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Validity of body adiposity index in predicting body fat in Brazilians adults

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Abstract

Objectives: The aim of this study was to compare various methods of assessing body compositions with body adiposity index (BAI) and to identify the validity of BAI as a predictor of body fat in Brazilian adults.

Methods: This study included 706 individuals (average age 37.3 years, SD = 12.1). Anthropometric data included percent body fat obtained by skinfold thicknesses, bioelectrical impedance analysis and DXA. Body mass index (BMI), waist/hip ratio, and BAI were calculated. The correlation between variables was assessed by Pearson's correlation coefficient, and the Bland–Altman and Kaplan Meier graphic approaches were used to verify the agreement between BAI and DXA.

Results: There was a strong correlation between BAI and BMI (r = 0.84 in men and r = 0.86 in women, $P < .001$), waist circumference (r = 0.77 in men and r = 0.75 in women, $P < .001$) percent fat by skinfold thicknesses (r = 0.71 in men and r = 0.71 in women, $P < .001$) and by DXA (r = 0.72 in men and r = 0.78 in women, $P < .001$). The Bland–Altman approach showed an overestimation of BAI in males and an underestimation in women using DXA as the reference method. The agreement between BAI and DXA through the Kaplan-Meier analysis was 41%.

Conclusions: It was found that BAI does not replace other measurements of body fat, but compared with more complex methods can be an alternative for estimating the body fat in the absence of these methods.

KEYWORDS
body adiposity index, obesity, adults

1 | INTRODUCTION

Excess adiposity is an important risk factor for morbidity, mortality and overall quality of life. It is also related to high risk of developing insulin resistance, dyslipidemia and hypertension (Cornier et al., 2011; Shihab et al., 2012). The risk of diabetes increases by sevenfold in obese men and by 12-fold in obese women compared with individuals with normal weight (Guh et al., 2009). Furthermore, excess adiposity is associated with increased risk of cardiovascular disease (Apovian & Gokce, 2012).

The measurement of body adiposity is carried out using various techniques. Some are complex and expensive, such as the dual-energy X-ray absorptiometry (DXA) (Min & Min, 2014) and the plethysmography (Geliebter, Atalayer, Flancbaum, & Gibson, 2013; Rodriguez-Escudero et al., 2014). These techniques can hardly be used in population studies and in routine clinical practice due to the high cost and low mobility of the equipment. Alternatively, there are anthropometric measurements that are used as body fat indicators, particularly in population-based surveys. These measures are fast, practical, not very expensive and can be applied to large population groups (Prospective Studies Collaboration, 2009).

Among the various anthropometric variables, the measurements of skinfold thicknesses (Freedman et al. 2013a, Freedman, Ogden, Goodman, & Blanck, 2013b), waist circumference (Bajaj et al., 2014), the conicity index (Shidfar, Alborzi, Salehi, & Nojomi, 2012) and body mass index (BMI) (Ranasinghe et al., 2013) are frequently used to determine body fat in epidemiological studies. Despite their logistic advantages, these techniques also have limitations, such as the inability to differentiate fat from fat-free mass, a well-known limitation of BMI (Clarys, Provyn, & Marfell-Jones, 2005; Rahman & Berenson, 2010).

Despite such techniques being recommended to measure the impact of overweight on the risk of developing cardiovascular diseases (Borrell & Samuel, 2014) or metabolic disorders (Tobias et al., 2014), there is a gap with respect to a simple and efficient index that indicates excess body fat. Considering the absence of this index, a simple method has been proposed to determine body fat: the body adiposity index (BAI), which is calculated by measuring the hip circumference and height (Bergman et al., 2011), without the need for measuring weight, as required for BMI calculation. The equation proposed for BAI was developed with data from Mexican American adults aged 18 to 67 years and tested in an African American sample, using DXA as the standard method. It was observed that BAI presented a stronger correlation with percent body fat than BMI (Bergman et al., 2011).

Given that the BAI was created and validated in a population of African and Mexican Americans (Bergman et al., 2011) and its validation in the Brazilian population was carried out in specific subgroups (Alvim et al., 2014; Cerqueira et al., 2013; Godoy-Matos, Moreira, Valerio, Mory, & Moises, 2012; Silva, Vale, Lemos, Torres, & Bregman, 2013), it is important to check the behavior of this index in other population groups, particularly due to the fact that there is evidence for ethnic differences in the distribution of body fat (Lear et al., 2007). It is known that the Brazilian population is multi-racial and is becoming increasingly multicultural. With the migration of various ethnicities to Brazil, people are exposed to different patterns in the accumulation of body fat, justifying the need to validate BAI in the Brazilian population.

The aim of this study was to compare various methods of assessing body compositions with BAI, and to identify the validity of BAI as a predictor of body fat in Brazilian adults.

2 | MATERIALS AND METHODS

This population-based cross-sectional study was carried out in the urban area of Viçosa, a middle-sized city in the State of Minas Gerais, Brazil. Data collection took place in the calendar years of 2012 and 2013. The sample was obtained by probabilistic sampling procedures: we first sampled census tracts (delimited areas comprising approximately 300 households each) and then households. To calculate the sample size, we used Epi-Info, version 3.5.2®. The calculated sample included 922 individuals; 216 individuals were excluded for not completing laboratory tests. This study included 706 individuals of both sexes aged 20 to 59 years (mean =37.3 years, SD = 12.1) with complete data on body mass, height, hip circumference, waist circumference, skinfold thicknesses, BIA and DXA. Pregnant women, individuals with physical disabilities and individuals bedridden at the time of data collection were excluded. There was no statistical difference between the anthropometric characteristics of the sample included in the analyses and those excluded as a consequence of missing data.

This study was approved by the Ethics Committee for Research Federal University of Viçosa, Minas Gerais State, Brazil (OF. Ref. No. 02/2013/CEP/07-12-13), following the Brazilian legislation for studies with humans. After clarification of the aims of the study, informed written consent was obtained from all participants.

Anthropometric measurements included height, body mass, hip circumference and waist circumference following international standards for anthropometric assessment (International Society for the Advancement of Kinanthropometry, 2001). Data were collected in the morning, in a single meeting, after an approximately 12-h fast, by the same trained and experienced evaluator.

Height was measured to the nearest 0.1 cm, using a metal stadiometer (Welmy, in wall, Santa Bárbara D'Oeste, SP, Brazil), with participants in bare feet, arms along the body and head in the Frankfort horizontal plane. Body weight was measured on a digital scale (Tanita, model Ironman TM, BC-554, Tanita Corporation), with a capacity of 200 kg and accuracy of 100 g, with as little clothing as possible, no shoes and no metal objects on the body, following the procedures described by the manufacturer. We calculated BMI ($BMI = weight/height^2$) from the height and weight measurements.

Hip circumference was measured at the widest point around the buttocks with the tape horizontal and parallel to the ground using an inelastic tape with 0.1 mm accuracy. Waist circumference was measured taking the navel as a reference point with the individual standing with arms along the sides of the body and after a normal expiration.

Percent body fat was obtained by measuring skinfold thicknesses and by using Tetrapolar, Biodynamics BIA (Biodynamics Corporation, Seattle, WA) following the procedures described by the manufacturer. To calculate percent body fat by skinfold thicknesses, we estimated body density

TABLE 1 Anthropometric characteristics of adults aged 20 to 59, Viçosa, Minas Gerais, Brazil, 2012–2013

	Total (*n* = 706), mean (SD)	Men (*n* = 311), mean (SD)	Women (*n* = 395), mean (SD)	*P*
Age (yr)	36.0 (12.8)	34.3 (11.9)	37.4 (12.4)	<.01
Weight (kg)	70.3 (15.1)	77.4 (13.9)	64.7 (13.6)	<.01
Height (m)	1.7 (0.1)	1.7 (0.1)	1.6 (0.1)	<.01
BAI (%)	28.6 (5.6)	25.0 (3.7)	31.4 (5.1)	<.01
BMI (kg/m^2)	25.3 (4.8)	25.5 (4.3)	25.1 (5.1)	>.05
Waist circumference (cm)	87.9 (12.7)	89.5 (11.6)	86.8 (13.4)	<.01
Hip circumference (cm)	99.7 (8.9)	98.8 (8.0)	100.4 (9.4)	<.05
Waist/hip ratio	0.9 (0.1)	0.9 (0.1)	0.9 (0.1)	<.01
Skinfold thicknesses (%)	26.8 (8.8)	20.4 (6.5)	32.4 (6.4)	<.01
BIA (%)	27.0 (8.0)	21.5 (6.6)	31.3 (6.2)	<.01
DXA (%)	30.4 (9.8)	24.0 (8.3)	35.5 (7.7)	<.01

BAI Body adiposity index, BMI body mass index, skinfold thicknesses for women were triceps, abdomen and iliac crest and for the men were triceps, pectoral and subscapular. BIA body fat percentage estimated by the bioimpedance, DXA body fat percentage estimated by the dual-energy X-ray absorptiometry.

in men (Jackson & Pollock, 1978) and women (Jackson, Pollock, & Ward, 1980). Then we applied the equation proposed by Siri (1961) to calculate the percentage of fat. Skinfold thicknesses were measured using a Lange skinfold caliper (Cambridge Instrument, Cambridge, MA) with a precision of 1 mm.

We used DXA as the reference method to determine body fat. We used the densitometer equipment (GE Healthcare Lunar Prodigy, Incore version 13.31 software) and the tests were performed by a qualified professional with experience in radiological measurements. All measurements were made in the Health Division of the Federal University of Viçosa and the equipment was calibrated daily according to the manufacturer's instructions.

For the BAI calculation we used the hip circumference and height, applying the formula proposed by Bergman et al. (2011): $\text{BAI} = [(\text{hip circumference})/(\text{height} \sqrt{\text{height}})] - 18$. In addition to BAI, we also calculated the waist/hip ratio.

Statistical analysis included a description of the variables (mean and standard deviation) and t-test analyses to check for differences of means. The correlation between variables was assessed by Pearson's correlation coefficient. We used the graphical approach of Bland–Altman to verify the agreement between BAI and DXA. To analyze the degree of

TABLE 2 Correlation matrix between the body adiposity index, body mass index, waist circumference, waist/hip ratio, skinfold thicknesses, bioimpedance, and dual-energy X-ray absorptiometry for men

	BAI	BMI	WC	WHR	Skinfold	BIA	DXA
BAI	1						
BMI	0.84*	1					
WC	0.77*	0.93*	1				
WHR	0.47*	0.65*	0.79*	1			
Skinfolds thicknesses	0.71*	0.75*	0.81*	0.66*	1		
BIA	0.60*	0.63*	0.69*	0.54*	0.72*	1	
DXA	0.72*	0.76*	0.83*	0.65*	0.89*	0.75*	1

*$P < .001$.
BAI, body adiposity index; BMI, body mass index; WC, waist circumference WHR, waist/hip ratio; Skinfold thicknesses for women were triceps, abdomen, and iliac crest, and for men were triceps, pectoral and subscapular; BIA, body fat percentage estimated by the bioimpedance; DXA, body fat percentage estimated by the dual-energy X-ray absorptiometry.

TABLE 3 Correlation matrix between the body adiposity index, body mass index, waist circumference, waist/hip ratio, skinfold thicknesses, bioimpedance and dual-energy X-ray absorptiometry among women

	BAI	BMI	WC	WHR	Skinfold	BIA	DXA
BAI	1						
BMI	0.86*	1					
WC	0.75*	0.94*	1				
WHR	0.40*	0.66*	0.80*	1			
Skinfolds thicknesses	0.71*	0.80*	0.78*	0.53*	1		
BIA	0.76*	0.80*	0.81*	0.62*	0.73*	1	
DXA	0.78*	0.82*	0.82*	0.55*	0.86*	0.83*	1

*$P < .001$.
BAI, body adiposity index; BMI, body mass index; WC, waist circumference WH*R*, waist/hip ratio; Skinfolds thicknesses, for women was triceps, abdomen and iliac crest and the men triceps, pectoral and subscapular; BIA, body fat percentage estimated by the bioimpedance; DXA, body fat percentage estimated by dual-energy X-ray absorptiometry.

agreement or disagreement, the Kaplan-Meier graph was generated using survival analysis. The difference between BAI and DXA was checked by Cox regression. We adopte a *P* values below 0.05 considered significant and the data were analyzed using Stata, version 13.

3 | RESULTS

Table 1 describes the characteristics of individuals in the sample. Women had higher values when compared with men in the following variables: age ($P < .01$), BAI ($P < .01$), hip circumference ($P < .01$), percent body fat estimated by skinfold thicknesses ($P < .01$), BIA ($P < .01$) and DXA ($P < .01$).

Coefficients of bivariate correlations among anthropometric variables were calculated. When all the participants were taken into account, significant correlations were found for all parameters ($P < .01$). BAI showed a strong correlation with percent body fat predicted by skinfold thickness ($r = 0.81$), BIA ($r = 0.80$) and DXA ($r = 0.83$) and a moderate correlation with BMI ($r = 0.67$) and waist circumference ($r = 0.55$). The correlation between BAI and percent fat predicted by DXA was stronger than the one observed for BMI ($r = 0.62$), waist circumference ($r = 0.60$) and waist/hip ratio ($r = 0.31$). Skinfold thicknesses ($r = 0.92$) and BIA ($r = 0.87$) were more strongly correlated with DXA for the total sample as compared with BAI.

Tables 2 and 3 show the correlation matrices of anthropometric variables for men and women, respectively. The correlations between BMI ($r = 0.76$ in men and $r = 0.82$ in women, $P < .001$), waist circumference ($r = 0.83$ in men and $r = 0.82$ in women, $P < .001$) and waist/hip ratio ($r = 0.65$ in men and $r = 0.55$ in women, $P < .001$) with the percent fat predicted by DXA were higher when compared with the total sample values.

When analyzing the correlations between BAI and each of the other variables, there were strong correlations with

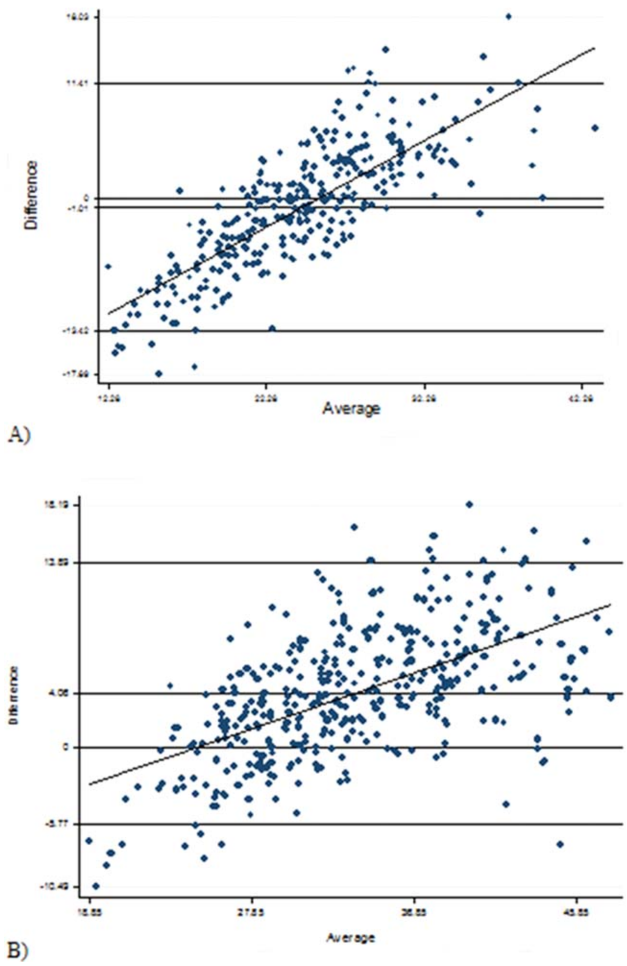

FIGURE 1 Level of agreement by Bland–Altman approach to DXA and BAI. (A) Men and (B) women

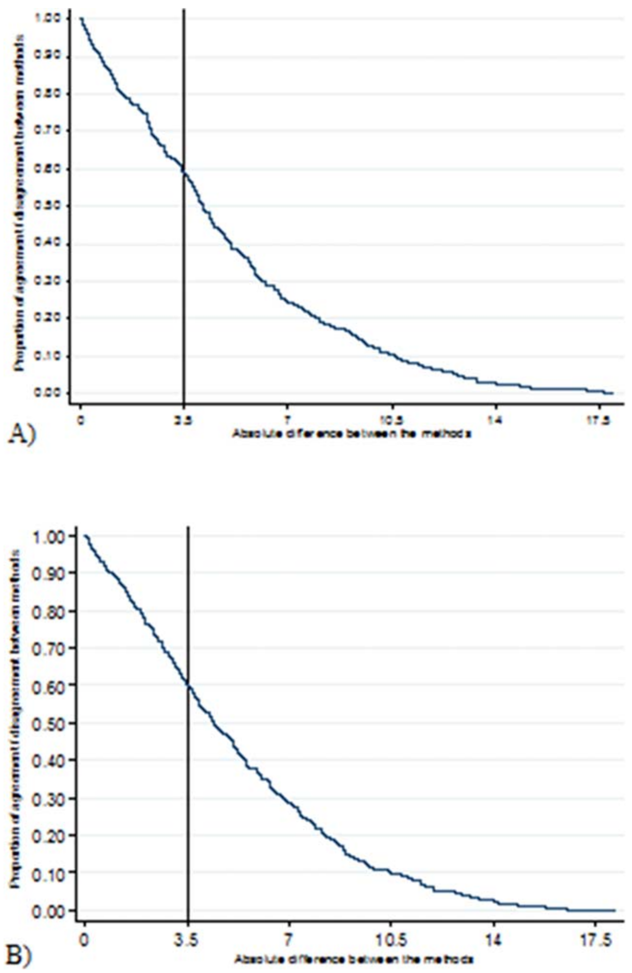

FIGURE 2 Proportion of agreement by Kaplan-Meier analysis between the BAI and DXA. (A) Men and (B) women

BMI (r = 0.84, P < .001), waist circumference (r = 0.77, P < .001), percent fat by skinfold thicknesses (r = 0.71, P < .001) and percent fat by DXA (r = 0.72, P < .001) for men (Table 2) and with BMI (r = 0.86, P < .001), waist circumference (r = 0.75, P < .001), percent body fat estimated by skinfold thicknesses (r = 0.71, P < .001), percent fat by BIA (r = 0.76, P < .001) and percent fat by DXA (r = 0.78, P < .001) among women (Table 3). In the sex-stratified analysis, on one hand, the magnitude of the associations between BAI and BMI and BAI and waist circumference was stronger when compared with the associations observed in the entire sample. On the other hand, the magnitude of the associations between BAI and skinfold thicknesses and BAI and BIA was reduced in the sex-stratified analysis.

Bland–Altman plots were used to show the mean overall differences and limits of agreement between DXA and BAI (Figure 1). Bland–Altman's limits of agreement showed that BAI overestimates percent body fat (mean difference = −1.83%). Among males, the mean difference was −1.01%, whereas in women there was an underestimation (mean difference = 4.06%). The Bland–Altman plots of the agreement between percent body fat measured by DXA and predicted by BAI showed a tendency towards an overestimation (−5.4% for men and −5.0% for women) of body fat among subjects with lower percent body fat (<20%) and underestimation (4.8% for men and 5.7% for women) in subjects with higher percent body fat (>30%). Furthermore, Bland–Altman analysis showed that the magnitude of the bias is proportional to percent body fat in both males and females (Figure 1).

Figure 2 displays the agreement between BAI and DXA through the agreement-survival chart. On the *X*-axis, the observed differences are displayed and the *Y*-axis shows the ratio of cases to certain differences. Accepting a difference of up to 3.5% (Lohman, 1992) between the methods, there was a correlation between percent fat determined by BAI and DXA of approximately 41% in both sexes. In agreement with findings from the Bland–Altman plots, the Cox regression confirmed an overestimation in men (P = .030) and an underestimation in women (P < .001).

4 | DISCUSSION

The aim of this study was to compare various methods of assessing body compositions with BAI and to identify the validity of BAI as a predictor of body fat in Brazilian adults. In the Brazilian population, only a few studies on this topic are available (Alvim et al., 2014; Cerqueira et al., 2013; Godoy-Matos et al., 2012; Silva et al., 2013). Of these studies, only one was population-based (Alvim et al., 2014). The remaining studies (Cerqueira et al., 2013; Godoy-Matos et al., 2012; Silva et al., 2013) were conducted with samples of specific population subgroups. Our study used a sample covering a wide age range and different biotypes and compared the results obtained by BAI with various methods for assessing body composition. To our knowledge, this is the first study to demonstrate the degree of agreement between BAI and DXA through the Kaplan-Meier survival analysis, contributing to a better understanding of this index as a predictor of body fat.

BAI was correlated with the main indicators of body adiposity (BMI, waist circumference, percent body fat by skinfold thicknesses, bioimpedance and DXA) in men (Table 2) and in women (Table 3). Highest correlation values were observed between BAI and BMI, waist circumference, skinfold thicknesses and DXA in males and BMI, waist circumference, skinfold thicknesses, bioimpedance and DXA in women. These results corroborate studies using bioimpedance (Lopez et al., 2012), DXA (Freedman et al., 2012) and skinfold thicknesses (Freedman et al., 2013a, 2013b). The strongest correlation was found between the methods of skinfold thicknesses and DXA. This finding is justified by the strong correlation between skinfold thickness and total body fat (Van Der Ploeg et al., 2003). However, it is known that the association between subcutaneous fat and total fat vary according to sex, age and place of measurement (Clarys et al., 2005). It should be noted, however, that the measurement of skinfold thicknesses in research studies like ours tends to be more standardized than it would be in clinical practice.

BAI's ability to predict body fat has been analyzed in the literature, especially in relation to BMI. Some studies have shown that BAI is a better predictor of body fat when compared with BMI (Chang, Simonsick, Ferrucci, & Cooper, 2014; Dhaliwal, Welborn, Goh, & Howat, 2014; Godoy-Matos et al., 2012; Johnson, Chumlea, Czerwinski, & Demerath, 2011; Silva et al., 2013; Sun et al., 2013;), while others have found a similar or higher capacity of BMI as a predictor of body fat when compared with BAI (Appelhans et al., 2012; Barreira et al., 2011; Freedman et al., 2012; Gibson, Atalayer, Flancbaum, & Geliebter, 2012; Lopez et al., 2012; Schulze & Stefan, 2011; Vinknes et al., 2013). In the present study, despite the strong correlation with DXA in men ($r = 0.72$) and in women ($r = 0.78$), BAI was not shown to be a better indicator of body fat than BMI. BMI is not a good indicator of excess body fat and has been criticized due to its limitations (Rahman & Berenson, 2010), such as its use in evaluating athletes who have high levels of lean mass and low levels of body fat (Garrido-Chamorro et al., 2009).

Another criticism is that BMI does not consider differences between men and women (Lopez et al., 2012). We understand that BAI and BMI measure different parameters, i.e., the percentage of body fat and nutritional status, respectively. Despite its limitations, BMI is widely used in research to identify overweight and obesity (Pan et al., 2013). In addition, it is strongly associated with cardiovascular disease, mortality risk (Borrell & Samuel, 2014) and metabolic disorders (Tobias et al., 2014).

BAI was proposed (Bergman et al., 2011) as an index to measure the amount of body fat based on the premise that an excess of this tissue is associated with morbidity. We therefore decided to compare it with other widely used instruments for measuring body fat. As for the agreement between BAI and DXA, we detected an overestimation of percent body among lean individuals and an underestimation among fat people. The results of our study were similar to those found by others (Cerqueira et al., 2013; Chang et al., 2014; Johnson et al., 2011; Vinknes et al., 2013). It was observed that among subjects with percent fat values between 20% and 30%, the highest correlation between BAI and DXA was observed, as was also the case in other studies (Bergman et al., 2011; Chang et al., 2014). A study conducted with middle-aged Brazilian women concluded that underestimation was a serious problem because it generated a large percentage of false negatives for overweight and obesity (Cerqueira et al., 2013). In our study, the highest correlation results were for men aged 40-50 years, whereas, for women, correlations were similar regardless of age.

To analyze the degree of agreement (or disagreement) between the methods, with the standard error of 3.5% estimate for the percentage of fat (Lohman, 1992), the Kaplan-Meier plot was used. There was a degree of agreement of approximately 41% between BAI and DXA. These agreement values are considered low in regards to a method that aims to replace high cost measures. However, when comparing other body fat measurements, agreement values were approximately 53% for skinfold thicknesses and 40% for bioimpedance.

A limitation of the present study was the loss of 23.4% of the participants during the collection of laboratory data. These individuals chose not to complete the survey, since they had health insurance and underwent physical and nutritional counseling. Furthermore, the validity of BAI in children, adolescents and the elderly was not evaluated. The use of DXA as a reference method is common in the literature, but to be a true gold standard it would be necessary to model at least three compartments (Van Der Ploeg, Withers, & Laforgia, 2003). However, we emphasize that the strengths of this study that contribute to the understanding of the validity of BAI in adults as a predictor of body fat are the wide age range of subjects, the various biotypes covered and the fact that all anthropometric measurements were performed by a single evaluator.

In conclusion, we observed that, while BAI does not replace the other measures of body fat, there is correlation and agreement with other referenced methods in the literature. Because of its advantages, in terms of application, BAI can be an alternative to estimate body fat in the absence of other, more complex techniques such as skinfold thicknesses, bioimpedance, DXA and even BMI. Therefore, BAI can be useful in clinical settings, especially in population-based studies in which more accurate measurements are often limited. It is recommended that BAI should be validated in other populations.

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participated on the definition of the research question, design of the study, collection, and analysis of the data and article write-up. D. C. G. da Silva, F. A. Coelho, and S. H. O. Morais R. Morais collaborated on the literature review, data collection, and write-up the article. P. C Hallal, J. C. B. Marins, A. Q. Ribeiro, and M. C. Pessoa contributed analyses and interpretation of the results, writing of the article, and approval of the final version. G. Z. Longo contributed to the planning of the study, the training of the fieldwork team, analysis and interpretation of data, wrote the article, and revised the final version

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