## Nutrición Hospitalaria

Original/*Pediatría*

# Prediction of body fat in adolescents: comparison of two electric bioimpedance devices with dual-energy X-ray absorptiometry

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## Abstract

*Introduction:* An accurate estimate of body composition is important in assessing and monitoring the nutritional status of adolescents.

*Objectives:* To compare the accuracy of 2 electrical bioimpedance devices with that of dual-energy X-ray absorptiometry (DXA) to predict body fat in Brazilian adolescents.

*Methods:* We evaluated 500 adolescents aged between 10 and 19 years, stratified by sex and divided into overweight and non-overweight groups. The percentage of body fat (%BF) was estimated using 2 types of electrical bioimpedance devices: BIA1 (horizontal tetrapolar bioimpedance equipment) and BIA2 (vertical 8-electrode bioimpedance equipment), as well as by DXA. A Bland–Altman plot was used to calculate the total errors and standard errors of estimate.

*Results:* Considering BMI for age, 19.4% were overweight and 47.4% as assessed by %BF of DXA were overweight. The %BF estimated by BIA2 correlated well (p < 0.05) with the %BF predicted by DXA, and only the total errors for BIA2 in the overweight group were acceptable (≤2.5%). The standard errors of estimate was <3.5%, with the lowest values observed for BIA2. Both BIA1 and BIA2 underestimated the %BF in overweight adolescents, while overestimating the %BF in male adolescents of normal weight.

*Conclusions:* The BIA2 was found to be more effective in the evaluation of body fat. Regardless of the method used, the results should be carefully interpreted when assessing the body composition of adolescents.

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Key words: *Adolescents. Electric impedance. Body composition.*

**PREDICCIÓN DE LA GRASA CORPORAL EN ADOLESCENTES: COMPARACIÓN DE DOS DISPOSITIVOS DE BIOIMPEDANCIA ELÉCTRICA CON ABSORCIOMETRÍA DUAL DE RAYOS X**

## Resumen

*Introducción:* Una estimación precisa de la composición corporal es importante para evaluar y monitorear el estado nutricional de los adolescentes.

*Objetivos:* Comparar la exactitud de 2 dispositivos de bioimpedancia eléctrica con la absortometria de rayos X de doble energía (AXD) para predecir la grasa corporal en adolescentes brasileños.

*Métodos:* Se evaluaron 500 adolescentes entre 10 y 19 años, estratificados por sexo y divididos en grupos con sobrepeso y sin sobrepeso. El porcentaje de grasa corporal (%GC) se estimó utilizando 2 tipos de bioimpedancia eléctrica: BIA1 (equipo de bioimpedancia tetrapolar horizontal) y BIA2 (vertical equipo de bioimpedancia 8 electrodos), así como por AXD. Un gráfico de Bland-Altman se utilizó para calcular los errores totales y errores estándar de estimación.

*Resultados:* Teniendo en cuenta el IMC para la edad, el 19,4% tenían sobrepeso y el 47,4% según la evaluación de %GC de DXA tenían sobrepeso. El %GC estimado por BIA2 buena correlación (p<0,05) con el %GC pronosticado por AXD, y sólo los errores totales para BIA2 en el grupo de sobrepeso eran aceptables (≤2,5%). Los errores estándar de estimación fue <3,5%, con los valores más bajos observados para BIA2. Tanto BIA1 y BIA2 subestimaron el %GC en los adolescentes con sobrepeso, mientras que sobreestimar el %GC de los adolescentes varones de peso normal.

*Conclusiones:* El BIA2 se encontró que era más eficaz en la evaluación de la grasa corporal. Independientemente del método utilizado, los resultados deben interpretarse con cautela al evaluar la composición corporal de los adolescentes.

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Palabras clave: *Adolescentes. Impedancia eléctrica. Composición corporal.*

## Abbreviations

%BF: Proportion of body fat.
BIA: Electrical bioimpedance analysis.
BIA1: Horizontal tetrapolar bioimpedance equipment.
BIA2: Vertical 8-electrode bioimpedance equipment.
BMI: Body mass index.
DXA: Dual-energy X-ray absorptiometry.
G1: Group 1, not overweight.
G2: Group 2, overweight.
k: Kappa coefficient.
NPV: Negative predictive value.
PPV: Positive predictive value.
r: Pearson linear correlation coefficient.
r2: Determinant coefficient.
SD: Standard deviation.
SDS: Standard deviation score.
SEE: Standard error of estimate.
Sens: Sensivity.
Spec: Specificity.
TBM: Total body mass.

## Introduction

Adolescence is defined as the period between 10 and 19 years of age and is characterized by rapid growth marked by the onset of puberty, which promotes physiological, corporal, psychological, and social changes that occur unevenly among individuals[1]. During the maturation process, body composition changes in a sex-specific manner, with female adolescents developing a higher proportion of fatty tissue[1].

An accurate estimate of body composition is important in assessing and monitoring the nutritional status of adolescents, and acts as a predictor of cardiovascular disease, diabetes mellitus, dyslipidemia, hypertension, metabolic syndrome, and excess body fat[2-4], all of which can persist in adulthood[5].

The prevalence of obesity and related metabolic disorders has been increasing worldwide, and both are evenly distributed with respect to sex, age, and ethnicity[6]. The Household Budget Survey, conducted in the metropolitan areas of Brazil between 2008 and 2009, indicated that 20.5% of adolescents were overweight (21.5% of male and 19.4% of female adolescents), which represents an increase of approximately 4% when compared with the results of the same survey in 2002–2003[7]. Moreover, excess body fat has been found even in adolescents of normal weight[8-10].

There are different methods to assess body composition, including electrical bioimpedance analysis (BIA), which measures the resistance or impedance of a low-intensity electrical current passed through body tissue. It is a simple, fast, relatively inexpensive, noninvasive, portable, and safe method for assessing the proportion of body fat (%BF)[3,11-13]. However, BIA devices using 4 electrodes can give different %BF values from those using 8 tactile electrodes. This discrepancy was apparent in a study of children and adolescents between 6 and 13 years of age[14], as well of young adults between 18 and 29 years of age[12], but has not yet been studied in adolescents between 10 and 19 years of age.

Given the frequent use of BIA in clinical practice and in population studies, it is important to accurately and reproducibly assess the proportion of body fat. The aim of this study was to determine which of the electrical bioimpedance devices, when compared to DXA, would more accurately determine the amount of body fat in male and female Brazilian adolescents who were of normal weight or were overweight.

## Methods

### Study design and data collection

This was an epidemiological, cross-sectional study conducted between March 2010 and April 2012 involving adolescents of both sexes aged between 10 and 19 years of age, selected from public and private schools in both urban and rural areas of Viçosa, Minas Gerais, Brazil. Inclusion criteria were the absence of chronic disease, no regular use of medicines that alter blood pressure, fasting glucose levels, or lipid metabolism, no continuous use of diuretics or laxatives, no pacemaker or implant, and, for female adolescents, no use of oral contraceptives for at least 2 months before the study commenced, as well as no current or previous pregnancy.

Sample selection was based on the total number of adolescents who lived in the city and met the age criterion in 2012. The sample size was calculated using software Epi Info version 6.04 based on a specific formula for cross-sectional studies. We considered the population of 12080 adolescents at the age studied, in Viçosa-Minas Gerais[18], the expected frequency of excess body fat of 28.5%[16], and a variability of 5%. We anticipated a loss of 20% of subjects from the study, indicating a minimum enrollment of 480 adolescents, with a confidence interval of 99.9%.

The adolescents were selected by simple random sampling with the school as a means of access. The study included a total of 27 public and private schools, with students in the age group of interest. During selection, the principal of each school was contacted, and after providing their permission, invitations were distributed to the adolescents to participate. Those adolescents who accepted received an informed consent form explaining the study. Study participants were randomly selected from among those who returned the signed informed consent form.

The project was approved by the Ethics Committee on Human Research of the Federal University of Viçosa (Of. Ref. N°. 0140/2010). Participation was voluntary, and required verbal clarification and written

informed consent from both the adolescents and their parents.

On the basis of a previously described classification of nutritional status[17], adolescents were grouped as follows: Group 1, not overweight (underweight and normal weight, body mass index [BMI]/age ≤+1 standard deviation); Group 2, overweight, BMI/age >+1 standard deviation; and these were further stratified by sex.

### Anthropometric assessment

Subjects were weighed using a digital scale with a maximum capacity of 150 kg in 50-g subdivisions, and height was measured using a portable stadiometer with a bracket coupled to one end, with a scale up to a maximum of 2.13 m in 0.1-cm gradations. Measurements were taken twice and the average value was used. If the difference between them exceeded 0.5 cm, further assessments were performed. Weight and height were measured according to the techniques described by Jellife[18].

Nutritional status was assessed using the result obtained from z-score calculations adjusted for age and gender to give a BMI standard deviation score (SDS) using the cutoff and anthropometric reference points recommended by the World Health Organization[19]. Overweight and obese adolescents were classified as overweight (>+1 standard deviation)[19].

### Body composition

In this study, %BF was estimated using 2 electrical BIA devices: BIA1 (horizontal tetrapolar bioimpedance equipment; *Biodynamics* Model 450®) and BIA2 (vertical 8-electrode bioimpedance equipment; *InBody* 230®), as well as DXA (dual-energy X-ray absorptiometry) (Lunar Prodigy Advance DXA System – analysis version: 13.31, GE Healthcare). All assessments were conducted in the morning as outlined in specific protocols for testing[20].

The electrical bioimpedance method relies on the conduction of low-intensity (500 to 800 μA) and high-frequency (50 kHz) electrical current and on the calculation of impedance, which is determined by the sum of resistance and reactance. The impedance varies with body tissue composition, being higher in leaner bodies due to the higher concentration of water and electrolytes in this tissue[3].

In addition to the %BF, the total body mass according to DXA (the sum of the fatty and lean tissue, and bone) was evaluated. The %BF was analyzed according to the classification proposed by Lohman[21], defining overweight as a value ≥20% for boys and ≥25% for girls.

The protocol was also designed to standardize the hydration status of subjects prior to BIA assessment. Subjects needed to be assessed at least 7 days after their last menstrual period and 7 days before the next. They also needed to have undergone complete fasting and re-frained from physical exercise in the previous 12 hours, not to have consumed alcohol in the previous 48 hours, not to have used diuretics for at least 7 days before the assessment, and to have urinated 30 minutes before the assessment. Adolescents were also asked to remove metal objects such as earrings, rings, and watches, which could interfere with the passage of electrical current.

### Statistical analysis

The database was doubly entered in Microsoft Office Excel 2007 and, after checking the consistency of the data, analyses were performed in SPSS for Windows 13.0 and Stata 11.0. The Kolmogorov–Smirnov normality test was used to assess the distribution of variables and the Kappa index was used to assess the agreement between the measurements provided by BIA1 and BIA2, as well as the DXA, in accordance with Lohman's criteria[21].

We calculated the sensitivity, specificity, and positive and negative predictive values of BIA1 and BIA2 for excess body fat in adolescents. A simple linear regression model was used to assess the relationship between the %BF, as estimated by electrical bioimpedance (independent variable), and the measurements provided by DXA (dependent variable), stratified by sex and nutritional status.

To test the accuracy of the electrical bioimpedance methods compared to DXA, we used the criteria proposed by Lohman[21]. These were a Pearson linear correlation coefficient (r) >0.79; a paired *t*-test to detect differences between the mean %BF as estimated by electric bioimpedance and by DXA; a total error ≤2.5%, and a standard error of estimate (SEE) <3.5% for the prediction of %BF. The limits of agreement of the %BF estimated by the different devices were assessed using a Bland–Altman plot. The level of rejection of the null hypothesis for all tests was 5%.

## Results

### Characteristics of the subjects

This study enrolled 500 participants with a mean age of 13.79 years (range, 10.02–19.99 years), of whom 279 (55.8%) were female. On the basis of the BMI corrected for age, 22 subjects (4.4%) were underweight, 381 were normal weight (76.2%), and 97 were overweight (19.4%), of which 27 (5.7%) were obese[17]. The proportion of overweight subjects was very similar amongst male (20%) and female (18.6%) adolescents.

The %BF as assessed using DXA showed that 47.4% of participants were overweight[21], with female participants significantly more likely to be overweight (62.7%) than male participants (28.1%) (p<0.001), which was expected given the physiological differences between men and women. Among subjects who were

**Table I**
*Body composition in adolescents stratified according to sex and weight. Minas Gerais, Brazil*

| Variable | Overweight (n = 403) | | Not overweight (n = 97) | |
| --- | --- | --- | --- | --- |
| | Female Mean ± SD | Male Mean ± SD | Female Mean ± SD | Male Mean ± SD |
| Weight (kg) | 46.17 ± 9.71 | 47.65 ± 13.79 | 57.05 ± 11.17 | 63.54 ± 18.92 |
| Height (cm) | 156.09 ± 10.0 | 159.76 ± 14.7 | 152.76 ± 9.02 | 159.22 ± 13.90 |
| BMI (kg/m²) | 18.74 ± 2.47 | 18.21 ± 2.58 | 24.22 ± 2.78 | 24.43 ± 4.04 |
| BMI (SDS) | -0,40 ± 0,85 | -0,58 ± 0,97 | 1,62 ± 0,52 | 1,78 ± 0,59 |
| TBM DXA (kg) | 45.94 ± 9.66 | 47.96 ± 14.1 | 56.58 ± 11.14 | 63.37 ± 18.97 |
| %BF DXA | 24.89 ± 6.34[a] | 12.96 ± 5.55[a] | 37.38 ± 5.60[a] | 29.12 ± 7.38[a] |
| %BF BIA1 | 23.00 ± 4.6[b] | 13.87 ± 5.17[b] | 30.70 ± 4.21[b] | 24.57 ± 5.17[b] |
| %BF BIA2 | 23.54 ± 5.88[c] | 14.19 ± 4.77[c] | 36.56 ± 5.78[c] | 28.22 ± 6.80[c] |

SD, standard deviation; BMI, body mass index; DXA, dual-energy X-ray absorptiometry; TBM, total body mass by DXA (DXA sum of fatty and lean tissue, and bone); %BF, percentage of body fat; BIA1, horizontal tetrapolar bioimpedance equipment; BIA2, vertical 8-electrode bioimpedance equipment.
Paired *t*-test (DXA vs. BIA1; DXA vs. BIA2; BIA1 vs. BIA2), grouped according to sex and weight; a, b, or c indicates discrepancies between the values of percentage body fat given by different devices (p < 0.05).

not overweight, excess body fat was predicted in 53.7% and 11.9% of female and male participants, respectively.

*Comparison of %BF according to bioimpedance and DXA*

The characterization of body composition and the relationship between the %BF as assessed using BIA1 and BIA2, or DXA, are shown in table I. Significant differences (p<0.05) were found between the %BF as measured by DXA compared with BIA1 and BIA2 for both sexes and the overweight and non-overweight groups. For overweight and non-overweight female adolescents, BIA1 underestimated the %BF by −6.68 ± 3.01% and −1.89 ± 3.93%, respectively, whereas BIA2 underestimated the %BF by −0.82 ± 2.32% and −1.35 ± 2.63%, respectively. In non-overweight male adolescents, BIA1 and BIA2 overestimated the %BF by 0.91 ± 3.08% and 1.23 ± 2.68%, respectively, and underestimated the %BF in overweight male adolescents by −4.55 ± 4.00 and −0.90 ± 2.54%, respectively.

The %BF estimated by BIA2 correlated more closely (p < 0.05) with the %BF measured by DXA for male and female adolescents irrespective of whether they were overweight (Table II). Only the total errors of BIA2 for

**Table II**
*Linear regression for the percentage of body fat (%BF) according to DXA and bioimpedance equipment in adolescents grouped by sex and weight. Minas Gerais, Brazil*

| Variable | Overweight (n = 403) | | Not overweight (n = 97) | |
| --- | --- | --- | --- | --- |
| | Female | Male | Female | Male |
| **BIA1** | | | | |
| Equation | Y = 1.081204X + 0.0149939 | Y = 0.7964547X + 1.917352 | Y = 1.127074X − 2.780695 | Y = 1.219052X − 0.8329755 |
| r² | 0.6199* | 0.5506* | 0.7197* | 0.7294* |
| r | 0.787* | 0.742* | 0.848* | 0.854* |
| Total Error (%) | 3.90 | 3.69 | 2.93 | 3.79 |
| SEE (%) | 2.41 | 1.85 | 1.57 | 2.03 |
| **BIA2** | | | | |
| Equation | Y= 0.9821347X + 1.763344 | Y = 1.020325X − 1.515125 | Y = 0.8883529X + 4.904636 | Y =1.018983X + 0.3575502 |
| r² | 0.8287* | 0.7673* | 0.8407* | 0.8819* |
| r | 0.910* | 0.876* | 0.917* | 0.939* |
| Total Error (%) | 2.62 | 3.16 | 2.21 | 2.5 |
| SEE (%) | 1.09 | 1.13 | 1.18 | 1.34 |

BIA1, horizontal tetrapolar bioimpedance equipment; BIA2, vertical 8-electrode bioimpedance equipment; r², determinant coefficient; r, Pearson correlation coefficient; SEE, standard error of estimate; *p < 0.0001
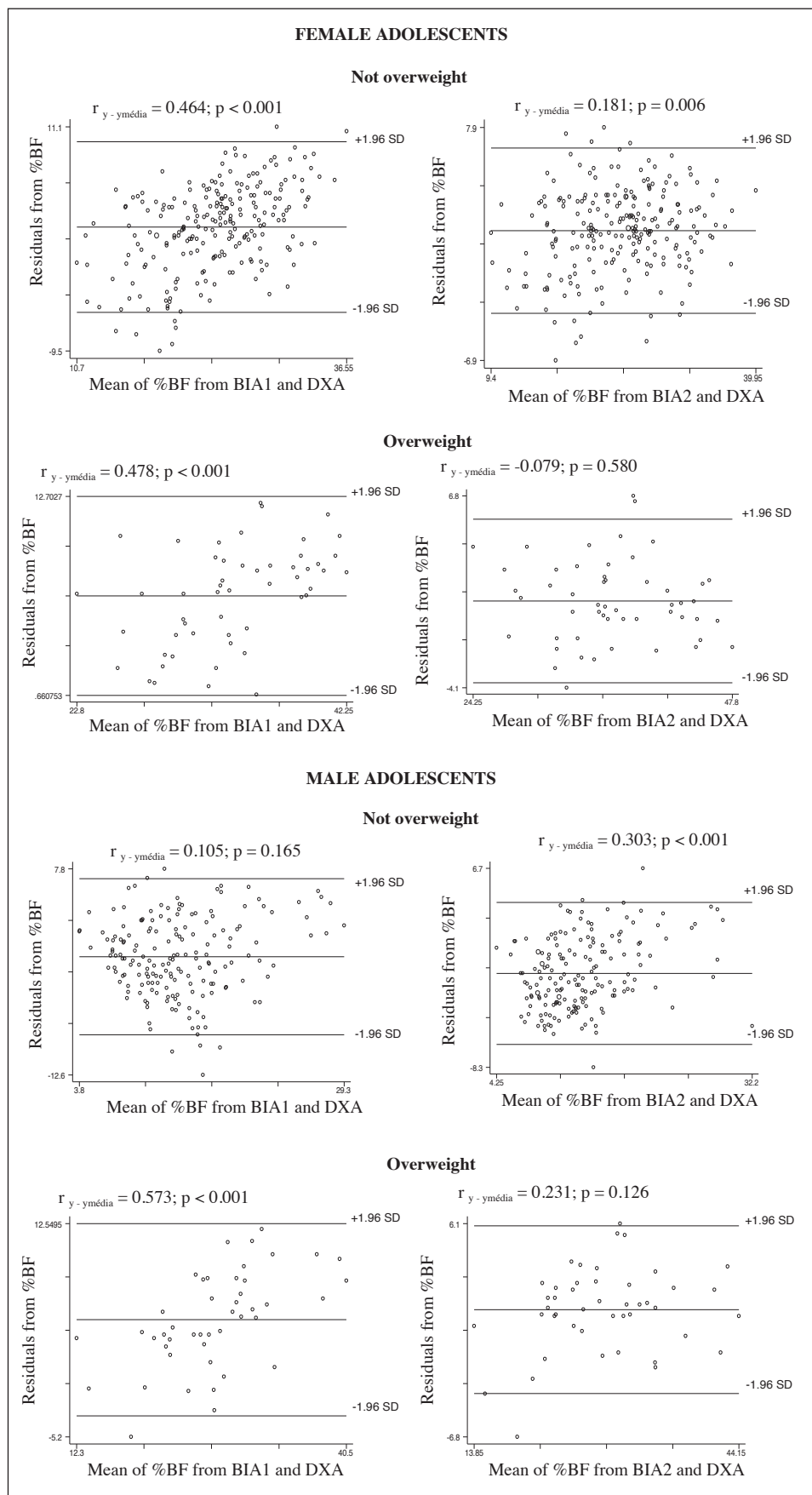
## FEMALE ADOLESCENTS

### Not overweight



$r_{y - ymédia} = 0.464; p < 0.001$

$r_{y - ymédia} = 0.181; p = 0.006$

### Overweight

$r_{y - ymédia} = 0.478; p < 0.001$

$r_{y - ymédia} = -0.079; p = 0.580$

## MALE ADOLESCENTS

### Not overweight

$r_{y - ymédia} = 0.105; p = 0.165$

$r_{y - ymédia} = 0.303; p < 0.001$

### Overweight

$r_{y - ymédia} = 0.573; p < 0.001$

$r_{y - ymédia} = 0.231; p = 0.126$

*Fig. 1.—The Bland–Altman plot and residual scores of percentage body fat (%BF) as measured by DXA and electrical bioimpedance (BIA1 and BIA2) in both overweight and non-overweight female and male adolescents. Minas Gerais, Brazil.*
*DXA, dual-energy X-ray absorptiometry; BIA1, horizontal tetrapolar bioimpedance equipment; BIA2, vertical 8-electrode bioimpedance equipment; %BF, percentage of body fat; SD, standard deviation*

**Table III**

*Agreement between percentage of body fat determined using DXA or bioimpedance analysis. Minas Gerais, Brazil*

| Evaluations | Total Sample | | G1 | | G2 | |
|---|---|---|---|---|---|---|
| | *Male* | *Female* | *Male* | *Female* | *Male* | *Female* |
| DXA vs. BIA1 | k = 0.55<br>p < 0.001<br>80.6% | k = 0.48<br>p < 0.001<br>67.2% | k = 0.42<br>p < 0.001<br>61.9% | k = 0.42<br>p < 0.001<br>57.4% | k = 0.33<br>p = 0.011<br>90.2% | -<br><br>90.4% |
| DXA vs. BIA2 | k = 0.64<br>p < 0.001<br>88.7% | k = 0.66<br>p < 0.001<br>81.0% | k = 0.49<br>p < 0.001<br>66.7% | k = 0.62<br>p < 0.001<br>73.8% | k = 0.65<br>p < 0.001<br>100.0% | -<br><br>98.1% |

Group 1 (G1), not overweight; Group 2 (G2), overweight; DXA, dual-energy X-ray absorptiometry; BIA1, horizontal tetrapolar bioimpedance equipment; BIA2, vertical 8-electrode bioimpedance equipment; k, Kappa coefficient; %, percentage of agreement between body fat estimations using DXA or bioimpedance; -, unable to perform the test owing to too few subjects.

overweight adolescents were considered statistically significant ($\leq$ 2.5%) for female (2.21%) and male (2.5%) adolescents. The SEE was <3.5% and deemed to be sufficiently low by the criterion of accuracy suggested by Lohman[21], with lower values for BIA2 (Table II).

Strong and positive correlations were found, exceeding 0.79, between the %BF estimated by BIA2 and DXA for both sex and weight groups. The BIA2 measurements showed a higher correlation with the DXA values than did the BIA1 measurements (p<0.05) for the whole cohort (Table II).

The Bland–Altman plot for BIA1 and BIA2 are shown in figure 1. Evaluating BIA1, BIA2, and DXA resulted in an r-value close to zero, with no statistically significant difference between the BIA1 and DXA measurements for male adolescents who were not overweight (Fig. 1), or between the BIA2 and DXA measurements for both male and female overweight adolescents (Fig. 1). Therefore, BIA1 can be used to assess male adolescents who are not overweight, and BIA2 can be used to assess both male and female adolescents who are overweight. Both BIA devices tended to underestimate the %BF in female participants (Fig. 1), and overestimate the %BF in male participants who were underweight or of normal weight, while underestimating it in those who were overweight. The agreement between the body composition estimates provided by DXA, BIA1, and BIA2 are shown in table III. For all groups, BIA2 estimates agreed better with DXA measurements for the determination of %BF than did those for BIA1.

Overall higher sensitivity, specificity, and positive and negative predictive values were achieved using BIA2, which proved more accurate at both the individual and population level than did BIA1 (Table IV). Therefore, although the results are differentiated by group and sex, it is clear that the BIA2 is better predictor of excess body fat when compared to BIA1.

**Table IV**

*Sensitivity, specificity, and positive and negative predictive values of data from the 2 bioimpedance devices compared to the "gold standard" DXA. Minas Gerais, Brazil*

| DXA ("gold standard") | High percentage of body fat Values (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | BIA1 | | | | BIA2 | | | |
| | *Sens* | *Spec* | *PPV* | *NPV* | *Sens* | *Spec* | *PPV* | *NPV* |
| *Total Sample* | | | | | | | | |
| Female | 93.64 | 79.92 | 80.7 | 93.4 | 94.07 | 90.15 | 89.5 | 94.4 |
| Male | 88.51 | 77.14 | 86.5 | 80.2 | 87.36 | 96.19 | 97.4 | 82.1 |
| | 88.71 | 88.05 | 74.3 | 95.2 | 88.71 | 98.11 | 94.8 | 95.7 |
| *Not overweight* | | | | | | | | |
| Female | 81.36 | 66.67 | 83.7 | 62.9 | 85.88 | 75.0 | 87.9 | 71.6 |
| Male | 85.25 | 77.14 | 81.2 | 81.8 | 91.8 | 88.57 | 90.3 | 90.3 |
| | 85.71 | 80.65 | 37.5 | 97.7 | 100.0 | 81.9 | 42.0 | 100.0 |
| *Overweight* | | | | | | | | |
| Female | 90.32 | 100.0 | 100.0 | 30.8 | 94.62 | 100.0 | 100.0 | 44.4 |
| Male | 90.4 | 0 | 100.0 | 0 | 98.1 | 50.0 | 94.9 | 33.3 |
| | 94.5 | 50.0 | 94.9 | 33.3 | 100.0 | 50.0 | 95.4 | 100.0 |

BIA1, horizontal tetrapolar bioimpedance equipment; BIA2, vertical 8-electrode bioimpedance equipment; Sens, sensitivity; Spec, specificity; PPV, positive predictive value; NPV, negative predictive value.

## Discussion

In this study, we found significant, but also previously well-characterized differences between sexes with respect to their proportion of body fat (Table I). During adolescence and maturation, body composition changes in a sex-specific manner, whereby female adolescents develop a greater proportion of body fat[1]; these effects are largely attributable to changes in estrogen and testosterone during puberty[22,23].

The higher prevalence of adolescents with excess body fat seen in this study is concordant with the findings from other studies conducted in Brazil[19,24,25] and elsewhere[22, 26], especially with regard to adolescent girls, which highlights this change even in adolescents with normal weight in terms of BMI[8-10,19,24]. The number of adolescents with excess weight explains the higher percentage of dystrophic adolescents by BMI, as reported by the Household Budget Survey 2008–2009[7] and studies with adolescents from Viçosa, MG/Brazil[27].

There are several methods of assessing body composition and the appropriate method depends on which body compartments are to be evaluated, the population of interest, cost, validity/reliability, and the degree of training necessary for the evaluator[28]. Electrical BIA analysis has been used in clinical and epidemiological studies for the evaluation of body compartments and results in fewer errors in the estimation of body composition than do skinfold equations[19,29]. However, results between different types of bioimpedance equipment can vary widely. In this study, the 2 pieces of bioimpedance equipment tests (tetrapolar BIA1 and the 8-tactile electrode BIA2) gave differing values for body fat composition. Thus, despite being an easy, noninvasive, and highly reproducible method, the accuracy of BIA analysis may have been affected in certain situations, such as those involving alcohol consumption and intense physical activity performed prior to the test, the presence of edema or water retention[30], obesity[31], and ingestion before meals[32], thereby emphasizing the need for more defined protocols.

Several studies have compared different methods for assessing body composition[11,26,33,] but only a few have compared the 2 types of BIA equipment with DXA in adolescents between 10 and 19 years of age, as in the present study.

Gupta[11] compared horizontal tetrapolar BIA with DXA in Chinese adults and found that there was good agreement between the methods. However, its use was only recommended for epidemiological studies because the confidence intervals ranged widely. In this study, BIA tended to overestimate the %BF of the total population, as well as of men, and underestimate it in women, as compared to DXA. Kim et al.[4] compared the 8-electrode BIA method with DXA in 174 adults. Correlations between the %BF according to BIA and DXA were 0.956 and 0.960 for men and

women, respectively, and the total error was 2.1% and 2.3% fat in men and women, respectively. The mean difference between methods was small, but significant (p<0.05), as in our study, and resulted in an overestimation of 1.2 ± 2.2% fat (95% confidence interval: −3.2–6.2%) in men and an underestimation of −2.0 ± 2.4% fat (95% confidence interval: −2.3–7.1%) in women. Using the Bland–Altman analysis, the %BF (86.3% in men and 66.0% in women) was found to be an accurate estimate within the accepted range of error of 3.5% fat. They concluded that BIA2 measurements generally agreed with those obtained using DXA in predicting the %BF in Korean adults. However, this equipment had small but systematic errors concerning the accuracy of individual %BF estimates. The total of errors led to an overestimation of the %BF in lean men and an underestimation of the %BF in obese women.

On the basis of these previous findings and those of the present study, the assessment of body composition by different methods should be interpreted with caution, and it is important to consider the sex and nutritional status of the individual.

In this study, subjects were stratified by sex and group (overweight or not overweight). We found that BIA2 gave the best results, regardless of sex, especially in the overweight group, wherein this equipment was more accurate than BIA1 (Fig. 1; Tables III and IV). In addition, when BIA2 was compared to BIA1, it proved to be more sensitive for the detection of excess body fat (Table IV), identifying more adolescents who required monitoring, regardless of sex. It was also more accurate, correlating better with the values generated using DXA, and resulting in a correspondingly greater agreement in the Bland–Altman analysis, particularly for overweight adolescents. Conversely, BIA1 was not adequate for male and female adolescents of any weight, and gave a correlation of <0.79, a larger difference with the DXA measurements, and an error of >2.5%.

In a similar study to ours, Kriemler et al.[14] evaluated 333 Swiss children and adolescents between 6 and 13 years of age with the aim of validating the measurements of BIA1 and BIA2 equipment. They found that BIA2 was more accurate in the assessment of lean mass and segmental body fat. In a related study, Leahy et al.[12] compared BIA2 to DXA amongst 403 subjects aged 18 to 29 years in Ireland, and found that BIA2 underestimated the percentage of total fat in both men and women. The underestimation was higher in men with a %BF above 24.6% and higher in women with a %BF above 32%. Therefore, the BIA should be used with caution in the assessment of body composition, especially in individuals with a %BF >25%.

Another important issue is the lack of studies using BIA2, especially in the age range of this study, making comparisons with this method difficult. Nonetheless, a careful analysis of this equipment could be of great importance in generating more accurate results,

which in turn could enable its wider use in population studies and in clinical practice. However, owing to its high cost, simpler and cheaper equipment is often chosen. BIA1 resulted in a SEE of <3.5% and reasonable sensitivities and positive predictive values, and can be used in the absence of more sensitive methods of assessing body composition.

Therefore, it is important to consider the method used, the age range of the study subjects, and the nutritional status of the individual when assessing %BF, because the errors made by the equipment may lead to an estimation of excess body fat that is too far from the true value. Consequently, many teenagers may not receive appropriate nutritional treatment. Excess body fat is a risk factor for insulin resistance and related metabolic disorders and must be diagnosed early to prevent current and future problems[22,24].

This study has a number of limitations. These include a lack of pubertal staging, as it is well established that fat mass is highly dependent on pubertal development. For example, on average the fat mass of a pre-pubertal 10-year-old girl differs significantly from that of a pubertal girl; however, the evaluation of children and adolescents between 10 and 19 years of age is important owing to the lack of data in the literature for this age group. Furthermore, although many studies have compared the performance of electrical bioimpedance equipment to that of gold standard methods for assessing body fat, relatively little work has been done to assess the accuracy of body composition using the vertical, 8-tactile-electrode BIA equipment, especially in adolescents, which makes our findings particularly relevant.

## Conclusions

We found that the vertical 8-electrode bioimpedance equipment (BIA2) was more accurate in assessing body fat than the horizontal tetrapolar bioimpedance equipment (BIA1), as the former underestimated/overestimated the %BF less often, gave a higher correlation and agreement with DXA measurements, and resulted in a lower error and higher sensitivity and specificity. This was more evident in overweight adolescents than among those of normal weight. Therefore, BIA2 appears to be a superior method for measuring body fat compositions in adolescents at both the population and individual levels.

The horizontal tetrapolar bioimpedance equipment (BIA1), although less accurate than BIA2, can also be used with caution, in the absence of more sensitive methods for assessing body fat composition. BIA1 is less expensive, more widely available to health services, and results in a SEE of <2.5%. Care should be taken when assessing body composition in adolescents, regardless of the method used, but should also be considered as a clinical priority, as it is likely to play a role in the prevention of metabolic abnormalities.

## Authors' contribution

Eliane Rodrigues de Faria, Franciane Rocha de Faria and Vivian Siqueira Santos Gonçalves were responsible for data acquisition and transcription. Statistical analysis was performed by Eliane Rodrigues de Faria and Franciane Rocha de Faria. Eliane Rodrigues de Faria wrote most of the manuscript, including the discussion. Sylvia do Carmo Castro Franceschini, Maria do Carmo Gouveia Peluzio, Luciana Ferreira da Rocha Sant'Ana and Silvia Eloiza Priore were involved in planning and organization, and reviewed the manuscript before submission. All authors were involved in writing the paper and approved the submitted and published versions.

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