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Bipolar bioelectrical impedance: lack of accuracy in estimating relative body fat in men

Impedância bioelétrica bipolar: falta acuracidade para estimar a gordura relativa em homens

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Abstract – Bioelectrical impedance (BI) is commonly used to estimate body composition in different populations. The aim of this study was to determine the accuracy of bipolar BI (Omron BF 300) in estimating relative body fat (%F) by comparing it with dual-energy X-ray absorptiometry (DEXA). %F was measured in 66 men (18 to 33 years) with a mean body weight of 73.7 ± 8.4 kg, height of 175.1 ± 6.5 cm, body mass index of 23.9 ± 2.2 kg/m^2, %F$_{BI}$ 15.1 ± 4.4%, and %F$_{DEXA}$ 17.7 ± 5.1%. A paired t-test, correlation test, standard error of the estimate (SEE), and residue analysis were used to evaluate the accuracy of the method. BI significantly ($p < 0.05$) underestimated %F and, the correlation between the two methods was moderate ($r = 0.769$). Residue analysis showed the lack of agreement between the two methods, with an average error of -2.6 percentage points (95%CI: -9.1; 3.9). The SEE was above the recommended level (>3.5%F) in 42% of the sample. In subjects with higher fat accumulation (%F >20%), the Omron BF BI model produced greater bias in the %F measurement. Therefore, in the case of adult men, the Omron BF 300 BI model does not agree with the DEXA measurement for the estimation of %F in adult men. In addition, the higher the level of fat accumulation, the higher the error in estimated %F.

Key words: Bioelectrical impedance; DEXA; Body composition; Adiposity; Test validity.

Resumo – *O objetivo deste estudo foi verificar a acuracidade da IB Bipolar (Omron BF 300) para a estimativa da gordura corporal relativa (G%), comparada com a absortometria de raio X de dupla energia (DXA). A G% foi mensurada em 66 homens (18-33 anos), com massa corporal média de 73,7 ± 8,4 kg; estatura 175,1 ± 6,5 cm; índice de massa corporal 23,9 ± 2,2kg/m^2; G% $_{IB}$ 15,1 ± 4,4% e G% $_{DXA}$ 17,7 ± 5,1%. A acuracidade foi verificada por teste t pareado, correlação, erro padrão de estimativa (EPE) e análise de resíduos. A IB subestimou significativamente (p <0,05) os valores de G% e a correlação entre os métodos foi moderada (r= 0,769). A análise dos resíduos demonstrou que não houve concordância, sendo o erro médio de -2,6% (IC$_{95\%}$: -9,1;3,9). Observou-se que 42% da amostra apresentaram EPE acima do recomendado (>3,5 G%). Nos indivíduos com maior acúmulo de gordura (G% >20) a IB modelo Omron BF produziu maiores vieses na estimativa da G%. este modelo de IB não apresentou concordância com a medida da DXA para estimar a G% em homens adultos, sendo o erro maior em sujeitos com maior acúmulo de gordura.*

Palavras-chave: *Impedância bioelétrica; Absortometria de raio X de dupla energia; Composição corporal; Gordura corporal; Validade dos testes.*

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INTRODUCTION

The scientific community has shown great interest in the quantification of body composition, particularly body fat[1,2]. Excessive accumulation of body fat is a risk factor for the occurrence of morbidities and mortality at different ages[3,4], whereas low levels are associated with disorders such as anorexia and bulimia, which show a significant prevalence among young adults[5] and adolescents[6].

The fact that relative body fat (%F) is associated with non-transmissible chronic diseases has encouraged the search for an accurate estimation technique. Dual-energy X-ray absorptiometry (DXA) is considered to be the gold standard, mainly because it also measures bone density[7]. However, due to its laboratory characteristic and high cost, DXA is limited to large-scale screening. In contrast, bioelectrical impedance (BI) analysis has been used for different purposes in Brazil over the last years[8-10], especially because of the easy handling of the equipment, rapid data collection, and low cost. BI is based on the concept that an electric current passes more easily through hydrated fat-free tissue and extracellular water than fat because of the higher electrolyte content of the former, reducing electric resistance or impedance[11]. Thus, resistance to the electric current is inversely proportional to fat content. The traditional BI method is based on the estimation of electric resistance using four or eight electrodes (tetrapolar or octapolar BI, respectively) to transmit the electric current through the body. The resistance observed permits to estimate %F and other body composition components using regression equations. The tetra- and octapolar devices are more expensive, a fact limiting their use in population studies. However, there are simpler devices containing only two electrodes (bipolar BI) coupled to the apparatus itself, which are based on the same principle as the other methods.

Despite its practicality of data collection, the accuracy of bipolar BI devices is still questionable since these devices provide relative and absolute body fat values rather than resistance values. Therefore, the objectives of the present study were a) to compare the accuracy of bipolar BI analysis (Omron BF 300) and DXA for the estimation of %F in adult men, and b) to evaluate the influence of excess body fat on the estimation of %F by bipolar BI compared to DXA.

METHODOLOGICAL PROCEDURES

Study design, sampling, and ethical aspects

The present descriptive, cross-validation study compared bipolar BI analysis and DXA (reference method) for the estimation of %F. The study population consisted of adult men.

The sample was recruited by the distribution of posters and leaflets in places such as clubs, gyms and universities. The sample consisted of 74 adult men ranging in age from 18 to 33 years. Eight subjects were excluded because they did not follow the recommendations for BI analysis. The final sample consisted of 66 subjects. All participants were volunteers and signed a free informed consent form that guaranteed anonymity and confidentiality of the individual data. The subjects had the right to withdraw from the study at any time without penalty as established by the ethical guidelines of Resolution 196/96 of the National Health Council. The study was approved by the Ethics Committee of Universidade Católica de Brasília (process 36/2007).

Data collection

All procedures were conducted at the same place at a controlled ambient temperature (20º to 22ºC). For each subject, all measurements were obtained on the same day. The DXA exams were performed and analyzed by an examiner with 3- year experience. The individual error was <1.6% (coefficient of variation).

Body weight and height were measured with a balance to the nearest 100 g coupled to a stadiometer (scale of 0.5 cm)[12].

Measurement of %F by BI: The subjects were asked to adhere to the following protocol: 4-h fast, no consumption of coffee or alcoholic beverages 24 h prior to the test, no strenuous physical activity, and no use of diuretics. The subjects were instructed to empty their bladder and bowel before the measurement. The Omron BF 300 device was used, which is equipped with software that provides relative and absolute body fat values. However, the manufacturer does not inform the regression equation used for their estimation. Measurements were obtained according to the manual of the apparatus. The subject remained standing with the elbows extended in front of the body and holding the device until BI was estimated and %F and fat mass were calculated.

Measurement of %F by DXA: The Lunar DPX-IQ™ (4.7e software) apparatus was used and the procedures were performed according to the manual of the device. The equations used by the software to estimate body composition components including %F are also unknown. Whole-body scanning was performed with the subject remaining still in the supine position and the elbows and knees extended. Two calibrations of the apparatus, one weekly and one daily, were performed to ensure the quality of the measurements. A phantom test was performed for weekly calibration and quality assurance testing was used for daily calibration. The calibrations were performed according to the manual of the equipment.

To evaluate the effect of excess adiposity on the estimation of %F by BI, the sample was stratified into two groups: 1) %F <20%, and 2) %F ≥20%. The cut-off values established are based on evidence that indicates risk factors associated with excessive body fat accumulation[13].

Statistical analysis

The data showed a normal distribution (Kolmogorov-Smirnov test). Descriptive statistics was used for characterization of the sample. The criteria proposed by Lohman[14] were used to test the accuracy of BI compared to DXA: Pearson's linear correlation coefficient (*r*) >0.79; paired *t*-test (*t*) where $t_{calculated} < t_{tabulated}$, and a standard error of the estimate (SEE) <3.5% for the prediction of %F. The formulas cited in another study[9] with a similar design were used for the calculation of the constant error and SEE. Residual scores were analyzed as proposed by Bland and Altmann[15]. A level of significance of $p<0.05$ was adopted. The calculations were performed using a licensed copy of the Statistical Package for the Social Sciences (SPSS), version 14.

RESULTS

The sample consisted of adult men ranging in age from 18 to 33 years. Table 1 shows the descriptive characteristics of the sample. Mean %F measured by DXA was 17.7% (range: 8.3 to 28.9%), indicating the presence of subjects with adequate %F and overweight and obese subjects[13,16]. These findings demonstrate the external validity of the study since the sample was heterogenous in terms of %F as observed in the general population, permitting generalization of the results. This is supported by the variability in body mass index (Table 1), with the observation of subjects who belong to different categories of nutritional status[17].

Comparison of the two methods (Table 2) indicates that BI tends to significantly underestimate ($p<0.05$) %F, on average 2.6% in relation to DXA. The correlation between methods ranged from moderate to high ($r=0.769$; $p<0.05$). The SEE (3.3%) was below the criterion established[14]. Residue analysis (Figure 1) confirmed the tendency of BI (Omron BF 300) to underestimate %F when compared to DXA. There was a higher concentration of residues below point zero, with a mean error of -2.6% (95%CI: -9.1;3.9). As can be seen in Figure 2, the SEE for %F was £3.5% in only 58% of the sample studied, whereas 42% presented an SEE above the cut-off considered to be acceptable (3.5%)[14].

Table 1. Descriptive analysis of anthropometric variables and relative body fat in the sample studied (n = 66).

Variable	Mean ± SD	Range
Height (cm)	175.1 ± 6.5	161.2 – 188.0
BW (kg)	73.7 ± 8.4	54.6 – 90.2
BMI (kg/m²)	23.9 ± 2.2	18.8 – 28.6
$\%F_{BI}$	15.1 ± 4.4	5.1 – 25.1
$\%F_{DXA}$	17.7 ± 5.1	8.3 – 28.9

SD: standard deviation; BW: body weight; BMI: body mass index; $\%F_{BI}$: relative body fat measured by bioelectrical impedance; $\%F_{DXA}$: relative body fat measured by dual-energy X-ray absorptiometry.

Table 2. Statistical comparison of relative body fat (%F) obtained by dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance (BI) in adult men.

$\bar{x}\ \%F_{DXA}$	$\bar{x}\ \%F_{BI}$	*t*	*r*	CE	SEE
17.7 ± 5.1	15.1 ± 4.4	6.43[a]	0.769[a]	- 2.6	3.3

t: *t*-test; *r*: Pearson's correlation coefficient; CE: constant error ($\%F_{BI} - \%F_{DXA}$); SEE: standard error of the estimate; [a] $p<0.05$.

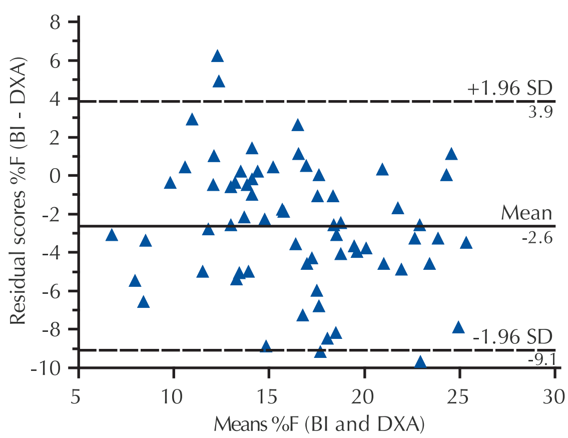

Figure 1. Comparison of residual scores of relative body fat (%F) measured by dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance (BI) ($\%F_{BI} - \%F_{DXA}$) with mean $\%F_{DXA}$ and $\%F_{BI}$. The dotted lines indicate the 95% confidence interval. The continuous line corresponds to the mean error.

The mean error and standard deviation obtained for the two groups classified according to %F are shown in Figure 3. Mean errors were significantly higher in the group with %F ≥20% (-4.47%) compared to the group with %F <20%

(-1.48%) ($p<0.05$). Mean errors significantly differed in the group with %F ≥20% (%F_{BI} 18.6 ± 3.5% *vs* %F_{DXA} 23.1 ± 2.4%) ($p<0.01$), but were similar in the group with %F <20% (%F_{BI} 12.95 ± 3.38% *vs* %F_{DXA} 14.4 ± 3.12%).

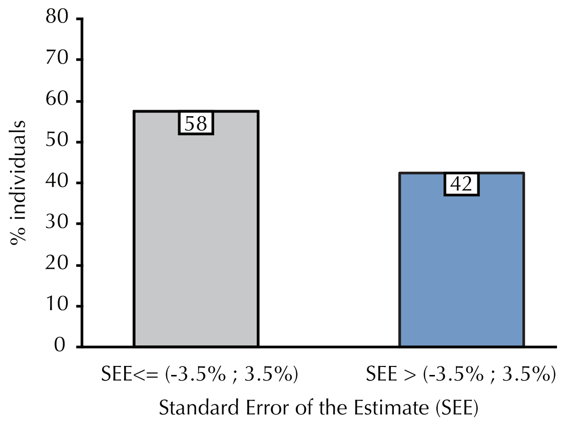

Figure 2. Analysis of the standard error of the estimate (SEE) for agreement between relative body fat estimation by dual-energy X-ray absorptiometry and bioelectrical impedance (BI).

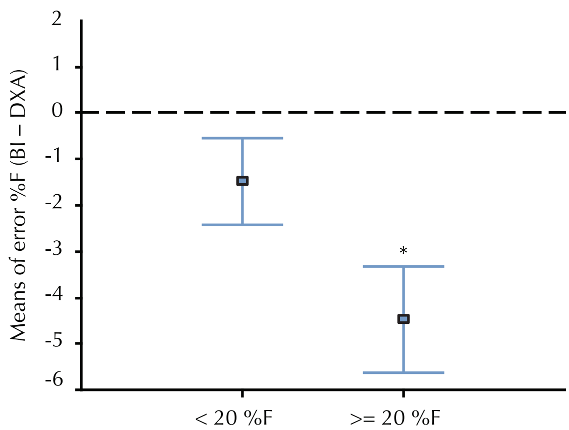

Figure 3. Comparison of mean errors of relative body fat (%F) obtained by dual-energy X-ray absorptiometry and bioelectrical impedance (BI) between subjects with %F <20% and %F ≥20%. * $p<0.05$ (paired *t*-test).

DISCUSSION

Despite the excellent applicability of BI measures in field studies[18,19], the validity and accuracy of the equipment and of the regression equations used to estimate %F should be determined for a given population. The Omron BF 300 BI device underestimated %F when compared to DXA in the sample studied (Table 2). Bipolar BI has also been shown to underestimate %F by 5.75% in adult women (20-40 years)[20], by 4.5% in Indians[21], and by 11% in youngsters[22] when DXA was used as the reference method. The same trend has been reported in another study[23], but no difference ($p>0.05$) was observed between the Omron BF 300 BI device and the anthropometric equation of Durnin and Womersley[24]. These findings indicate the lack of accuracy of this method/device for the estimation of %F.

Although the correlation between methods was moderate and the SEE was acceptable[14], indicating agreement between the two techniques, residue analysis (Figure 1) confirmed the tendency of BI to underestimate %F when compared to DXA. In this respect, the results showed that, if the Omron BF 300 BI model was applied to estimate %F in adult men, the SEE was ≤ 3.5% in only 58% of the subjects. Therefore, the use of this method/device may lead to incorrect diagnoses. As a consequence, possible interventions may also not be the most adequate. A study comparing bipolar and tetrapolar BI analysis revealed no differences between the two models and there was also no influence of the amount of body fat on the estimation of %F[25]. However, these findings should be interpreted with caution since no reference method was used for comparison of the two models.

The constant error and residual scores indicate that a subject may present %F of 16%, whereas, in fact, it is much higher than 20%. As a consequence, the subject is erroneously classified as overweight, although he should be in the normal/adequate group.

The BI device used in the present study can yield a large number of false-positive and, especially, false-negative results. Users should therefore be aware of this fact in order to correctly interpret the results, taking into account an error in %F quantification of at least 3.5% as recommended[14]. Once demonstrated that the Omron BF 300 device tends to underestimate %F, an SEE of ±3.5% should be added to the value estimated in order to obtain a more reliable diagnosis. The advantage of this BI device seems to be its low cost and practicality, even permitting self-evaluation by the subject.

With respect to the effect of excess adiposity on the estimation errors of bipolar BI compared to DXA, these errors tend to be higher in men with higher adiposity. These results agree with Glaner[9], who tested the validity of BI equations by comparing a tetrapolar model with DXA and observed that few of the equations developed in other countries are valid for the Brazilian population. In addition, this author[9] showed that the only equation valid for adult men is that specific for subjects with elevated adiposity (%F ≥ 20%). This fact demonstrates that BI models should include the degree of adiposity of the subjects to increase the accuracy of estimation.

The Omron BF 300 BI device was not valid for the estimation of %F in men. However, other models (Omron BF 550) have shown good agreement with DXA measurements in women[26], and no difference in %F estimates was observed between the Omron BF 306 BI and DXA[22].

One limitation of the present study is that DXA was used as the gold standard for the quantification of %F, although the manufacturer of these devices only recommends their use for the quantification of bone density[27]. This may increase the possibility of errors and reduce the validity of the results. However, *in vitro* experiments found no differences ($p \geq 0.05$) in the estimates of different body components[28,29], a fact justifying the use of this method in the present study. Another limitation is the use of only one bipolar BI model. As a consequence, the present results can only be extrapolated if the same device is used.

CONCLUSIONS

The present results demonstrate that the Omron BF 300 BI model is not accurate for the estimation of %F in adult men, with the estimation error increasing with increasing body fat.

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