed high correlation particularly in the upper half of the BMI regardless of gender, suggesting that BMI is a good proxy for body fat in children with higher BMI. The authors thus concluded that BMI could be a good surrogate for body fat in pre-pubertal children (26).

The results showed that BMI Z-score had high sensitivity but moderate specificity for detecting excess BF% in both boys and girls. The AUC is a measure of the overall accuracy of a diagnostic test, with a value of 1 indicating perfect accuracy and 0.5 indicating no better accuracy than chance. The AUC values for BMI in this study were 0.824 for boys and 0.846 for girls, which are considered moderately accurate. This is consistent with other studies that have reported high AUC for BMI (27, 28). The AUC in this study revealed that the BMI Z-score was acceptable as a tool to diagnose excess BF%. However, it has been suggested that it would be more informative to have direct measures of body fatness rather than a crude proxy such as BMI in future epidemiological studies (29). Several factors are known to influence the diagnostic performance of BMI-based criteria to detect excess BF. These include the methods of body composition assessment, the cut-offs to define excess percent body fat in the evaluation of the BMI-criteria, and characteristics of the reference population such as ethnicity, maturity, and gender (30,31,32).

The high sensitivity of BMI Z-score to identify the excess BF% suggests that BMI is effective in identifying individuals who have excess body fatness. This level of accuracy is confirmed by the AUC 0.82 (0.757-0.891) and 0.846 (0.781-0.910) for boys and girls, respectively. However, the specificity of BMI in identifying excess body fatness was moderate, with a value of 65% for boys and 60% for girls. Specificity refers to the ability of a test to correctly identify those who do not have the condition being tested for. A low specificity means that there is a higher chance of false positives, meaning that some individuals without excess body fatness may be incorrectly identified as having it based on their BMI alone. Similar values of sensitivity of BMI Z-score to detect excess BF% was reported by Taylor (33) and Pandit *et al*. (25) on adolescents from New Zealand and India, respectively. A Brazilian study among 7-10 year olds reported similar high sensitivity (92.5 – 98.6%) and moderate specificity (75.9 – 85.0%) for both sexes (34). Another Brazilian study with a sample of 807 adolescents aged 11 to 17 years with Brazil-2006 classification for overweight as reference standard, reported sensitivities and specificities of 95.2 and 75.6% for boys; 86.8 and 88.0% for girls, respectively (35).

Contrary to this study, Karchynskaya *et al*. (27) in a study of 782 Slovakia adolescents found that the sensitivity of BMI was relatively low, ranging from 66% to 82%, while the specificity was high, ranging from 90% to 92%. Another study by Hammadi and Reilly (29) also reported that the sensitivity of BMI to identify excess body fat was moderately low (66%) compared to specificity which was high (96%). Low sensitivity and high specificity of BMI to detect excess body fat has been reported in some other studies. For instance, the overall sensitivity of WHO BMI was low (59.4%), while specificity was high (98.7%) in a study among Ghanaian children (8-11 years) (19). In another study of Kuwait adolescent girls and young women, the sensitivity of BMI to identify the excessively fat individuals was moderate (66%) but specificity was high (96%) (29).

Other studies have used other measures ranging from Mid Upper Arm Circumference, waist circumference and Fat Mass Index to assess body fatness in children and adolescents and they have consistently reported higher specificity compared to sensitivity of these measures to identify excess body fat in adolescents (28). The high sensitivity of BMI in this study to detect excess BF in adolescents could be attributed to use of BIA technique as compared to studies that used self-reported BMI and other methods (27). It is important to note that the accuracy of the BMI Z-score in identifying excess body fatness depends on the degree of body fatness. For children with higher levels of BF, the BMI is an effective indicator of excess adiposity. However, among relatively thin children, variations in BMI may be primarily due to fat-free mass, and may not be an accurate reflection of their body fatness. Furthermore, the accuracy of BMI as a tool to identify children with excess BF is influenced by selected cut-off points (36). In addition, predicting body fat levels also depends on race, gender, and age (37). While some studies have reported different results, this study suggests that BMI is a sensitive measure for identifying individuals with excess body fat, but it may not be as specific in actually identifying those without the disease. This thus highlights the importance of using additional measures, such as waist circumference, skinfold thickness, Fat Mass Index (FMI), Mid Upper arm circumference as well as more sophisticated techniques like DEXA, Deuterium oxide etc. to more accurately assess body fatness and associated health risks.

Table 1: Mean Anthropometric and body composition characteristics of the adolescents according to age and gender (mean ±SD)

Variables	Age group			P value	Sex		Total	P value
	10-12 (n=77)	**13-15 (n=165)**	**>16 (n=35)**		**Male (n=144)**	**Female (n=133)**		
BMI for age Z score	-0.62 ± 0.82	-0.29 ± 1.20	-0.36 ± 1.08	0.036*	-0.46 ± 1.17	-0.25 ± 0.96	-0.36 ± 1.08	0.120
Skeletal muscle %	36.05 ± 2.24	37.03 ± 4.03	36.98 ± 4.29	0.231	37.84 ± 4.97	35.57 ± 2.77	36.75 ± 4.21	0.000*
Visceral fat	4.00 ± 0.00	4.00 ± 0.00	3.91 ± 0.51	0.031*	3.98 ± 0.25	4.00 ± 0.00	3.99 ± 0.18	0.337
% body fat	13.45 ± 4.86	16.17 ± 6.78	21.49 ± 7.72	0.000*	14.77 ± 6.80	17.51 ± 6.61	16.09 ± 6.84	0.001*
Weight (kg)	35.46 ± 6.84	45.95 ± 12.66	54.23 ± 6.50	0.000*	42.95 ± 14.49	45.30 ± 9.05	44.08 ± 12.22	0.109
Height (cm)	146.00 ± 8.70	154.46 ± 8.57	160.42 ± 6.43	0.000*	151.40 ± 10.87	154.45 ± 7.64	152.86 ± 9.57	0.007*

*Significant at $p<0.05$, BMI=Body mass index

Table 2: Prevalence of Overweight, obesity and excess body fat percentage

Variables	Male		Female		Total		p-value
	F	%	F	%	F	%	
BMI for age Z score							0.880
Underweight (<-2SD)	10	6.9	8	6.0	18	6.5	
Normal (≥ -2 - ≤+1SD)	122	84.7	112	84.2	234	84.5	
Overweight/obesity (>+1SD)	12	8.3	13	9.8	25	9.0	
Body fat (%)							0.237
Low	61	42.4	63	47.4	124	44.8	
Normal	83	57.6	70	52.6	153	55.2	

* Significant at $p<0.05$

Table 3: Pearson's correlation between anthropometric and body composition variables

	weight (kg)	height (cm)	Body fat %	Visceral fat	Skeletal muscles (%)	BAZ
Weight (kg)	1	.723**	.527**	-.056	.123*	.788**
Height (cm)	.723**	1	.262**	-.099	.337**	.338**
Body fat %	.527**	.262**	1	.078	-.424**	.626**
Visceral fat	-.056	-.099	.078	1	-.175**	.002
Skeletal muscle (%)	.123*	.337**	-.424**	-.175**	1	-.078
BAZ	.788**	.338**	.626**	.002	-.078	1

**Correlation significant at 0.01 *Correlation significant at 0.05, BAZ=BMI for age Z score, RMR=resting metabolic rate

Table 3. Sensitivity and specificity BMI Z-score to identify excess BF%

	Sensitivity (95% CI)	Specificity (95% CI)	AUC
Boys	80.7%	65%	0.824 (0.757–0.891)
Girls	84.3%	60%	0.846 (0.781-0.910)
Total	81.7%	58%	0.822 (0.774-0.870)

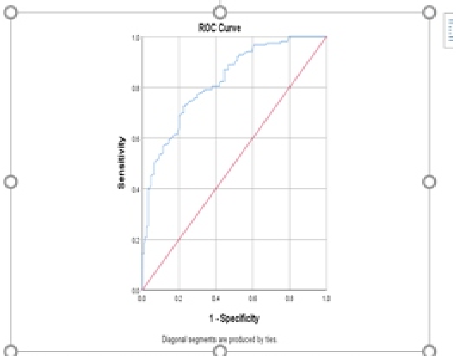

Fig 1: ROC for adolescent boys and girls

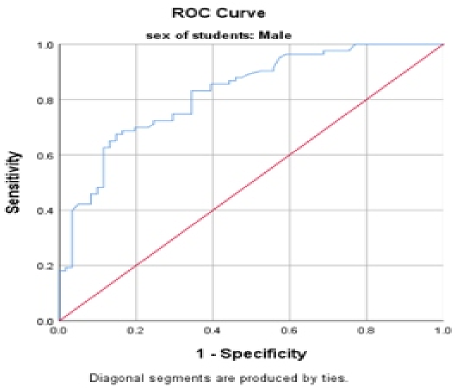

Fig 2: ROC for adolescent boys

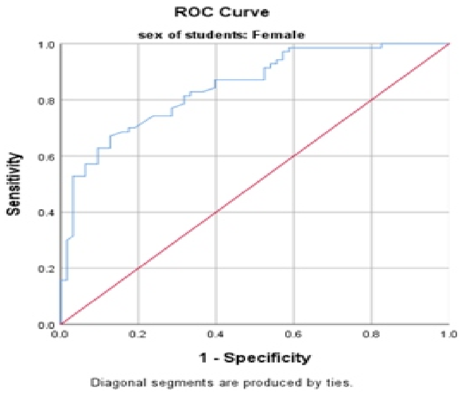

Fig 3: ROC for adolescent girls

Strengths and Limitations

The novelty of the study lies in the fact that to the best of our knowledge no previous studies on the accuracy of BMI Z-score to define excess BF% in adolescents (10-19 years) has been documented in Nigeria. The limitations are the relatively small sample size, and the use of only adolescents in an urban school setting, which limits generalisability. However, results of the present study can be used as baseline information for assessing usefulness of BMI Z-scores in predicting excess BF% in children and adolescents. Another limitation was that we did not use a "gold standard" such as DEXA or Deuterium oxide to measure body fat. It has however been reported that these methods are not practical for field studies (38), but the field technique BIA chosen in this study is practical for field studies and has acceptable accuracy (39).

CONCLUSION

The correlation between BMI Z-score and BF% in adolescents (10-19 years) indicates that BMI could be used as a proxy of body fat in adolescents for screening purposes, but it may not be as specific in actually identifying those without excess BF%. Thus, the high sensitivity and moderate specificity of the BMI Z-score in predicting the prevalence of excess BF% indicates the need for caution when applying it in epidemiological studies where obesity is used as either an exposure or an outcome variable. Hence, there is a need for more direct measurement of body fat, to improve the diagnostic accuracy in the use of BMI for assessment of overweight and obesity.

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