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Bioelectric impedance analysis versus prediction equations for percent body fat in healthy nigerian adults: correlation or conflict

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Abstract

Background and objective: There is dearth of studies on the validation of equations for predicting Percent Body Fat (PBF) in sub-Saharan Africa. This study compared Bio-electrical Impedance Analysis (BIA) estimated PBF and PBF predicted from equations.
Materials and Methods: 1,350 volunteers whose ages ranged between 18 and 65 years participated in this study. Anthropometric parameters and indices were assessed following standardized procedures. BIA was used to estimate PBF based on standard formulae. Deurenberg -#1, Deurenberg-#2, Gallagher and Jackson-Pollock equations were used to compute PBF. Data was analyzed using descriptive and inferential statistics. Alpha was set at 0.05.
Results: The mean values for PBF obtained from BIA, Deurenberg #1, Deurenberg #2, Gallagher, Jackson-Pollock and the present study's equations were 21.5±9.3, 11.5±6.76, 9.3±7.09, 9.4±7.38, and 7.9±7.87. BIA estimated PBF was significantly higher than predictive PBF ($p= 0.001$). BIA estimated PBF was significantly correlated with each of Deurenberg #1 ($r = 0.122$; $p = 0.001$); Deurenberg-#2 ($r=0.102$; $p=0.001$); Gallagher ($r=0.080$; $p=0.001$); Jackson-Pollock ($r=0.060$; $p=0.016$) and the present study's ($r=0.997$; $p=0.001$) equations. Socio-demographic and anthropometric variable except WHR were significantly correlated with BIA estimated PBF ($p<0.05$). Age, sex and BMI could significantly predict PBF at 68.3% level of variability.
Conclusion: There were significant inverse but weak relationships between BIA estimated PBF and each of Deurenberg-#1, Deurenberg-#2, Jackson-Pollock and Gallagher prediction equation. The BIA estimated PBF was significantly higher than predicted PBF. Socio-demographic and anthropometrical variables were significantly determinants of BIA estimated PBF. The prediction equation derived from this study provides an easy method of estimating PBF but not without significant error as indicated by level of variability in the standard error of measurement.

Key words: Percent body fat, bioelectric impedance analysis, prediction equation, Nigeria

Introduction

Literature is replete with a range of options including anthropometric, physical, chemical, and electrical means to evaluate body composition. Some of the body composition assessment methods include underwater weighing, dual-energy X-ray absorptiometry, magnetic resonance imaging, air-displacement plethysmography and skinfold thickness measurement [1-4]. A number of these methods have limited applicability and clinical usability as they are often difficult to administer, complex, costly, time consuming and requires specialized training and skills [1, 5, 6].

Accurate assessment of the presence of excessive body fat is believed to be the first step in initiating correct preventive and treatment programmes [3, 5]. Although, there is no ubiquitous method for the assessment of excessive body fat [1,3, 5], however, the classical variables of anthropometry such BMI is extensively used as simple index of body adiposity and surrogate measure of obesity in both clinical and research settings [6-10]. The drawbacks of this classical anthropometry approach included its inability to take into account factors such as frame size, muscular mass and distribution of body fat [8, 9, 11] and it does not fully adjust for the effects of morphological variations across ethnic and racial divides [12].

Consequently, other anthropometric measures of central adiposity such as waist circumference, waist-to–hip ratio, and waist-height-ratio; and the Bioelectrical Impedance Analysis (BIA) are the most preferred indicators of total body fatness in clinical practice and research [4, 5, 13-15]. The BIA is the method of body fat assessment that take advantage of the principle of body tissue conductivity of electricity based on the water and dissolved electrolyte content by using a small, alternating, single-frequency current that passes through electrodes applied to extremities of the body or contact sensors to measure impedance or opposition to the flow of the electric current through body tissues which can then be used to calculate an estimate of total body water [16, 17]. There is increasing studies on the psychometric properties of BIA in the assessment of body fat in health and disease across different population [18, 19].

Other than the anthropometrical and electrical methods, studies to develop and validate predictive models from the anthropometric [20, 21] and BIA [22-24] equations to predict body composition are populating [20-24]. Most of these equations are reported to have excellent psychometric properties and are recommended for use as indirect method of determining body composition in epidemiologic and clinical studies [20-24]. However, most of the equations have been shown to be dependent on factors not limited to age [25], gender [25] and ethnicity [26, 27]. Unfortunately, most of these prediction equations originated among Europeans, Caucasians and Asians who differ significantly in anthropometric and morphologic characteristics from sub-Saharan Africans. Despite, recommendations for validation of body composition estimates by BIA compared with the indirect method involving predictive formulae in order to establish the universality of their application [28], these equations have not been widely validated in sub-Saharan Africa. The objectives of this study was to compared BIA estimated Percent Body Fat (PBF) and PBF predicted from equations involving Deurenberg -#1, Deurenberg -#2, Gallagher and Jackson-Pollock. In addition, this study investigated the influence of demographic and anthropometric variables on BIA estimated PBF.

Materials and methods

The Ethical Review Committee of the Obafemi Awolowo University Teaching Hospitals Complex (OAUTHC), Ile-Ife, Nigeria gave approval for this study. Informed consent was obtained from every consecutive participant after the purpose of the study was fully disclosed. A total of 1,350 apparently healthy volunteers (778 males and 572 females) who were 18 years and older participated in this study.

The students' participants in this study were recruited randomly from the Obafemi Awolowo University (OAU), Ile-Ife, Nigeria using random sampling technique. Nine faculties including Administration, Basic Medical Sciences, Clinical Sciences, Law, Pharmacy, Sciences, Social Sciences and Technology were randomly selected among the thirteen faculties in the university using fishbowl technique. From the selected faculties, those that have only one degree awarding department were automatically included in the study while two departments each were randomly selected from those faculties with more than one degree awarding departments. The selected departments were Accounting, Biochemistry, Economics, Electrical Engineering, Law, Mechanical Engineering, Medicine, Medical Rehabilitation, Microbiology, Pharmacy, Psychology, and Sociology and Anthropology. The non-students' participants included consecutive academic, clinicians, administrative and support staffs of the OAU and OAUTHC respectively. The OAU academic and administrative staff that participated in this study were recruited from same departments as the students. The recruitment of staff from the OAUTHC was carried out separately. Staff were recruited from the departments of Medical Rehabilitation, Accounts, Maintenance and the Administration unit. Participants for the study were determined for eligibility via interview to ensure that they satisfied the selection criteria. Exclusion criteria for the study were a positive history of endocrinologic and/or metabolic condition; being pregnant; participation in high-intensity regular exercise or elites sports; and a presence of metallic implant or cardiac pacemaker in situ or other contraindications to the use of BIA.

Anthropometric parameters assessed in the study included height, weight, body mass index (BMI), waist circumference, hip circumference, waist-hip ratio and waist-height ratio. A height-meter (Seca Alpha Brand) calibrated from 0 to 200 cm was used to measure the height of each participant to the nearest 0.1 cm. The participants' heels, back and occiput touched the stadiometer scale with the participants looking straight ahead during measurement. Body weight in light clothes was measured to the nearest 0.1 kg using a weighing scale (Inter Ikea systems B.V. 1999) calibrated from 0 to 120kg with the participant in standing position with shoes off. Tape measure was used to measure the waist circumference of the participants around the body at the level of the umbilical cord with the participants asked to remove clothing materials around the body part. Tape measure was used to measure the participants' hip circumference at the level of the greater trochanter with the participants in minimal clothing materials around the part. Waist-to-hip ratios were obtained by dividing waist circumference by hip circumference while waist-to-height ratios were obtained by dividing waist circumference by height. Socio-demographic variables were obtained using a proforma.

Bioelectric Impedance Analysis (BIA) machine (Omron BF306; Model HBF-306-E CE, Japan) was used to estimate PBF. The participants were instructed to remove all metal objects, e.g. earrings, chains, wrist watches. They were instructed to stand erect with the two feet together and also to hold the machine in both hands such that the palms covered the metal surfaces of the instrument. They were then instructed to hold the arms straight at 90° of shoulder flexion. Dryness of the palms was ensured by using a dry towel for cleaning if the palms were wet, and by also making sure that the participants did not have hyperhidrosis. The height, weight, age and sex of the participants were fed into the micro data processor of the instrument, and the start button was switched on. The participants were then asked to stand still till a new set of data was displayed on the meter [29].

Predictive equations used to predict PBF in this study included.

- Deurenberg [7] -#1: (1.20 x BMI) + (0.23 x Age) - (10.8 x gender) - 5.4
- Deurenberg [8] -#2: (1.29 x BMI) + (0.20 x Age) – (11.4 x gender) – 8.0
- Gallagher [30]: (1.46 x BMI) + (0.14 x Age) - (11.6 x gender) - 10
- Jackson-Pollock [31, 32]: (1.61 x BMI) + (0.13 x Age) - (12.1 x gender) - 13.9

Data Analysis

The data was summarized using descriptive statistics of mean and standard deviation. Independent t-test was used to compare PBF between male and female participants. Pearson product moment correlation was used to determine the correlates of PBF. Scatter plot with linear curve estimation was use to depict the agreement between BIA estimated PBF and equations predicted PBF. Multiple regression analysis was used to develop a predictive model in this study. Data was completed using Statistical Package for Social Sciences (SPSS) software version 16. Alpha level was set at α = 0.05.

Results

The age range of the participants was between 18 and 65 years. Age and general characteristics of all the participants and by gender is presented in table 1.

Table 1: Age and general characteristics of all the participants and by gender

	Male	Female			
Variables	X±SD	X±SD	t-cal	p-value	All participants
Age (years)	24.1 ± 5.83	23.4 ± 5.91	2.350	0.615	23.8 ± 5.87
Height (m)	1.7 ± 0.08	1.6 ± 0.07	16.710	0.009	1.7 ± 0.09
Weight (Kg)	64.0 ± 8.46	61.1 ± 10.06	5.871	0.001	62.8 ± 9.28
BMI (Kg/m^2)	21.9 ± 3.05	22.8 ± 3.93	4.725	0.001	22.3 ± 3.48
PBF (BIA)	16.3 ± 6.96	28.6 ± 7.23	31.475	0.941	21.5 ± 9.35
WC (m)	0.7 ± 8.46	0.8 ± 9.45	2.003	0.196	0.78 ± 0.88
HC (m)	0.8 ± 9.90	0.9 ± 9.26	3.923	0.147	0.87 ± 0.98
WHR	0.9 ± 0.16	0.9 ± 0.12	4.240	0.009	0.9 ± 0.16

Key: BMI = body mass index; PBF = percent body fat; BIA = bioelectric impedance analysis; WC = waist circumference; HC = hip circumference; WHR = waist –hip-ratio.

The mean age, BMI, BIA estimated PBF, WC, HC, and WHR was 23.8±5.8 years, 22.3±3.48 Kg/m2, 21.5 ± 9.35, 0.78 ± 0.88, 0.87 ± 0.98 and 0.9 ± 0.16 respectively. The independent –test comparison showed that WC, HC and WHR of the male and female participants were comparable (p>0.05). However, the females had significantly higher BMI than the male counterparts (p<0.05).

Each of the scatter plots showed direct relationship between the PBF and the predictive equations (figures 1, 2, 3, 4 and 5). Scatter plots were used to highlight the linearity of the Cartesian co -ordinates that formed the variables that were correlated. Pearson product moment correlation analysis incorporated into the figures showed a significant correlation between BIA estimated PBF and each of Deurenberg (BIA) (r = 0.122, p < 0.001); Deurenberg (BMI) (r = 0.102, p < 0.001); Gallagher (r = 0.080, p < 0.001); Jackson-Pollock (r = 0.060, p < 0.016) and the present study's (r=0.997; p=0.001) equations. Table 2 shows the Pearson product moment correlation between BIA estimated PBF and participants general characteristics. Socio-demographic and anthropometric variable except WHR were significantly correlated with BIA estimated PBF (p<0.05).

Table 3 showed the One-Way ANOVA comparison of the BIA estimated PBF and the predictive equations. From the result, a significant difference was found in the F-ratio. Post-Hoc analysis was used to elucidate where the difference found in

Table 2: Correlation matrix between PBF and each of age and selected anthropometric parameters

	Age	HT	WT	BMI	PBF (BIA)	WC	HC	WHR
Age	1							
	0.019							
HT	0.027	1						
	0.329	0.001						
WT	0.278	0.396	1					
	0.001	0.001	0.001					
BMI	0.243	0.362	0.688	1				
	0.001	0.001	0.001	0.001				
PBF (BIA)	0.172	0.446	0.292	0.580	1			
	0.001	0.001	0.001	0.001	0.001			
WC	0.027	0.116	0.350	0.216	0.121	1		
	0.544	0.008	0.001	0.001	0.006	0.153		
HC	0.133	0.128	0.297	0.170	0.203	0.063	1	
	0.002	0.004	0.001	0.001	0.001	0.153	0.001	
WHR	0.092	0.021	0.028	0.033	0.058	0.648	0.706	1
	0.037	0.637	0.521	0.449	0.188	0.001	0.001	0.001

HT = height; WT = weight; BMI = body mass index; PBF = percent body fat; BIA = bioelectric impedance analysis; WC = waist circumference; HC = hip circumference; WHR = waist-hip-ratio.

the F-ratio lie. The result showed that BIA estimated PBF was significantly higher ($p<0.05$) than the values obtained from the predictive equations. No significant difference was found in the PBF values estimated using Deurenberg and Gallagher equations (9.3±7.09 vs. 9.4±7.38; $p>0.05$).

Table 3: Comparison of PBF estimated using BIA and Prediction Equations

Variable	BIA X ± SD	DE -#1 X ± SD	DE -#2 X ± SD	GE X ± SD	PE X ± SD	PSE X± SD	F-ratio	p-value
PBF	21.5±9.3[a]	11.5±6.76[b]	9.3±7.09[c]	9.4±7.38[c]	7.9±7.87[d]	10.54±6.94[b]	2527.3	0.001

Superscript ([a, b, c, d]) - For a particular variable, mode means with different superscripts are significantly ($p<0.05$) different. Mode means with the same superscript are not significantly ($p>0.05$) different.
BIA = Bioelectric Impedance Analysis; Deurenberg-#1 Equation; Deurenberg-#2 Equation; Gallagher Equation; Jackson-Pollock Equation; PBF = Percent Body Fat; PSE = The Present Study Equation

Multiple regression model was used to develop a predictive equation from this study. From this study, Age, Sex and BMI were significant predictors of PBF. The regression equation for predicting PBF is - Y= B0 + B1 x 1 + B2 x 2 + B3 x 3, Where Y is PBF; B0 is a constant; B1-B3 are co-efficient of the independent variables. Y= -26.960 + (0.148 x 1) + (11.267x 2) + (1.296 x 3). Y= -26.960 + 0.148 (Age) + 22.534 (Sex) + 3.888(BMI). The level of variability for the prediction equation was 68.3% (i.e. R^2 =0.683).

Discussion

This study compared BIA estimated PBF and PBF predicted from equations involving Deurenberg (BIA), Deurenberg (BMI), Gallagher and Jackson-Pollock. The study found that BIA estimated PBF was significantly higher than equation predicted PBF. It was found that the Jackson-Pollock prediction equation yielded the least PBF mean value. Mazariegos et al [33] in a similar study submitted that the Jackson-Pollock prediction equation has a tendency to underestimate body fat. Overall, this study showed that predicted PBF where significantly lower than BIA estimated PBF. Similar findings have been reported in some other studies [34-37].

Kupper et al [35] reported that prediction equations generally underestimate PBF especially in females than males. The validity of prediction equations has been reported to be different among ethnic groups [38-40]. Therefore, it has been reported that use and applicability of prediction formulae developed in other populations is limited in other ethnic groups [26, 27, 41]. The differences observed between estimated and predicted PBF could be due in part to variation in pattern of fat distribution in the population from which the equations were developed [42], measurement error [35] and variation in body water [41].

There was significant correlation between BIA estimated PBF and each of the prediction equations. However, the relationships were somewhat weak and inverse. The negative and weak association of all prediction equations with BIA estimated PBF may indicate poor applicability of these prediction equations developed in other population to Nigerians. Furthermore, the inverse correlations observed between estimated and predicted PBF could indicate under-estimation of PBF using these equations. Ideally, a prediction equation should be sufficiently precise to detect changes in the predicted variables in PBF [43], however, these predictive equations are believed to be limited in their generalizability to other populations because of the potential influence of race [44], age [25] and ethnicity [26, 27, 41]. Nonetheless, the use of regression equations in estimating body fats is populating in literature. The findings of this study also show that predictive equations were directly and strongly correlated with one another. Strong significant correlation was observed between Deurenberg -#2 and Gallagher (r = 0.997); Gallagher and Jackson-Pollock (r = 0.999) and Deurenberg -#2 and Jackson -Pollock (r = 0.995) prediction equations.

The results of this study showed that there was a strong influence of sex on PBF. The finding of this study on higher PBF among females is largely consistent with literature [33, 35, 45, 46]. There was significant relationship between BIA estimated PBF and each of height, weight, BMI, waist circumference and hip circumference. However, there was no significant correlation between PBF and waist-hip -ratio. According to de Menezes et al [47], waist-hip -ratio demonstrated a weak and non-significant correlation with PBF. Similar studies have suggested that waist-hip-ratio is not a strong indicator of body fat [47.48]. On the other hand, waist circumference correlated moderately and significantly with PBF in this study. Freitas et al [49] described waist circumference as the best anthropometric index for diagnosing adiposity. This study showed that there was a strong relationship between age and PBF. This agreed with the outcome of a study by Meeuwsen et al [50] where it was discovered that measures of adiposity increases with age. However, this influence of age on body adiposity as observed in this study was more pronounced in females than in males corroborating the findings of Meeuwsen et al [50]. Several other previous studies have come up with similar findings [51-54].

This study is an important investigation into the applicability of the prediction equations as an indirect methods for body composition assessment among Nigerian adult populations. However, the results of this study implicate that foreign prediction equations should be used with caution as they may potentially under-estimate PBF. This submission was hinged on the strength of correlation between BIA estimated PBF and the predicted PBF from the equation developed from this study. The present study does not assume that the BIA perfectly estimates body fats. As some studies have reported underestimation of body fat using BIA as compared with other methods such as skinfold thickness, Dual-energy X-Ray Absorptiometry (DXA) [1-4]. The underestimation of body fats by BIA has been implicated on anthropometric and morphological disproportion in body segments [20-22], in relation to body water to total body impedance [55]. Therefore, if BIA under-estimates body fats as reported in literature, prediction equations seem to under-estimates much more. However, a potential limitation of this study is the heterogeneity of its samples as the volunteers were screened on the basis of being lean or obese even though such participants were few in this study.

Conclusion

There were significant inverse but weak relationships between BIA estimated PBF and each of Deurenberg-#1, Deurenberg-#2, Jackson-Pollock and Gallagher prediction equation. The BIA estimated PBF was significantly higher than predicted PBF. Socio-demographic and anthropometrical variables were significantly determinants of BIA estimated PBF. The prediction equation derived from this study provides an easy method of estimating PBF but not without significant error as indicated by level of variability in the standard error of measurement.

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