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PREDICTION OF BODY FAT USING SEGMENTAL BODY COMPOSITION BY BIOELECTRICAL IMPEDANCE IN THE EVALUATION OF OBESITY

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ABSTRACT

One of the drawbacks of the most commonly used tool for obesity screening, body mass index (BMI) is its inaccuracy in assessing body fat. In order to address the issue associated with the aforementioned screening tool; this study aims at predicting body fat percentage (%BF) using segmental body composition variables measured by bioelectrical impedance analysis (BIA). A total of ninety women between the age group of 20 to 75 years participated in the study. From the women who partook in the study %BF, regional (arm, leg, trunk) fat distribution parameters and bioelectrical impedance variables were measured using multifrequency BIA. Pearson's correlation was applied onto the obtained measurement data and was found that BMI and %BF were significantly correlated (r=0.952). Substantiated by the high value of correlation, %BF cut-off values for corresponding BMI cut off values recommended by WHO were calculated and obesity was evaluated for the population under study. Regression equations from the best model (r^2=0.97) was used to predict %BF values for the subjects. Receiver Operating Curves (ROC) analysis was executed to evaluate the ability of predicted %BF values to distinguish between obesity and non-obesity. With the help of the analyses that were performed it was inferred that the predicted %BF was able to distinguish obesity clearly with sensitivity being 95.5% and specificity being 97.7%, the Area Under the Curve (AUC) was found to be 0.997. Corroborated by the high levels of sensitivity, specificity and AUC obtained from the analysis, the %BF computed from the segmental BIA variables can be used as an additional tool for screening population for obesity.

Keywords: obesity, bioimpedance analysis, BMI, body fat percentage, segmental body composition.

1. INTRODUCTION

The increasing incidence of obesity in all parts of the world has led to an increased need to identify obesity with a practical and clinically approachable method. The precise evaluation of obesity has become remarkably important due to the health threats posed by surfeit adiposity. Obesity is allied with increased occurrence of cardiovascular disease, diabetes, sleep apnea, degenerative joint disease and site-specific cancers [1-6]. The presence of obesity is most commonly addressed by BMI. However, the accuracy of body mass index (BMI) (kg/m^2) in estimating body fat still remains debated. World Health Organization (WHO) recommends the criteria to be BMI of >25kg/m^2 as overweight and >30 kg/m^2 as obesity irrespective of the gender in adults. BMI is a measure of excess body weight (kg) relative to body height (m) rather than excess body fat [7]. It is inefficient in distinguishing fat mass and lean mass. Additionally, the distribution of fat over the body is also not addressed. Also, the accuracy of BMI seems to be affected by ethnicity [8-10]. Hence, BMI classifications suggested for Asians by WHO was used in this study, which is as follows: 18.5 to 22.9 as normal; 23 to 24.9 as overweight and ≥25 as obese [11]. Direct measures of body fat like Dual Energy X-ray Absorptiometry (DXA), Under-Water Weighing (UWW) require complicated equipments and are costlier, difficult to access and not so easy. Hence Bioelectrical Impedance Analysis (BIA) is used in the estimation of body fat percentage (%BF), which is far easier, less expensive and more accessible method. BIA is non-invasive and also provides relatively accurate estimation of body composition [12]. Multifrequency BIA offers advantage of providing regional fat distribution and also the impedance values at various frequencies. Knowledge and implementation of segmental body composition are essential to ascertain health-related risk factors since regional fat distribution is a predictor of risk of cardiovascular disease and diabetes [13, 14]. Hence, this study aims to assess the regional fat distribution measurements as estimates of %BF in women.

2. MATERIALS AND METHODS

The study included 90 female participants and was carried out at the Department of BME, SRM University, Kattankulathur, Chennai, India. Adults above the age of 20 years were included. Those who were pregnant or had any kind of physical disease were excluded. Informed written consent was obtained from each participant. Confidentiality was maintained during the storage, retrieval and analysis of data. Body height was measured without shoes by using a stadiometer to the nearest 0.1cm. In order to compute Waist-to-hip ratio, waist and hip circumference were measured using non-stretchable measuring tape.

The multifrequency, hand-to-foot, 8-electrode BIA instrument (MC-980MA, Tanita Corp, Japan) was used to measure %BF, segmental fat distribution and bioimpedance measurements. As per the manufacturer's instruction manual the standard positioning of the subject was as follows: subject has to stand on the electrode panel with bare feet and hold the electrodes in both hands with the electrodes in contact with thumb and palm. During the measurement, the arms were hung down as in a natural standing position. It was ensured that no skin to skin contact was observed. A measurement current of 90µA or less at various frequencies such as 1 kHz, 5 kHz, 50 kHz, 250 kHz, 500 kHz, and 1000 kHz was used. Using this instrument the following variables were measured: a) %BF; b) Regional body composition: 1. Leg fat mass, 2. Leg Free Fat Mass (FFM) 3. Leg muscle mass, 4. Arm fat mass, 5. Arm FFM, 6. Arm muscle mass, 7. Trunk fat mass, 8. Trunk FFM, 9. Trunk muscle mass; c) Segmental bioelectrical impedance: 1. Arm resistance, 2. Arm reactance, 3. Arm phase angle, 4. Leg resistance, 5. Leg reactance, 6. Leg phase angle, 7. Trunk resistance, 8. Leg reactance, 9. Leg phase angle. This test took approximately 30 seconds.

Data analysis was done by IBM SPSS Statistics v21 (SPSS Inc, Chicago, USA) software. The mean and standard deviation (SD) for each parameter were calculated. Pearson's correlation was performed. Scatter plot demonstrating the relationship between BMI and % BF was plotted. Linear regression analysis was executed to evaluate the relationship between % BF and BMI. Using this equation, %BF values associated with WHO based BMI classifications were estimated. With the help of stepwise multiple regression, various estimates for %BF other than age and BMI was identified and an equation was framed for the prediction of %BF. Paired t test was performed to evaluate its efficiency by testing the null hypothesis that the difference between actual and predicted % BF has a mean value of zero. In this test, by comparing each subject's actual and predicted %BF, each subject is effectively used as their own control. Also Receiver Operating Characteristics (ROC) analysis was carried out. It examined the ability of predicted %BF value to discriminate obesity from non obesity. Obese women who are correctly classified as obese by predicted %BF represent true-positive cases, while obese subjects classified as non obese represent false-negative cases. Similarly non-obese women correctly classified as non-obese are represent true-negative cases, whereas non-obese subjects classified as obese represent false-positive cases.

The sensitivity of predicted %BF refers to the probability that it will classify a true obese subject as obese, whereas probability of classifying a truly non-obese subject as non-obese is termed as specificity. Sensitivity was plotted against 1-specificity as ROC graph. Area under the curve (AUC) reflects the overall accuracy of predicted % BF to evaluate obesity. The closer the AUC is to 1.0, the greater the chance that any given obese subject will have a higher %BF than that of any given non-obese subject. Conversely, if it is unable to distinguish between obese and non-obese, the AUC will be close to 0.5, and the ROC curve will approach a diagonal line [15].

3. RESULTS

Table-1 presents means and SDs of the baseline characteristics of all the subjects. The statistical correlation was computed between various parameters and %BF and is shown in Table-2. It was found that BMI was strongly significantly correlated with %BF (r=0.952). Also it was observed that resistance reactance values of various body segments also highly significantly correlated with %BF. Figure-1 illustrates the relationship between BMI and %BF and shows the resulting regression line [%BF=1.5052*BMI - 1.402]. This equation was used to estimate %BF values associated with WHO BMI classifications and the following was found: BMI (kg/m^2) of 18.5, 23 and 25 equals 26.4 % BF, 33.2 % BF and 36.2 % BF, respectively.

Table-1. Baseline characteristics of the study subjects.

Parameters	Female N=90
Age (years)	37.6 ± 15.1
Body Height (cm)	155.0 ± 6.5
Body Weight (kg)	60.6 ± 11.9
BMI (kg/m^2)	25.2 ± 4.9
Total body composition parameters	
%BF	36.6 ± 7.7
Regional body composition	
Leg Fat mass (kg)	4.2 ± 1.5
Leg FFM (kg)	7.0 ± 1.1
Leg muscle mass (kg)	6.6 ± 0.9
Arm Fat mass (kg)	0.9 ± 0.6
Arm FFM (kg)	1.8 ± 0.3
Arm muscle mass (kg)	1.7 ± 0.3
Trunk Fat mass (kg)	12.6 ± 5.4
Trunk FFM (kg)	20.1 ± 2.2
Trunk muscle mass (kg)	18.9 ± 1.9
Segmental Bioelectrical impedance measurements	
Resistance	
Arm (ohm)	411.7 ± 53.8
Leg (ohm)	277.9 ± 44.5
Trunk (ohm)	718.5 ± 94.8
Reactance	
Arm (ohm)	-41.1 ± 4.7
Leg (ohm)	-25.1 ± 4.7
Trunk (ohm)	-67.2 ± 8.5
Phase angle	
Arm	-5.8 ± 0.5
Leg	-5.2 ± 0.7
Trunk	-5.4 ± 0.5

BMI-Body Mass Index, FFM-Free Fat Mass, %BF-Body Fat Percentage.

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Table-2. Statistical correlation values with %BF.

	%BF (r)**
BMI	0.952
Leg fat mass	0.899
Leg FFM	0.604
Leg muscle mass	0.608
Arm fat mass	0.925
Arm FFM	0.758
Arm muscle mass	0.751
Trunk fat mass	0.957
Arm resistance	-0.453
Leg resistance	-0.750
Trunk resistance	-0.627
Arm reactance	0.430
Leg reactance	0.629
Trunk reactance	0.642

**p<0.01

Based on the calculated %BF cut-off values, 7.7% were underweight, 25.6% were within the healthy range, 15.6% were overweight and 51.1% were obese in the studied population.

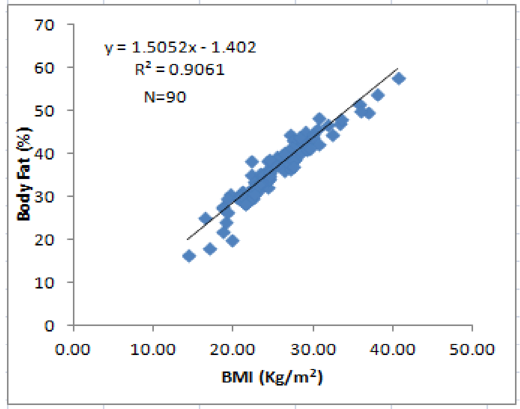

Figure-1. Scatter plot of %BF versus BMI.

Stepwise multiple regression analysis was performed to predict %BF by regional body composition parameters alone and that gave a square of the correlation coefficient (r^2) value of 0.95. When bioimpedance variables were added as predictors, r^2 increased to 0.97 ($p<0.01$). But when only bioimpedance variables were used as predictors, r^2 was 0.61 only. This is presented in Table-3. The regression equation framed based on the best model (Model c) from Table-3 was used by us to predict %BF for all the studied subjects. [Predicted %BF = Constant + (a*Trunk fat mass) + (b*Trunk muscle mass) + (c*Trunk FFM) + (d*Arm fat mass) + (e*Leg fat mass) + (f*Leg muscle mass) + (g*Leg resistance); where a- g are coefficients mentioned in Table-3].

Table-3. Results of stepwise multiple regression with %BF as dependent variable.

	Coefficients	**Standard error**	**Significance**
Model - a R^2=0.951			
Constant	37.55	2.78	0.000
Trunk fat mass	1.40	0.041	0.000
Trunk muscle mass	-7.08	2.54	0.006
Trunk FFM	5.76	2.30	0.014
Model - b R^2=0.610			
Constant	95.85	7.87	0.000
Leg resistance	-0.14	0.012	0.000
Trunk phase angle	3.72	1.15	0.002
Model - c R^2=0.977			
Constant	52.32	3.32	0.000
Trunk fat mass	1.30	0.09	0.000
Trunk muscle mass	-5.84	1.94	0.004
Trunk FFM	4.86	1.76	0.007
Arm fat mass	-8.45	1.25	0.000
Leg fat mass	4.16	0.46	0.000
Leg muscle mass	-2.74	0.32	0.000
Leg Resistance	-0.036	0.01	0.000

Dependent variable: %BF

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Paired t - test was performed to check the null hypothesis (no difference between observed and predicted %BF values). The significance was found to be 0.978 ($p>0.05$) and hence the null hypothesis was retained, implying that observed and predicted %BF are similar and correlating. The result of this is shown in Table-4. Figure-2 depicts the correlation between them.

Table-4. Results of paired samples t-test.

	t	Correlation	Sig (2-tailed)
Pair: Observed %BF- Predicted %BF	0.027	0.989**	0.978

** Correlation significant at 0.01 level

ROC analysis was done to examine the ability of predicted %BF to distinguish obesity from non-obesity using ≥ 36.2% BF as the criterion value for obesity. The ROC curve is depicted in Figure-2. The sensitivity and specificity of 95.7% and 97.7% respectively correspond to the cut-off value of 35.5%BF. This implies that the predicted %BF would classify a subject as obese 95.7% of the time when the subject is truly obese but will misclassify them as obese 4.3% of the time. The AUC value was 0.97. The 95% confidence interval was 0.991 to 1.000. The lower limit is quite high and indicates good diagnostic performance of the predicted %BF.

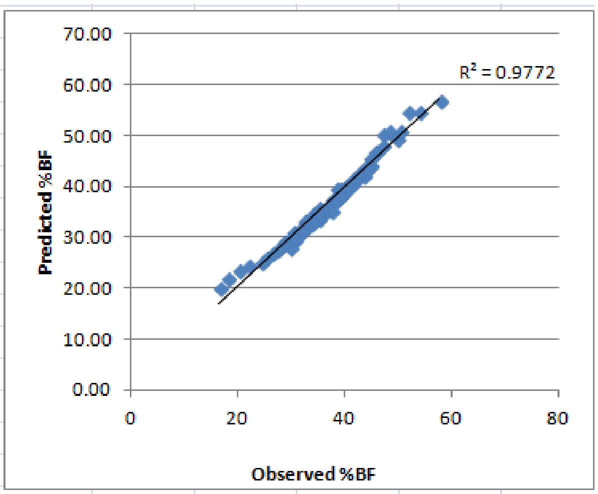

Figure-2. Scatter plot of observed %BF versus predicted % BF.

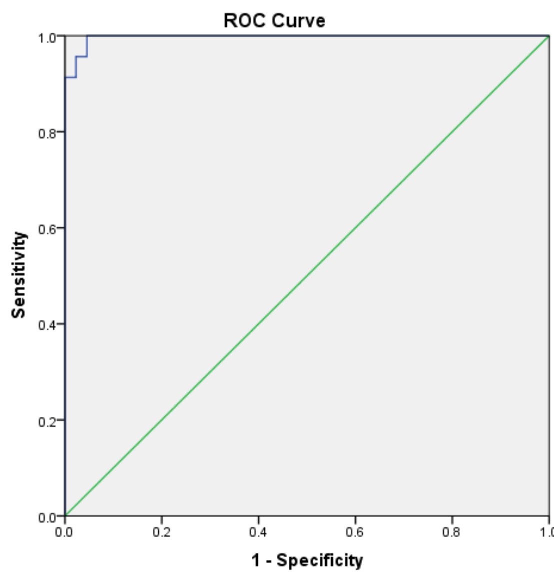

Figure-3. ROC curve of predicted %BF versus Obesity classification by %BF corresponding to WHO based BMI cut-off values.

4. DISCUSSIONS

Employing BMI as a surrogate for body composition has shown various limitations [16-19]. These studies expound that adjusting one's body weight for height may not succumb to consistent body fatness as anticipated. Hence, two persons having same BMI may differ in their fat level, particularly when they are from different ethnicity or age. In a study, it was observed that the relationship between % BF and BMI vary among ethnic groups [16]. Hence the relationship was evaluated in this study group and the corresponding % BF values were used for obesity classification. Several studies addressed the debate of validity of multifrequency segmental bioimpedance method to estimate % BF [20, 21]. Shafer *et al*, 2009, compared body composition estimates using multifrequency BIA with DXA in normal healthy adults and concluded that it is a valid method to estimate %BF in adults. But they have utilized only the resistance and reactance values of various segment of the body in % BF estimation rather than the segmental body composition. Demura et al, 2004, compared the accuracy of estimating % BF among three BIA devices with DXA and hydrostating weighing methods as references. They suggest that accuracies of estimating %BF depend on the accuracies of the regression equation and found that multifrequency BIA is superior to other BIA devices and the estimation error was least. Similar to the previous study, they have also considered only the segmental impedances instead of segmental composition. Earlier studies have framed prediction formulas for % BF based on BMI [22, 23]. Both these studies include BMI, age and sex in their equations to predict %BF measured by densitometry method. In this study, %BF was predicted using an equation with segmental body composition variables as predictors instead of BMI. Hence this is unbound by the effects of BMI or age. Also this study addresses the segmental distribution of fatness in body. From the regression model it can be suggested that trunk segment of the body (r^2=0.95) proves to be more accurate description of %BF. Several studies have investigated the segmental bioelectric impedance analysis for the estimation of whole body composition [24-27]. One such study has revealed that body cell mass can be assessed with more accuracy with segmental BIA in malnourished patients [27]. Therefore, segmental body composition studies prove to be a good estimate of whole body fatness.

This study concludes that the use of segmental BIA variables in the prediction of %BF aids in improved evaluation of obesity. The limitations of this study include no larger set of data and also the assessment of obesity in women alone.

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