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An Optimal Method for Measuring Body Fat in Overweight Individuals in Clinical Practice

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Abstract

Background: Excess body fat is associated with increased morbidity and mortality. Accordingly, it is important to choose reliable, simple and straightforward methods for measuring body composition in clinical practice. The aim of this study was to verify the concordance between body composition obtained by Skinfold Thickness (SF) and Bioelectrical Impedance Analysis (BIA) as well as their correlation with anthropometric indices.

Methods: The study was conducted from August 2007 to July 2009 among the adults and elderly patients (n = 85) receiving nutritional counseling at a primary health care unit in a Brazilian city. It was investigated all patients seen in the period. The following indices were used for comparison: Body Mass index (BMI), Waist Circumference (WC), Waist-Hip Ratio (WHR) and body composition evaluated by BIA and the sum of skinfolds (tricipital, bicipital, subscapular and suprailiac). The statistical analyses included the Kolmogorov-Smirnov test, Student's t-test, Wilcoxon signed-rank test, the Pearson and Spearman correlation tests and the Bland-Altman method. **Results:** Eighty-five individuals were evaluated, predominantly women (91.8%) and overweight individuals (92.8% adults, 89.7% elderly), with a mean age of 51.8 ± 13.0 years (22;85). The percentage of body fat estimated by SF was significantly higher than that estimated by BIA (42.8%; 95% CI: 12.6-49.2 vs. 40.4%; 95% CI: 21.0-51.2; p<0.001). However, a moderate correlation (r = 0.58; p<0.001) and strong concordance [0.9797 (LC95%= -8.0519; 10.0113)] were observed between the two methods. Significant correlations were found between BMI and WC, but not WHR, with respect to body fat estimated by BIA and SF (r = 0.453 to 0.707; p<0.05). BIA presented stronger correlations with BMI and WC (r = 0.707 and 0.605, respectively) compared with SF (r = 0.493 and 0.453, respectively).

Conclusion: Strong concordance and a significant correlation were observed between BIA and SF, suggesting their validity in measuring body fat among overweight individuals. However, BIA appears to present better results when considering its higher correlation with the anthropometric indicators used.

Keywords: Anthropometry, Body composition; Bioelectrical impedance; Skinfold thickness

Abbreviations: SF: Skinfold Thickness; BIA - Bioelectrical Impedance Analysis; BMI - Body Mass Index; WC - Waist Circumference; WHR - Waist-Hip Ratio

Introduction

Obesity is currently one of the largest health problems globally due to its high prevalence and association with several co-morbidities. By 2025, it has been projected that approximately three billion people will be overweight worldwide; of these, 700 million will be obese [1].

The assessment of obesity does not depend solely on the measurement of an individual's total body mass but also on body composition and fat distribution. Body composition can be measured by various techniques, including highly sophisticated and accurate methods like densitometry, plethysmography, nuclear magnetic resonance and Dual-energy X-Ray Absorptiometry (DXA). However, these methods are complex and expensive, and their use in clinical practice and large epidemiological studies is limited [2].

Measurements of body mass index (BMI), waist circumference (WC) and waist-hip ratio (WHR), and body composition assessments using skinfold thickness (ST) and bioelectrical impedance analysis (BIA) have been widely used due to their convenience and relatively low cost [3].

BMI [BMI = weight (kg)/height (m)^2] has been the most widely used index for assessing weight status [4] due to its simplicity, ease of application, reduced demand for training and reliance on less expensive equipment. Despite its advantages, BMI provides a lower sensitivity for assessing body fat composition and distribution [5]. Franken field et al. [6] confirmed this low sensitivity among American adults, identifying 30% of men and 46% of women as having a BMI less than 30 kg/m^2 yet with body fat levels categorized as obese. This limitation of BMI may be explained by the fact that body fat, unlike BMI, is associated with levels of activity or physical fitness.

The WC is a qualitative measurement of the central distribution of body fat and is considered a strong indicator of visceral fat, thereby predicting metabolic risks and potential chronic disease burden. Like WC, WHR indicates the type of fat distribution and an individual's risk for developing disease [7,8].

ST is a measure of body composition that allows the indirect estimation of body density and percent body fat (%BF) by means of equations. It is one of the most widely used assessment methods because it is easy to perform in daily practice, is cost effective, and is highly correlated with total body fat. Ketel et al. [9] reported that %BF measured by ST correlates well and does not differ significantly from values obtained by DXA (r>0.80). Nevertheless, aspects like the calibration of equipment, standardization of techniques, training of

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evaluators and the choice of prediction equation for body fat estimation are essential for the accuracy and reproducibility of ST [10].

BIA has also been widely used in the evaluation of body composition because it is noninvasive, portable and easy to use [2]. It is based on the principle of electrical conductivity to estimate body compartments. For BIA validation, it is important to consider the conditions under which it is performed, the type of equipment used and the equation for calculating body composition [10]. Factors like the position of the individual, alcohol intake, intense physical activity, and the presence of edema or fluid retention during certain times in the menstrual cycle and recent ingestion of food can affect accuracy [3].

Sun et al. [11] compared the %BF predicted by BIA and reference methods like DXA and indicated that the validity of BIA may be compromised in obese individuals, as they may have changes in geometry and body fluid balance. However, it is possible to obtain satisfactory estimates of longitudinal changes in lean mass and body fat [11]. Horie et al. [2] compared the %BF obtained by BIA and plethysmography from 109 severely obese individuals and found a strong accuracy and agreement between the methods with no significant differences. Equations have been developed to improve the accuracy of BIA for estimating body composition.

Few studies in the literature have assessed the ability of these methods to measure body fat among overweight individuals, especially among obese participants. However, the assessment of body composition in these individuals can assist in identifying risks of co-morbidities and monitoring their evolution in clinical practice [2]. The present study is aimed to assess the agreement between body composition obtained by BIA and ST and their correlation with anthropometric parameters among overweight individuals in clinical practice.

Materials and Methods

A total of 85 individuals aged 20 or older, who were receiving individualized nutritional counseling, were recruited from a primary health care unit in a Brazilian city from August 2007 to July 2009. All participants were informed of the goals and methods of the research and gave their informed consent. The protocol was approved by the ethical committee of the University of Minas Gerais and the City Hall of Belo Horizonte.

The criteria for referral for nutritional counseling included obesity (BMI $\geq$ 30 kg/m^2) in adults [4], overweight (BMI$\geq$27 kg/m^2) in elderly [12], and hypertension or diabetes mellitus.

The anthropometric measurements included weight, height, WC, WHR and arm circumference, following the recommendations of the World Health Organization (WHO) [4] and Lohman [13]. Body composition was assessed by the sum of four ST measurements (triceps, biceps, subscapular and suprailiac) and tetrapolar BIA. Measurements of weight and height were used to calculate BMI, and classification was assessed differently among adult [4] and elderly [12] participants.

WC was measured at the midpoint between the lower margin of the last palpable rib and the top of the iliac crest. The hip circumference was measured around the widest portion of the buttocks, without compressing the skin. WHR was calculated from the waist and hip circumference measurements. Guidelines set by the WHO [8] were used for the classification of WC and WHR.

ST was measured with Lange skinfold calipers to the nearest 1.0 mm and with the same instruments throughout the study. The measurements were performed by three trained examiners according to standard procedures [13]. The %BF was estimated from the sum of the four skinfolds according to the Durnin & Womersley [14] method with respect to the age and sex of each individual. All anthropometric measurements (ST, WC, arm and hip circumference) were measured three times, and the mean was used for analysis.

ST was measured during the first visit. BIA was measured one week after the first visit in order to instruct patients about the procedures of the test [15]. If the individual had a significant weight change during this period, anthropometric measurements and body composition were performed again.

BIA was performed using tetrapolar, single-frequency bioelectrical impedance (Biodynamics Corporation, Model 450. Biodynamics Corporation 3809 Stone Way N, #100

Seattle, WA 98103-8036, USA). The procedures used to measure body fat by BIA, including the measurement of height and weight of patients prior to the BIA test, were those recommended by The European Society for Clinical Nutrition and Metabolism [15].

The operating procedures of the equipment were used in estimating %BF from BIA. Lohman's criteria [16] were used in evaluating %BF from BIA and ST.

Statistical analyses were performed using Statistical Package for the Social Sciences, version 17.0 (SPSS Inc., Chicago, IL, USA). The Kolmogorov-Smirnov test was performed to assess the behavior of normal variables. For a normally distributed variable, results are displayed as the mean and standard deviation. Non-normal variables are expressed as medians and ranges of minimums to maximums.

The paired t-test or Wilcoxon signed-rank tests were used to compare the differences in body fat obtained using BIA and ST, depending on the distribution of the variables. The Bland-Altman models and Pearson or Spearman correlation coefficient (r) were respectively used to assess the agreement between BF values from the two methods (BIA and ST) and to correlate them with the anthropometric parameters BMI, WC and WHR. Statistical significance was set at $p < 0.05$ for all tests.

Results

The characteristics of 85 patients are presented in Table 1. The majority of the individuals were women (91.8%); the mean age of participants was 51.8 ± 13.0 years (22;85). Approximately 89% of the adults were obese and 89% of the elderly were overweight, with a mean BMI of 33.5 ± 5.3 kg/m^2. The mean WC was 97.7 ± 9.9 cm, and 91.5% were at risk of complications associated with obesity (classification of the WHO) [8]. The mean WHR was 0.87 ± 0.67, and the proportion of inadequacy was also high (56.6%).

Estimates of %BF obtained by ST and BIA were 42.8% (12.6-49.2) and 40.4% (21.0-51.2), respectively (Table 1). This difference was significant ($p<0.001$), although the classification of %BF obtained by each method was similar ($p>0.05$) (Figure 1).

Correlations between anthropometric indicators and methods of body composition assessment are presented in Table 2. BMI and WC were the parameters that best correlated with BIA and ST ($r = 0.453$ to 0.707, $p<0.05$).

We identified a significant correlation between estimates of body fat measured by BIA and ST ($r = 0.58$, $p<0.001$) (Figure 2), and a strong agreement between these methods (Figure 3). The reduction in differences between the estimates with increasing values of %BF is a noteworthy result.

Variables	n	Values
Age (years)	85	51.8 ± 13.0
Adults (20 – 59 years) Elderlies (≥ 60 years)	56 29	65.9% 34.1%
Weight (kg)	85	82.6 ± 14.3
BMI (kg/m²)	85	33.51 ± 5.3
Adults (%)		
Normal range	4	7.2
Overweight	2	3.6
Obese class I	26	46.4
Obese class II	18	32.1
Obese class III	6	10.7
Elderlies (%)		
Normal range	2	6.9
Underweight	1	3.4
Overweight	26	89.7
Waist circumference (cm)	83	97.7 ± 9.9
Normal (%)	7	8.4
Increased (%)	7	8.4
Substantially increased (%)	69	83.1
Waist-hip ratio	83	0.87 ± 0.67
Normal (%)	36	43.4
Increased (%)	47	56.6
Percentage of body fat (BIA)	79	40.4 (21.0-51.2)
Percentage of body fat (ST)	79	42.8 (12.6-49.2)

BIA- Bioelectrical impedance analysis; ST- skinfold thicknesses; BMI - Body Mass Index

Note: Loss of three (WC and WHR) and six (BIA and ST) individuals due to patient non-attendance or absence of the equipment due to technical problems

Table 1: Demographic and anthropometric characteristics of the participants.

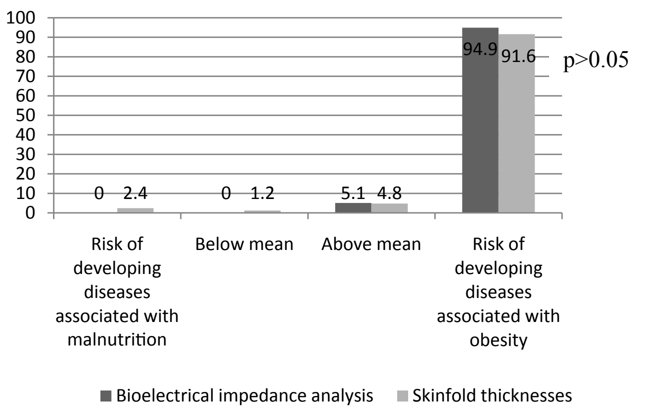

Figure 1: Comparison of the classification of percentage of body fat, according to Lohman's criteria (1992), obtained by bioelectrical impedance analysis and skinfold thickness.

Anthropometric variables	Method	r	p-Value
Body mass index	BIA[1]	0.707	<0.001
	ST[2]	0.493	<0.001
Waist circumference	BIA[1]	0.605	<0.001
	ST[2]	0.453	<0.001
Waist-hip ratio	BIA[1]	0.017	0.884
	ST[2]	0.160	0.148

Note: Pearson[1] and Spearman[2] correlation; BIA - Bioelectrical impedance analysis; ST - Skinfold thickness

Table 2: Correlation between anthropometric variables and the methods of body composition assessment (BIA and ST).

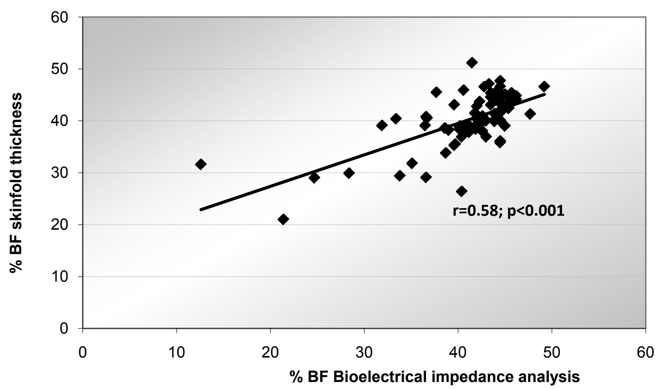

Figure 2: Correlation between percent body fat (% BF) obtained by bioelectrical impedance analysis and skinfold thickness.

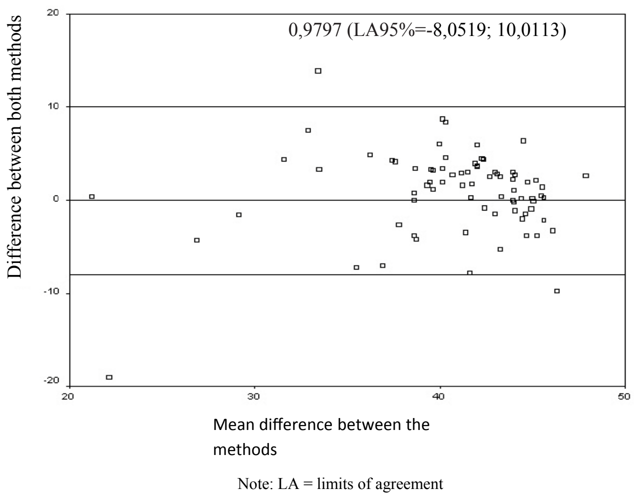

Figure 3: Difference in percentage of body fat obtained by bioelectrical impedance analysis and skinfold thickness.

Discussion

Estimates of %BF by BIA and ST were significantly different but produced similar classifications. In addition, a significant correlation and strong agreement between the methods were observed. Of the anthropometric variables, BMI indicated the greatest correlation with the body composition assessment methods. This correlation was positive and significant and was consistent with the findings of other studies [17,18].

BMI has been the most widely used anthropometric index in epidemiological studies; however, this method has limitations, as obesity reflects an excess of body fat and is not simply a measure of body weight [5,18]. It should be noted that although this research and other studies have revealed a positive correlation between BMI and the percentage of total body fat, its use alone is not advisable.

WC correlated moderately and significantly with %BF. Freitas et al. [19] evaluated the ability of anthropometric indicators to determine obesity measured by ST and BIA among 685 adults and seniors. As in this study, BMI was followed by WC as the best anthropometric index for diagnosing adiposity.

Among the advantages of using WC are its ease of measurement, low cost and evidence of its superiority compared to BMI in predicting the risk of chronic diseases [20]. Several studies have demonstrated the relationship of WC with hypertension, diabetes mellitus and metabolic syndrome [21-23]. Despite these findings, its use remains controversial because of the difficulty in establishing cut-points for different age groups and ethnic populations.

In contrast to BMI and WC, WHR demonstrated a weak and non-significant correlation with %BF. Similar studies have suggested that WHR is not a strong indicator of body fat [4,17] and shows weak correlations with other anthropometric measures like BMI [18,24]. WHR has been more strongly related to pelvic bone size than to body fat distribution [25].

The median %BF was greater when measured using ST rather than BIA (p=0.0001), which corroborates others studies [19,26]. For instance, Freitas et al. [19], using the same techniques of BIA and ST as the current study, found that the average %BF obtained for women was greater for ST (35.4 ± 5.9 vs. 33.5 ± 8.2 for BIA, $p<0.01$).

Although BIA and ST differ significantly from each other, they indicated significant moderate correlation. Aristizábal et al. [26] assessed 123 Colombian adults and verified a significant correlation between bipolar BIA and the sum of four ST measurements ($r = 0.8660$).

To our knowledge, the differential results for both methods can be derived from the different assumptions on which they rely. While ST estimated body density by the sum of skinfold thickness, BIA estimates total body water and then calculates the fat and lean mass. Similarly, the overestimation of %BF measured by ST when compared to BIA may be explained by the protocol of using four skinfold thicknesses to evaluate only the upper body, unlike the tetrapolar BIA, which considers the upper and lower limbs [26].

The agreement between the methods was evaluated by a Bland-Altman model and indicated that the mean differences in %BF between the methods were small (mean difference = 0.9797). The differences were well-distributed around the mean difference and were found mostly in the range of two standard deviations. A strong agreement was found, especially among the greater values of %BF. Therefore, the results from both techniques are more similar among individuals with increased body fat.

Junior et al. [27] compared %BF measurements from DXA with those from BIA and ST (the sum of four skinfold thicknesses, protocol of Durnin & Womersley [14]) and found no significant differences between them. However, there was no agreement between the estimates of body composition obtained by BIA or ST in relation to DXA. In contrast, Kamimura et al. [28] found strong agreement between ST (protocol proposed by Durnin & Womersley [14]) [0.47 ± 2.8 (-5.0 to 6.0) kg] and BIA [-0.39 ± 3.3 (-6.9 to 6.1) kg] with respect to DXA among all patients according to Bland-Altman analysis.

The results of this study indicate that BIA has stronger correlations with the anthropometric indices BMI and WC than with ST. Similarly, in a study by Freitas et al. [19], the strongest correlation was found between BMI and BIA ($r = 0.82$ for women and $r = 0.90$ for men, $p<0.05$), except for women older than 40 years, for whom the correlation of WC and BIA was greater ($r = 0.87$).

It should be noted that BIA classified a greater proportion of individuals as being at "risk of developing diseases associated with obesity", suggesting a potential sensitivity of BIA in assessing disease risk or a potential tendency to overestimate risk. Sun et al. [11] found that BIA provides increased values of %BF among individuals classified as lean by DXA; among these, the %BF was overestimated at 3.03% in men and 4.40% in women.

Our study demonstrates that the strongest correlation was observed between BMI and WC ($r = 0.803$, $p<0.001$). BMI correlated significantly with the variables of body composition and anthropometric measurements, excluding WHR. Similarly, a study by Sampaio et al. [24] among 634 older adults found a stronger correlation between BMI and WC ($r = 0.86$-0.93), compared to WHR ($r = 0.34$-0.66), in both age groups and both sexes.

In the present study, %BF obtained by BIA was based on the equation provided by the equipment because adopting an equation that has been adapted to the analyzed population is still a limitation of this method [29]. The difficulties related to the validation of equations, considering populations with different age groups, ethnicities, genders, heights, and other characteristics, resulted in an excess of equations, which can confuse rather than assist in the interpretation of results. In a multiethnic population (n=12,000) [30] in which the %BF measured by BIA was based on 51 different predictive equations, none of these was consistently better than the simpler alternative of BMI.

This study provided important information about which method should be used in clinical practice, especially in the assessment of overweight individuals. There was strong agreement and significant correlation between the methods used to assess body composition. BIA indicated greater correlations with the anthropometric indices BMI and WC than with ST. Furthermore, BIA presents an additional advantage of minimal intra- and inter-observer variability [29]. Although BIA is a method that depends on the individual, adherence to the protocol recommendations to ensure that the technique is applied under appropriate conditions can be strengthened through adequate participant instruction. BIA and ST appear to be equivalent methods among subjects with greater adiposity, considering that the amount of body fat estimated by BIA and ST was similar in these individuals.

However, these methods have some limitations and should not be the only ones applied to individuals and populations. Other indicators of nutritional status, like BMI and WC, which indicated strong correlations with body fat in this study, should also be used. We have highlighted the importance of concomitant assessments of body composition with total and abdominal obesity. These measures have an important application in health services and populations because they are reliable, easy to use and noninvasive. Even so, the difficulty in determining a specific method to be used remains due to the variability of the results obtained by different studies. This lack of comparability is further hampered by differences in population profiles and existing ways of measuring body composition by BIA (equipment, equations, polarity, frequency, protocols and cut-off values, hydration status of individuals) and ST (number of skinfold thickness measurements, equations, protocols and cut-off values).

The difficulty in determining the amount or proportion of body fat in obese individuals is well recognized. Most current methods used in this population are limited, either by their inability to accommodate the large physical size of these subjects, their inaccuracy in assessing extremely obese subjects or their tendency to produce discomfort to the subjects evaluated. Recently, plethysmography has been validated as a reference method for assessing body composition in severely obese individuals; however, its high cost limits its use in clinical practice [2].

Given that the current health profile of populations is characterized by a high prevalence of overweight, especially among women, this study is an important investigation into the applicability of the available methods for body composition assessment in clinical practice.

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