Body Adiposity Index (BAI) as a predictor of body fat in an oldest old and independent Brazilian elderly cohort

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Short title: Body Adiposity Index in oldest old patients
Body adiposity index as a predictor of body fat in an oldest old and independent cohort of Brazilian older adults
Abstract

Background: Anthropometry and body mass index (BMI) do not assess body composition or its distribution in older adults; thus, individuals may have different fat percentages but similar BMI values. The body adiposity index (BAI) was recently proposed as a feasible and inexpensive method for estimating the percentage of body fat based on measurements of hip circumference and height. Objectives: The present study evaluated whether BAI and BMI are useful alternatives to dual-energy X-ray absorptiometry (DXA), which is rarely used in clinical practice, for predicting body fat in independent long-lived older adults. Methods: In this cross-sectional study, we used DXA to calculate the percentage of body fat, which was compared with BAI and BMI values. We performed Pearson correlation analyses and used Cronbach’s alpha, described by Bland and Altman, to compare the reliability between the indexes. Results: Among 157 evaluated individuals (73.2% women, mean age 87 years, ± 3.57), men had a lower percentage of total fat, as assessed by DXA, and lower BAI indices than women. The correlation between BAI and DXA was moderate (r = 0.59 for men and r = 0.67 for women, p < 0.001). We confirmed the reliability based on Cronbach's alpha coefficients of 0.67 in men and 0.77 in women. We also observed that the BAI was strongly positively correlated with BMI in both men and women. Conclusion: The BAI, used in combination with BMI, can be an alternative to DXA for the assessment of body fat in the oldest old in clinical practice, mainly women, and can be used to add information to BMI.

Keywords: oldest old, body composition, body adiposity index, dual-energy X-ray absorptiometry.
INTRODUCTION

Obesity is characterized by an excessive accumulation of body fat resulting from a positive energy balance (Buffa et al, 2011) and is a risk factor for many diseases (Eskinazi et al, 2011).

Venturini et al (2013) suggested that the lower prevalence of obesity in older adults aged >80 years may be attributed to increased mortality before older adults reach more advanced ages. However, even in the oldest old, obesity is also associated with great risk, as demonstrated by Leigh et al (2018), who reported that obesity increased the risk of mortality and considerably increased the risk of poor health in the 18-year follow-up of older adult women born between 1921 and 1926.

Anthropometry is an important nutritional indicator in addition to weight, height, circumferences, and body mass index (BMI) in older adults. However, anthropometric measurements and BMI, which are widely used in clinical practice, do not assess body composition or distribution. Thus, older adults with similar BMIs may have different body compositions (Santos et al, 2013; Previato et al, 2014; Batsis et al, 2016; Kıskaç et al, 2022).

The distribution of body fat changes with age, becoming more centralized in the trunk, as well as increased infiltration into muscle tissue. Accumulation of fat in the hips appears to have a benign cardiovascular effect, whereas accumulation in the waist and a high waist-to-hip ratio are associated with mortality (de Koning et al, 2007; Coutinho et al, 2011).

Mortality is correlated with BMI in a U-shaped curve pattern (Donini et al, 2020), including in the oldest old patients (Lv et al, 2022). This paradox involves lipid metabolism, N-terminal pro-B-type, natriuretic peptides, prothrombotic factors, ghrelin, production of cytokines such as tumor necrosis factor and adipokines, and increased
mobilization of endothelial progenitor cells (Donini et al., 2020). However, in a systematic review of older adults, 20 of 58 studies did not find evidence of an obesity paradox. Nevertheless, obesity is associated with comorbidities or acute diseases (Drame and Godaert, 2023).

The UK National Institute for Health and Care Excellence guidelines (2023) indicate that the waist-to-height ratio is more accurate than BMI in estimating central adiposity, regardless of ethnic and sex differences.

Although bioimpedance analysis (BIA), ultrasonography (US), computed tomography (CT), magnetic resonance imaging (MRI), and dual-energy X-ray absorptiometry (DXA-gold standard) allow the determination of the percentages of fat and lean mass, they have the disadvantages of high cost and operational complexity (Santos et al., 2013), which mainly affect their use in underdeveloped countries.

Considering the importance of body fat estimation, alternatives that may be useful and feasible have been investigated (Previato et al., 2014). Bergman et al. (2011) proposed the body adiposity index (BAI) as a method to estimate the percentage of body fat in both men and women by measuring hip circumference (HC) and height. The BAI was developed using data from the “BetaGene study” and validated in the “Triglycerides Cardiovascular Risk in African-Americans (TARA)” study; some of the advantages of this index, in addition to its use when an accurate weight measurement is not possible, are that it does not require normalization or numerical correction.

Chang et al. (2014) were the first to apply the BAI in older adults, including 954 older adults aged 55–96 years from “The Baltimore Longitudinal Study of Aging” (BLSA). They showed that compared to DXA, the BAI was an accurate measure of adiposity in both white and black races and in women, but not in men (BMI worked better).
Segheto et al (2016) applied the BAI to 706 Brazilians with a mean age of 36 years, residing in the state of Minas Gerais. In this study of a probabilistic population sample, the researchers observed an overestimation of fat percentage by BAI in men and an underestimation in women using DXA as the reference (concordance/Kaplan-Meier = 41%).

Therefore, in the present study, we evaluated whether BAI and BMI may be useful for predicting body fat in independent long-lived older adults and be used as an alternative to (DXA), which is rarely used in clinical practice.

MATERIAL AND METHODS

Study type: Observational, cross-sectional.

Patients: This study included older adults aged ≥80 years who were independent, without cognitive impairment or serious illnesses, with compensated chronic illnesses, and living in the community. These individuals had been followed up since 2010 at the outpatient clinic of the Discipline of Geriatrics and Gerontology at the Federal University of São Paulo, UNIFESP, São Paulo, Brazil. All participants signed an informed consent form after being informed about the study, and the research project was approved by the ethics committee (number 0225/2017). This study analyzed data from 2014 to 2016, which included 167 individuals. Of these, 10 individuals were excluded: eight for incomplete data and one individual each for body fat percentages <20% and >55%, respectively, measured by DXA (Chang et al, 2014). None of the patients smoked.

Study variables: Data on comorbidities and medications in use were reported by the patients and also obtained from their medical records. Serum creatinine levels were measured in the peripheral blood using an automated technique. Body weight was measured using a Plenna® digital scale (with a maximum capacity of 150 kg) with the
individuals barefoot and wearing at least their own clothes. While stepping on the scale, the participants were instructed to remain upright. The average of three consecutive weight measurements was used for analysis. Height of the participants was measured using a non-extensible measuring tape fixed to the wall without a skirting board. The participants remained in erect standing position without shoes. The measurement was taken during expiration with the participants’ gaze on the horizon (forming a 90° angle between the chin and neck), and the value was marked with a measuring scale at the top of the head. The BMI was calculated as the ratio of weight (kg) to the square of height (m). The BMI cutoffs for normality or eutrophy, malnutrition, overweight, and obesity were 23–28 kg/m², <23 kg/m², 28–30 kg/m², and >30 kg/m², respectively (SABE, 2003). This BMI classification included patients living in São Paulo, Brazil, and was similar to other classifications proposed for older adults (Kiskäç et al, 2022). HC was measured using a non-extensible measuring tape that circled the hip in the region with the greatest perimeter between the waist and thigh, with the individual in an orthostatic position wearing thin clothes (ISKA, 2001). The BAI was calculated according to the formula proposed by Bergman et al (2011), as follows.

\[
\text{BAI} = \left[ \frac{\text{HC (cm)}}{\text{height (m)}} \times (\text{square root})\text{height(m)} \right] - 18
\]

No cutoff points for BAI normality are available for older adults. DXA was performed using Hologic equipment by a trained professional with experience in radiological measurements at the Research Laboratory of the Discipline of Endocrinology at the Federal University of São Paulo. This non-invasive technique is the gold standard for measuring body fat, is considered safe, and can measure three body components: fat mass, fat-free mass, and bone mass (Jackson et al, 1980; Lohman, 1992 Paiva et al, 2002). 

Statistical analysis: We performed the statistical analyses using IBM SPSS Statistics for Windows, version 21.0. The Kolmogorov–Smirnov test was used to verify the normality
of the distributions of continuous variables. The Z-score was used to standardize data that did not follow the normality curve. Continuous variables are represented as means and standard deviations, whereas categorical variables are represented as absolute frequencies and percentages. We applied the univariate general linear model (GLM) test to compare variables between sexes. The significance level was set at $p < 0.05$. We analyzed categorical variables using the chi-squared test. We also used Pearson's correlations, Bland–Altman scatterplots, and Cronbach’s $\alpha$ coefficients to compare the reliability between the methods for measuring body composition.

RESULTS

We analyzed data from 157 long-lived older adults, including 42 (26.8%) men and 115 (73.2%) women, aged 80–100 years. We did not observe any differences between the sexes in terms of the number of comorbidities (Table 1). Men had a lower percentage of total fat, as assessed by DXA, and lower BAI indices than women. The BAI values in both men and women showed a moderate positive correlation with DXA and a strong positive correlation with BMI (Table 2) (Dancey and Reidy, 2006).

We observed a positive correlation between BAI and DXA in the total sample and according to sex (Figure 1a, c, e). This dispersion of data suggests an agreement between methods. The Bland–Altman dispersion plots in Figures 1b, 1d, and 1f confirm the trends observed in the Pearson correlation plots. For the total sample of 157 individuals, the difference between the methods was $-15.06$ ($-15.80$ to $-14.81$) with limits of agreement for 95% of the cases (mean ± 1.96 standard deviation [SD]) between $-24.32$ and $-5.79$. We observed an underestimation of the values using the BAI compared with those using DXA, with only 4.45% of the sample “not meeting” the 95% agreement limit range. We confirmed the reliability of the measurements using Cronbach's $\alpha$ ($\alpha = 0.78$). In men ($n = 42$), the difference between the methods was $-11.85$ ($-13.12$ to $-10.53$) with limits of
agreement for 95% of the cases (mean ± 1.96 SD) between −19.97 to −3.67. We also observed an underestimation of the IAC values compared with those using DXA, with only 2.38% not adhering to the 95% agreement limit. We confirmed the reliability using Cronbach's α (α = 0.67). In women (n = 115), we observed a difference of −16.24 (−17.05 to −15.43) between the methods, with limits of agreement for 95% of the cases (mean ± 1.96 SD) between −24.81 and −7.67. We also observed data underestimation for BAI values compared with those using DXA, with only 4.34% of these older adult women not adhering to the 95% concordance limit. We confirmed the reliability based on the Cronbach's α value (α = 0.77).

DISCUSSION

This cross-sectional study was conducted on a uniquely old independently living population in Sao Paulo, Brazil to compare anthropometric measurements of BAI and BMI with fat percentage measured using DXA. This study aimed to identify whether the BAI would add information as a surrogate measure of body fat for this population.

In the present study, BAI showed a moderate correlation with the fat percentage assessed by DXA in both sexes, mainly in women, similar to other studies conducted in younger Brazilian populations (Barreira et al, 2011; Godoy-Matos et al, 2011; Silva et al, 2013; Dias et al, 2014; Gonçalves et al, 2014; Souza et al, 2014; Guedes et al, 2015; Segheto et al, 2016) and in other countries that included a small proportion of older adults (Bergman et al, 2011; López et al, 2012; Johnson et al, 2012; Sun et al, 2013). However, no studies have included only long-lived older adults; thus, no comparison with the present study is possible.

Studies on older adults are heterogeneous as they consider both robust and frail patients, with multiple comorbidities and different smoking habits being factors that modify the impact of obesity on mortality (Donini et al, 2020; Watanabe et al, 2024).
Even in the BLSA study, the average age was 70.4 +/- 9.5 (in those aged 65 and over), i.e., the study did not include exclusively long-lived people (Chang et al, 2014). Thus, the novelty of the present study and its main difference with the BLSA is the inclusion of exclusively long-lived older adults.

In the BLSA study (Chang et al, 2014), BAI was not a good predictor of fat percentage; BAI tended to be overestimated in older adults with <15% fat (as assessed by DXA), and underestimated for those with a high body fat percentage (40% as assessed by DXA). The linear regression model that included BAI explained 56% of the variance in fat percentage, whereas the model that included BMI explained 33% of the variance (interaction terms of sex x BMI were significant).

In the present study, we observed an underestimation of BAI values compared with those using DXA for both men and women, contrary to the findings in older adults reported by Chang et al (2014), which showed that BAI was an accurate measure of adiposity in older women. In contrast, in a study of a younger Brazilian population, Segheto et al (2016) reported an overestimation of the BAI in men and an underestimation in women compared with DXA values as the reference (concordance/Kaplan-Meier = 41%).

Thus, determining body adiposity in older individuals can be challenging, both in large population studies and in clinical practice, owing to the gold-standard DXA method being expensive; moreover, the equipment is not portable and requires several procedures to perform the test (López et al, 2012; Chang et al, 2014). Bergman et al (2011) suggested using the BAI to minimize the challenges of costs and technical training requirements in clinical practice, proposing an index with simple measurements and low cost to identify the amount of body fat. In older adults, this scenario must be evaluated with greater caution because of the body transformations that occur with age.
Height tends to reduce with increasing age due to changes in vertebral morphology, which results in an overestimation of BMI. In contrast, the BAI, which considers HC, offers an advantage because it can be obtained with less difficulty than other anthropometric measures.

Why is HC and not waist circumference a key variable for estimating body fat? Bergman et al (2011) used data from the “BetaGene” population study to develop the BAI. The percentage of body fat, as measured using DXA, was used as the “gold standard” for validation, and the authors used two characteristics to select the parameters for the new index. First, they considered the values with the strongest correlation with adiposity percentage: HC and height. They expected that the new surrogate index would be related to the ratio of HC to height, owing to the correlation being positive for HC and negative for height. The second consideration was independence; the minimal absolute correlation between the chosen variables suggested that they may contribute independent information to the prediction of adiposity percentage. Therefore, the authors concluded that the BAI can reflect body fat percentage in adult men and women of different ethnicities without numerical correction. In contrast, waist circumference, another frequently used anthropometric measure, reflects abdominal adipose tissue and cannot be used to distinguish deposits of visceral (VAT) and subcutaneous fat (SAT) (Kullberg et al, 2007; Bosy-Westphal et al, 2010; Cameron et al, 2012). However, no published studies have proposed a physiological explanation for the relevance of HC in estimating adiposity percentage. Therefore, further research on this topic is required.

BAI can be a good predictor of body fat (Bergman et al, 2011; Godoy-Matos et al, 2011; Johnson et al, 2012; Sun et al, 2013; Silva et al, 2013, Chang et al, 2014; Dias et al, 2014); however, it should only be used in combination with other data (López et al, 2012; Gibson et al, 2012; Freedman et al, 2012; Souza et al, 2014; Guedes et al, 2015).
and Segheto et al., 2016). BAI estimates body fat, whereas BMI estimates nutritional status (Johnson et al., 2012; Segheto et al., 2016); furthermore, BMI does not differentiate between fat and lean mass (Sung, Oh and Lee, 2014), and is not as accurate (Appelhans et al., 2012; Freedman et al., 2012). Therefore, the question remains: what is the best anthropometric index for measuring obesity in the oldest old? We hope that our study findings help answer this question.

**Study strengths and limitations:**

The main strength of this study is its casuistic nature: we included older adults aged ≥80 years without serious health problems. During follow-up, we observed that the participants compensated for their chronic diseases. We believe that these patients survived despite being obese because they had fewer factors that could aggravate obesity. However, as this was a cross-sectional study, we could not explore whether BAI and BMI have different predictive powers for adverse outcomes in this group of patients.

**CONCLUSION**

In conclusion, BAI in combination with BMI can be an alternative to DXA in clinical practice for the assessment of body fat in the oldest old patients, mainly women.

**Declaration of competing interest** The authors declare no conflicts of interest or financial support.

**Declaration of Generative AI and AI-assisted technologies in the writing process:**
The authors declare that no generative AI or AI-assisted technologies were used in the writing process.

**Author contributions:** EDS - conceptualization, data curation, formal analysis, validation, and writing - original draft. FKF, VAC, and RAS - data curation, investigation,
and methodology. GWB - validation, and writing - review and editing. MSC - conceptualization, formal analysis, investigation, project administration, supervision, validation, visualization, and writing - original draft and review and editing.