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Original Research Article

Predictive Validity of the Body Adiposity Index in Costa Rican Students

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Objective: To verify the validity of the body adiposity index (BAI) in a sample of Costa Rican students.
Methods: Volunteers were 93 females (mean age = 18.6 ± 2.4 years) and 106 males (mean age = 19.2 ± 2.8 years). Dual-energy X-ray absorptiometry (DXA) was used as the "gold standard" to determine body fat percentage (BF%). Pearson's correlation coefficient and paired samples *t*-test studied the association and mean differences between BAI and DXA BF%. Concordance between BAI and DXA BF% was determined by the Lin's concordance correlation coefficient and the Bland-Altman agreement analysis.
Results: Significant correlations between BAI and DXA BF% were found for females ($r = 0.74$) and males ($r = 0.53$) ($P < 0.001$). Differences between methods were found for females (BAI = 29.3 ± 4.1% vs. DXA = 36.5 ± 7.9%) and males (BAI = 24.8 ± 3.7% vs. DXA = 21.9 ± 8.6%; $P < 0.001$). Concordance was poor in females and males. Bland-Altman plots showed BAI underestimating and overestimating BF% in relation to the "gold standard" in females and males, respectively.
Conclusions: BAI presented low agreement with BF% measured by DXA; therefore, BAI is not recommended for BF% prediction in this Central American sample studied. Am. J. Hum. Biol. 28:394–397, 2016.

INTRODUCTION

Several adiposity indexes such as the body mass index (BMI = body weight in kg/body height in m^2) and others have been computed based on basic anthropometric measures such as body height, weight, waist, and hip circumferences. These methods are preferred in large-scale studies over more expensive and laborious ones such as magnetic resonance imaging or dual-energy X-ray absorptiometry (DXA) (Chang et al., 2014; Silva et al., 2013).

The BMI has been extensively used due to its low cost, easiness to obtain, and precision (Sun et al., 2013; Sung et al., 2014). However, BMI has been reported to lack accuracy to assess body fatness (body fat percentage, BF%), and is different for males and females with similar proportions of body adiposity (Gupta and Kapoor, 2014; Zwierzchowska et al., 2013). To diminish these limitations, a new adiposity index called the "body adiposity index" (BAI) has been proposed, and is currently under evaluation in different populations (Bergman et al., 2011; Gupta and Kapoor, 2014). BAI is calculated from hip circumference and height measures as follows (Bergman et al., 2011): BAI (% fat) = (hip circumference [cm]/height $[m]^{1.5}$) − 18. The equation was developed from data obtained from 1,733 Mexico-American participants (675 males, 1,058 females), aged 18–67. The formula was validated with data from BF% obtained in the same population using DXA as the "gold standard," and showing an association and concordance between the two methods. Therefore, the authors concluded that BAI is a valid formula to estimate BF% in this population (Bergman et al., 2011). The authors cross-validated their formula in a new population comprised 223 African-American participants (97 males, 126 females) aged 20–50. The results confirmed BAI as a valid predictor of BF% when compared to data obtained with DXA.

Since BAI is a relatively new index, validation studies performed in other populations are still scarce and controversial (Cerqueira et al., 2013; Kuhn et al., 2014). For instance, BAI has been shown to be valid for North Indian populations (Gupta and Kapoor, 2014) and nondialyzed chronic kidney disease patients (Silva et al., 2013). In one study by Silva et al. (2013), 134 patients (mean age = 64.9 ± 12.5 years) with chronic kidney disease were assessed to determine what method (i.e., BAI, bioelectrical impedance, and skinfolds) showed higher accuracy compared to DXA. A significant correlation was found between BF% values obtained with DXA and the data estimated with BAI and skinfolds (0.82 and 0.61, respectively). The bioelectric impedance method showed the lowest correlation with DXA, and the highest concordance (from Bland-Altman analysis) was obtained between DXA and BAI. Therefore, the authors supported the predictive validity of BAI for determining BF% in nondialyzed chronic kidney disease patients (Silva et al., 2013).

However, BAI has not been shown to be valid for other populations, for instance, Buryat men and women living in China (Zhao et al., 2013), a general population of China (Zhang et al., 2014), a European population in Norway (Vinknes et al., 2013), young and older overweight and obese women (Siervo et al., 2014), Brazilian women (Cerqueira et al., 2013) and children (El Aarbaoui et al., 2013). An example of the unsupported validity of the BAI for predicting BF% is the study on 1,707 females and 680 males aged 51–77 from China (Zhang et al., 2014). Participants were studied to evaluate the correlation between BF% measured using DXA and BAI. The results showed that although there was a correlation between BF% obtained from both methods, there was also a poor agreement based on the Bland-Altman analysis; BAI underestimated

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BF% in females (5.8%) and tended to overestimate BF% in males (0.28%).

In other populations, BAI has been shown to be valid for males but not for females (Zwierzchowska et al., 2013), and for non-obese participants rather than for overweight and obese participants (Sun et al., 2013). In Americans, BAI provided a valid estimation of body adiposity in an older adult population; however, BAI was not accurate in people with extremely low or high BF%s (Chang et al., 2014). In a study of 5,193 Europeans aged 47–74, BF% was obtained with DXA to determine the predictive validity of BAI. Adiposity values obtained with both methods were significantly correlated ($r = 0.78$); however, the Bland-Altman agreement analysis indicated that BAI only predicted BF% in participants with normal BF%, overestimated BF% in those with low BF%, and underestimated BF% in those with high BF% (Vinknes et al., 2013).

Since BAI has not been validated in Central American populations, this study was designed to verify the predictive validity of BAI in a sample of Costa Rican university students, using DXA as the reference method.

METHODS

Participants

Volunteers were 199 college students, 106 males, and 93 females (mean age = 18.9 ± 2.6 years). Participants were registered in different groups of a mandatory course of physical activity. The Institutional Ethics Committee in accordance with the latest version of the Declaration of Helsinki approved the study. After reading and signing an informed consent to participate in the study, volunteers were given an appointment for a testing session at the Body Composition Laboratory in the Human Movement Sciences Research Center (CIMOHU) at the University of Costa Rica.

Design and procedures

This was a cross-sectional analytical study where participants were measured only one time. Participants attended a previously scheduled testing session at CIMOHU during their regular class meeting. After completing a questionnaire of general information, participants were instructed to wear a short, a t-shirt, and remove any metal and jewelry from their persons. Height determined by stadiometry (Novel Products Inc., Rockton, IL) and scale weight (Tanita, model BF-350, Arlington Heights, IL) were recorded to the nearest 0.5 cm and 0.1 kg, respectively. Percent body fat for each participant was determined by a whole body DXA scan (Lunar Prodigy Advance, General Electric, Madison, WI), a device that uses direct-digital array detector and narrow-angle fan-beam (4.5° angle) technology to enhance measurements. Scans were performed and analyzed by the same trained operator, according to the laboratory standard protocol. To ensure data quality the equipment has been calibrated daily using a known calibration standard following manufacturer instructions.

Hip circumference (cm) was measured with a Gulick self-locking vinyl tape at the level of maximal girth of hip above the gluteal fold (American College of Sports Medicine, 2014). BAI was calculated from hip circumference and height as previously described (Bergman et al., 2011).

Statistical analysis

Statistical analyses were performed using SPSS for Windows version 21.0 (IBM Corporation, New York).

TABLE 1. Descriptive statistics for the sample (n = 199)

Variable	Males ($n = 106$) $M \pm SD$	Females ($n = 93$) $M \pm SD$	$P \leq$
Age (years)	19.2 ± 2.8	18.6 ± 2.4	0.087
Height (cm)	173.1 ± 7.0	161.5 ± 7.1	0.001
Weight (kg)	68.4 ± 11.8	58.2 ± 11.3	0.001
Hip circumference (cm)	97.3 ± 7.6	96.8 ± 8.3	0.627
BMI (kg/m^2)	22.8 ± 3.3	22.3 ± 3.6	0.281
Body fat (BAI, %)	24.8 ± 3.7	29.3 ± 4.1	0.001
Body fat (DXA, %)	21.9 ± 8.6	36.5 ± 8.0	0.001

P values are shown for between-gender comparisons.

Statistical significance was set at $P < 0.05$. The DXA method was used as the "gold standard" to determine BF%. Independent samples *t*-test were performed between genders to determine differences in BF% and anthropometric characteristics (Table 1). Pearson's correlation coefficient was used to evaluate the association between BAI and BF% assessed by DXA by gender. In addition, for each gender, paired samples *t*-tests were used to test differences in mean BF% obtained with BAI and DXA methods. Lin's concordance correlation coefficient was used to assess the reproducibility between BAI and DXA by gender (Lin, 1989). Lin's strength of agreement (ρ_c) was considered poor (< 0.90), moderate (0.90–0.95), substantial (0.95–0.99), or almost perfect (>0.99) (Lin, 1989; McBride, 2005). The plot of the differences between DXA and BAI was studied by the Bland-Altman procedure (Bland and Altman, 1986).

RESULTS

Descriptive statistics and between-gender comparisons are shown in Table 1. Significant ($P < 0.001$) Pearson's correlation coefficients between BF% obtained by DXA and that estimated by BAI were found to be strong for females ($r = 0.74$) and moderate for males ($r = 0.53$) (Taylor, 1990).

Further analyses are presented by gender since significant within-gender differences were also found on BF% measured by DXA and estimated by BAI. For females, a paired *t*-test showed a significant mean difference in BF% between methods (BAI = 29.3 ± 4.1% vs. DXA = 36.5 ± 7.9%; $P < 0.001$). The bias of the BAI was −7.2 ± 5.6 BF% (*95% CI* = −8.4 to −6.1), indicating that the BAI method significantly underestimated the BF% compared to the DXA method. For males, a paired *t*-test showed a significant mean difference in BF% between methods (BAI = 24.8 ± 3.7% vs. DXA = 21.9 ± 8.6%; $P < 0.001$). The bias of the BAI was 2.9 ± 7.4 BF% (95% CI = 1.5–4.3), indicating that the BAI method significantly overestimated the BF% compared to the DXA method.

For females and males, the Lin's concordance correlation coefficient was poor, $\rho_c = 0.36$ (95% CI = 0.27–0.45) and $\rho_c = 0.35$ (95% CI = 0.24–0.45), respectively (Lin, 1989). The Bland-Altman plot (Figs. 1 and 2) showed BAI underestimating and overestimating BF% in relation to the "gold standard" in females and males, respectively. These plots suggest that differences between the two methods exhibit a regular obvious pattern (proportional bias), with underestimation in females with higher BF% and overestimation of BF% by the BAI in males with lower BF%. Indeed, this visual information is verified by the percentage of participants classified as not overweight, overweight, and obese based on their BAI and

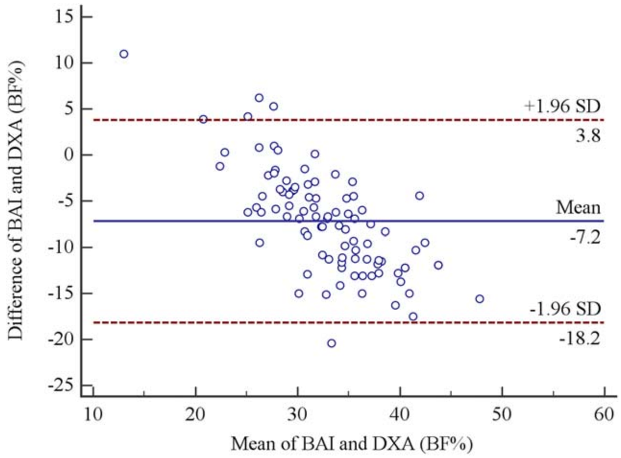

Fig. 1. Agreement limits of Bland-Altman between the BF% estimated by BAI and measured by DXA. The Bland-Altman plot depicts BAI underestimating and overestimating BF% in relation to the "gold standard" DXA in females.

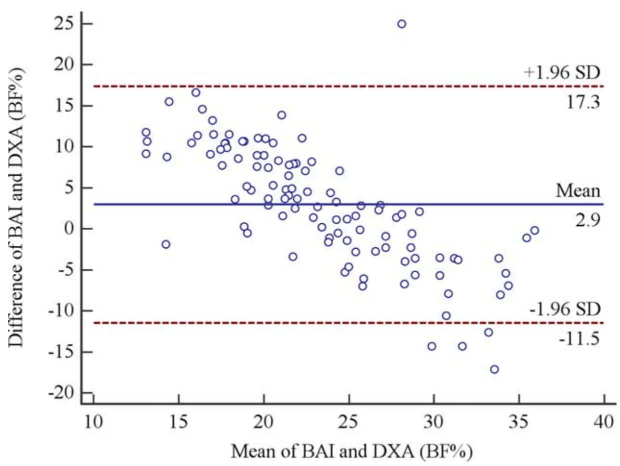

Fig. 2. Agreement limits of Bland-Altman between the BF% estimated by BAI and measured by DXA. The Bland-Altman plot depicts BAI underestimating and overestimating BF% in relation to the "gold standard" DXA in males.

DXA BF% scores (Table 2). For males, the overweight category was defined as BF% = 21–24 and for females was BF% = 31–36; the obese category was defined as BF% > 24 for males and > 37 for females (Jeukendrup and Gleeson, 2010).

DISCUSSION

The purpose of the study was to assess the predictive validity of BAI to estimate BF% in a sample of Costa Rican university students. The main finding was the lack of predictive validity of BAI for estimating BF% compared to DXA in females and males. Therefore, BAI is not recommended in this Central American population. The Bland-Altman plots showed a trend of BAI to overestimate adiposity in males and underestimate adiposity in females in relation to the criterion measure DXA (Figs. 1 and 2).

TABLE 2. Body weight classification based on BAI and DXA body fat scores. Values are percentages (n = 199)

	Males (n = 106)		Females (n = 93)	
Category	Body fat (BAI)	Body fat (DXA)	Body fat (BAI)	Body fat (DXA)
Not overweight	8.5	52.8	68.8	22.6
Overweight	34.9	6.6	25.8	21.5
Obese	56.6	40.6	5.4	55.9

Although BAI has been recommended in some studies as a useful and practical tool for predicting BF% (Bergman et al., 2011; Chang et al., 2014; Kuhn et al., 2014; Sun et al., 2013), caution is warranted due to its inaccuracy. In this study, BAI and DXA BF% showed significant high and moderate correlation coefficients in females and males, respectively. However, the BAI showed poor concordance (McBride, 2005), accuracy, and precision when examined with t-tests, Lin's concordance coefficient, and Bland-Altman plots. Therefore, conclusions drawn from simple correlational analysis (e.g., Pearson) are insufficient to support the usefulness of BAI since concordance between methods requires other analytical techniques (Silva et al., 2013). For example, the Lin's concordance coefficient correlation is a technique necessary to estimate the association between two measurement methods (Lin, 1989). This technique combines the precision and accuracy to determine to what extent the observed data from both methods deviate from perfect agreement as well as their reproducibility (Bergman et al., 2011; Silva et al., 2013). The Bland-Altman method also provides information regarding the agreement or disagreement between different measurement methods (Bergman et al., 2011; Bland and Altman, 1986; Zhang et al., 2014). Both analytical techniques were included in this study.

A plausible explanation for the lack of predictive validity of BAI in some populations is that the difference in anthropometric and body composition profiles between ethnic groups may result in changes in the distribution of body fat in the participants (Cerqueira et al., 2013; Kuhn et al., 2014; Sung et al., 2014). In addition, in some populations weight gain is hardly associated with increases in hip circumference but rather with waist circumference (Vinknes et al., 2013). The original BAI equation does not take into consideration gender, age, and waist and hip information (Bergman et al., 2011).

To the best of our knowledge, this is the first attempt to validate the BAI equation in a Central American sample. We have provided evidence for a lack of predictive validity and congruence between BAI and DXA in Costa Rican young university students. Yet, we recognize that this is, likewise, a limitation of our study given the homogenous nature of the sample (i.e., young university students). In addition, we recognize that the sample must be larger and heterogeneous when conducting validation studies. However, data collection devices and statistical analyses were appropriate and powerful to detect significant differences and associations (or lack of) between methods in males and females. This is a novel finding and supports our case for avoiding the use of BAI in this population.

In general, our results are in agreement with previous findings where the predictive validity of BAI has been studied in females (Cerqueira et al., 2013; Sung et al., 2014), males (González-Ruíz et al., 2015), and mixed samples (i.e., male and females) (Kuhn et al., 2014; Zhang et al., 2014). For instance, in females, the present findings are similar to those found in 102 Brazilian women aged 35–83 years (Cerqueira et al., 2013), where BAI-estimated BF% was compared to values obtained from DXA. The authors reported a significant difference between the BF% values obtained with these methods. Indeed, a poor between-method agreement was obtained (Lin's = 0.73). Furthermore, the Bland-Altman analysis revealed that BAI underestimated BF% values in participants with higher BF% while overestimating the BF% in participants with lower BF% (Cerqueira et al., 2013).

The results presented here are also consistent with findings from 2,950 Korean females aged 18–39 (Sung et al., 2014). Participants underwent anthropometric evaluations to determine BMI and BF% via bioelectrical impedance analysis. Then, the accuracy of BAI to predict BF% was studied using the bioelectric impedance method as the reference method. The main finding reported was that BAI was not superior to BMI for predicting BF% (Sung et al., 2014). For males, the results presented here are in agreement with those found in a 204 Colombian males (mean age = 23.6 ± 4.6 years) (González-Ruíz et al., 2015). In the study, the predictive validity of BAI was compared to the bioelectric impedance method (used as the reference method), and the results showed that BAI overestimated the BF% compared to bioelectric impedance.

Our results follow a pattern similar to a previous report from a large mixed sample of Chinese participants (i.e., 680 males and 1,707 females) (Zhang et al., 2014). In general, the researchers attempted to study the predictive validity of the BAI equation and found significant correlations between BF% estimated with BAI and measured by DXA (Zhang et al., 2014); however, the concordance between methods was poor as detected by the Bland-Altman procedure, given that BAI underestimated the body adiposity of females and overestimated it in males.

As described above, the findings of this study are similar to previous reports in males (González-Ruíz et al., 2015), females (Cerqueira et al., 2013), and mixed samples (Chang et al., 2014; Kuhn et al., 2014; Vinknes et al., 2013). BAI follows an obvious pattern of overestimation of adiposity in those with low adiposity and underestimation of adiposity in those with high adiposity. Therefore, new BAI validation studies for different populations are yet to come.

In conclusion, BAI is not recommended for estimating BF% in Costa Rican university students. In addition, caution is warranted when using BAI since this equation, like any other indirect methods for estimating BF%, has inherent limitations that may lead to underestimating or overestimating the BF% in the population.

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