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Original article

Evaluation of body adiposity index (BAI) to estimate percent body fat in an indigenous population

Patricia C. Kuhn [a], João Paulo B. Vieira Filho [a], Luciana Franco [a], Amaury Dal Fabbro [b], Laercio J. Franco [b], Regina S. Moises [a,*]

[a] Disciplina de Endocrinologia, Escola Paulista de Medicina, Universidade Federal de São Paulo, São Paulo, SP, Brazil
[b] Departamento de Medicina Social, Faculdade de Medicina de Ribeirão Preto, Universidade de São Paulo, Ribeirão Preto, SP, Brazil

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SUMMARY

Background & aims: The aim of this study was to evaluate the usefulness of Body Adiposity Index (BAI) as a predictor of body fat in Xavante Indians and to investigate which anthropometric measures of adiposity best correlate with body fat in this population.
Methods: We evaluated 974 individuals (476 male), aged 42.3 ± 19.5 years. Percentage of body fat (%BF) determined by bioimpedance analysis (BIA) was used as the reference measure of adiposity. Bland–Altman analysis was used to assess the agreement between the two methods: BAI and BIA. Associations between anthropometric measures of adiposity were investigated by Pearson correlation analysis.
Results: BAI overestimates %BF (mean difference: 4.10%), mainly at lower levels of adiposity. Significant correlations were found between %BF and all measurements, being the strongest correlation with BAI. However, stratified analyses according to gender showed that among men waist circumference has the strongest correlation ($r = 0.73$, $p < 0.001$) and among women BAI ($r = 0.71$, $p < 0.001$), BMI ($r = 0.69$, $p < 0.001$) and waist circumference ($r = 0.70$, $p < 0.001$) performed similarly.
Conclusion: BAI can be a useful tool to predict %BF in Xavante Indians, although it has some limitations. However, it is not a better predictor of adiposity than waist circumference in men or BMI and waist circumference in women.

1. Introduction

Obesity, a complex and multifactorial condition, is characterized by excess of body fat and involves genetic predisposition and environmental factors. Its prevalence has increased over the last decades being recognized as a major public health concern.[1] Obesity, particularly abdominal obesity, is associated with an increased risk of type 2 diabetes, cardiovascular disease, non-alcoholic fatty liver disease, premature mortality and certain types of cancer.[2,3]

Body mass index (BMI) is the most used tool to identify overweight or obese individuals. According to World Health Organization (WHO) overweight is defined as BMI between 25 and 29.9 kg/m^2 and obesity as BMI $\geq$ 30 kg/m^2.[1] However, these cut-off values may be inappropriate for some ethnic groups since using this anthropometric index it is not possible to distinguish body fat from lean mass.[4–6] Other indirect adiposity measures such as waist circumference, waist-hip ratio, waist-to-thigh ratio are used to diagnose abdominal obesity. Recently, Bergman et al. developed a new index, body adiposity index (BAI), as a parameter of adiposity.[7] This index could estimate percent body fat in both men and women without the need of statistical correction. Following this initial report other studies investigated the performance of BAI in predicting body fat.[8–12] However, depending of the population studied, results have been inconsistent.

Xavante is an indigenous population living in Mato Grosso State, Central Brazil. They are one of the largest native groups in Brazil, comprising approximately 10,000 individuals.[13] This indigenous people are experiencing a rapid and significant increase in fatness in the last decades.[14,15] Consequently, diagnosis and treatment of

Abbreviations: BAI, body adiposity index; BMI, body mass index; WHO, World Health Organization; CONEP, Brazilian National Ethics Commission; WHR, waist-to-hip ratio; %BF, percentage of body fat; BIA, bioelectrical impedance analysis.

* Corresponding author. Disciplina de Endocrinologia, Escola Paulista de Medicina, Universidade Federal de São Paulo, Rua Pedro de Toledo, 781 – 12 andar 04039-001 São Paulo, SP, Brazil. Tel.: +55 11 5576 4744; fax: +55 11 5579 6636.
E-mail addresses: pkuhn@unifesp.br (P.C. Kuhn), botelhovieira@hotmail.com (J.P.B. Vieira Filho), luciana_franco@yahoo.com (L. Franco), aafabbro@fmrp.usp.br (A. Dal Fabbro), lfranco@fmrp.usp.br (L.J. Franco), rmoises@unifesp.br (R.S. Moises).

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overweight and obesity is an important health issue in this population.

The aim of this study was to investigate the usefulness of BAI as a predictor of body fat in Xavante Indians. Furthermore, we tested which anthropometric measure of adiposity best correlated with body fat in this population.

2. Methods and procedures

2.1. Study population

A cross-sectional study was performed in the Xavante population from two indigenous reserves (Sangradouro and São Marcos) located in Mato Grosso State, central region of Brazil, from January 2009 to January 2012. For this current analyses, were excluded pregnant women, subjects with missing data and aged less than 18 years. The study sample consisted of 974 individuals (476 male, 498 female), aged 42.3 ± 19.5 years (range 18–99 years).

The Indian leaders and the study participants were informed about the purposes of this research and gave their written consent. Participants that were illiterate gave their approval through fingerprint signature. A Xavante health agent worked as an interpreter when necessary. This study was approved by Ethics Committee of Escola Paulista de Medicina, Universidade Federal de São Paulo and Brazilian National Ethics Commission (CONEP).

2.2. Anthropometrical measurements and calculations

All measurements were made in the morning with subjects wearing light clothes and barefoot. Weight was measured using a portable digital scale and height using a stadiometer. BMI was calculated as the ratio of weight (kilograms) to the square of height (meters). Measures of circumference were made using an inelastic tape. Hip circumference was measured at the level of the greater trochanter and waist circumference at the midpoint between the lowest rib and the iliac crest. Waist-to-hip ratio (WHR) was calculated by dividing the waist circumference (cm) by the hip circumference (cm). BAI was calculated as proposed by Bergman et al.: BAI = (hip/height^{1,5}) − 18 (7). Percentage of body fat (%BF) was determined by bioelectrical impedance analysis (BIA) (BioDynamics BIA 450 Body Composition Analyzer, Seattle, WA, USA) and was used as the reference measure of adiposity.

2.3. Statistical analysis

Differences in continuous variables between groups were evaluated by unpaired *t*-test. Paired *t*-test was used to test differences between %BF by BIA and BAI. Univariate associations between

Table 1
Characteristics of study subjects as a whole and by sex.

	Total (n = 974)	Men (n = 476)	Women (n = 498)	P
Age (years)	42.3 ± 19.5	42.7 ± 19.3	41.8 ± 19.6	0.47
Height (m)	1.6 ± 0.08	1.67 ± 0.05	1.54 ± 0.05	0.0001
Weight (kg)	78.6 ± 15.2	83.5 ± 14.2	73.9 ± 14.8	0.0001
Waist (cm)	97.1 ± 10.9	95.5 ± 10.5	98.5 ± 11.1	0.0001
Hip (cm)	101.2 ± 9.8	99.7 ± 8.3	102.6 ± 10.9	0.0001
WHR	0.96 ± 0.05	0.95 ± 0.06	0.96 ± 0.05	0.24
%BF	27.6 ± 7.8	22.5 ± 6,1	32.5 ± 5.8	0.0001
BMI (kg/m^2)	30.2 ± 5.1	29.7 ± 4.5	30.7 ± 5.6	0.003
BAI	31.7 ± 5.9	28.07 ± 3.7	35.2 ± 5.5	0.0001
BMI ≥ 30 (kg/m^2)	448 (46%)	277 (47.6%)	261 (52.4%)	0.001

Data are expressed as mean ± SD or *n* (%).
P values are given for comparison between men and women.

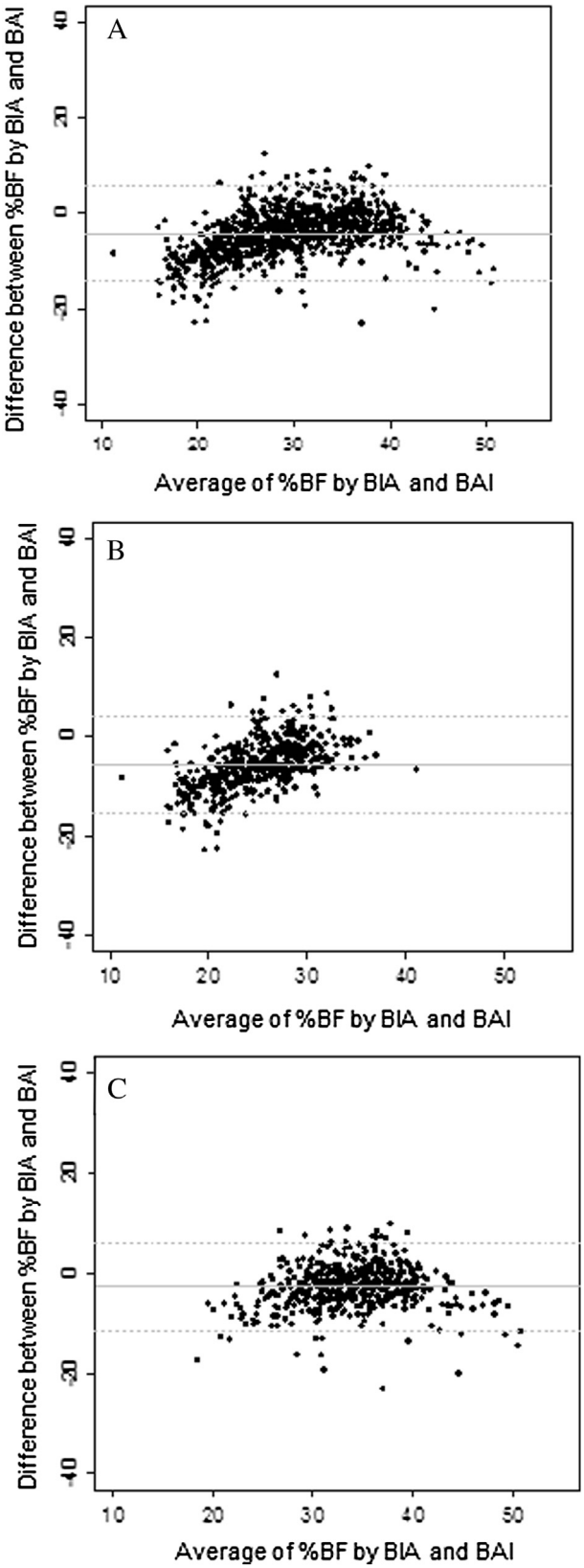

Fig. 1. Bland Altman plots of %BF assessed by bioelectrical impedance (BIA) and BAI among all the participants (A), men (B) and women (C). The differences between the two methods is plotted against the average of them. The solid line represents the mean value from the two methods and dashed lines mean ±2SD.

variables were investigated by Pearson correlation analysis and the significance of the differences between correlation coefficients was tested by the Cohen's formula.[16]

Bland and Altman analysis was used to assess the agreement between the two methods used to evaluate body adiposity: BAI and BIA.[17]

A P value < 0.05 was considered significant. All statistical analysis was performed using SPSS Statistics version 14 (SPSS Inc, Chicago, IL, USA) and the R Project for Statistical Computing (http://www.R-project.org).

3. Results

Table 1 shows the main features of the overall participants as well as by sex. Women showed higher values of waist and hip circumference, %BF, BMI, BAI and higher frequency of obesity when compared to men.

3.1. BAI as a predictor of body fat

For the overall individuals, there was a strong correlation between %BF measured by BIA and BAI ($r = 0.78$; $p < 0.001$). However, when men and women are investigated separately, the correlations were different. Women showed a higher correlation than men ($r = 0.71$ vs $r = 0.59$).

Paired t-test in the whole sample, as well as within each sex, showed a significant difference between %BF by BIA and BAI (whole sample: 27.6 ± 7.81 vs 31.7 ± 5.91, $p < 0.001$; men: 22.5 + 6.15 vs 28.1 + 3.67, $p < 0.001$; women:32.5 + 5.9 vs 35.2 + 5.5, $p < 0.001$, respectively). Bland—Altman's limits of agreement showed that BAI overestimates %BF (mean difference: 4.10%), being this difference greater in men (mean difference: 5.57%) than women (mean difference: 2.71%) (Fig. 1). Individuals, males and females, were then divided according to %BF and, as showed in Table 2, BAI overestimated %BF mainly at lower levels of adiposity. No significant differences were found in men with %BF greater than 30% and in women with %BF greater than 40%.

3.2. Correlations between anthropometric measures of adiposity and percent of body fat

Table 3 shows the coefficients of correlation between %BF and different anthropometric measures. Significant correlations were found for all measurements evaluated when considering the individuals as a whole or categorized by gender. When all the individuals were considered, BAI showed the strongest correlation with %BF. Even after age stratification, separating individuals into three groups, BAI persisted with the strongest correlation (Table 4). However, stratified analyses according to gender showed that among men waist circumference has the strongest correlation with %BF. Among women, BAI has the highest coefficient of correlation, but this association was not significantly different from the association with BMI (BAI $r = 0.71$, BMI $r = 0.69$; $p = 0.47$) or waist circumference ($r = 0.70$, $p = 0.64$).

Table 3
Pearson's correlation coefficients between %BF determined by bioelectrical impedance and different anthropometric variables.

	Total ($n = 974$)	Men ($n = 476$)	Women ($n = 498$)
BAI	0.78	0.59	0.71
Weight (kg)	0.23	0.57	0.62
Waist circumference (cm)	0.63	0.73	0.70
Hip circumference (cm)	0.56	0.59	0.66
WHR	0.33	0.49	0.19
BMI (kg/m^2)	0.56	0.60	0.69

All reported correlation coefficients are significant at $p < 0.001$.

4. Discussion

BAI, an index recently proposed to be a direct estimate of body adiposity, should be validated in different populations. To our knowledge this is the first study that examines the usefulness of this index in an American Native population. Xavante Indians are an isolated population with low level of genetic admixture.[18] As other indigenous populations in the Americas they are experiencing an increased prevalence of overweight and metabolic disorders. In this context is necessary to have a simple, inexpensive and accurate tool to assess body adiposity in this population.

Considering all individuals, we found a good correlation between BAI and %BF, estimated by bioelectrical impedance. However, BAI overestimates %BF in both genders, mainly at lower degrees of adiposity. As a consequence of this, in Xavante Indians, BAI performed better in women because they have a higher adiposity compared to men. This finding is in agreement with previous studies in different populations, such as European American, Mexican American and African American, which have showed that BAI overestimates %BF at lower levels of adiposity.[7,8,11] However, differently from our findings these studies showed that BAI underestimates %BF at higher levels of adiposity. Other studies found that BAI underestimates %BF.[19,20] The reasons for this discrepancy are not clear, but as BAI quantifies adiposity based on height-adjusted hip circumference, different body fat distribution among populations may reflect in different BAI.

To address the second aim of this study, i.e. to test which anthropometric measure of adiposity best correlate with %BF in Xavante Indians, we performed univariate associations between variables. Considering all individuals, BAI showed the strongest correlation with %BF compared with other anthropometric measures evaluated such as BMI, waist circumference and waist-hip ratio. This is in agreement with prior studies which reported a better correlation of BAI with %BF than the one of BMI with %BF.[7–10,12] However, when the individuals were categorized by gender, in men we observed a stronger correlation of waist circumference with %BF compared with BAI. Among women, BAI,

Table 2
%BF by BIA and BAI according to different levels of adiposity in men and women.

Level of adiposity (%)	Men					Women				
	n	%BF by BIA	BAI	P value	Difference between measures	n	%BF by BIA	BAI	P value	Difference between measures
<20	156	15.34 ± 3.12	25.58 ± 2.82	$p < 0.001$	−10.23 ± 3.64	16	17.47 ± 2.61	26.61 ± 2.06	$p < 0.001$	−9.13 ± 3.24
20–30	275	24.94 ± 2.71	28.85 ± 3.03	$p < 0.001$	−3.91 ± 3.30	142	26.69 ± 2.52	31.47 ± 3.50	$p < 0.001$	−4.78 ± 3.93
30–40	45	32.40 ± 2.00	31.99 ± 4.34	P: 0.505	0.42 ± 4.17	299	34.79 ± 2.74	36.30 ± 4.09	$p < 0.001$	−1.51 ± 3.66
>40	–	–	–	–	–	41	42.13 ± 1.75	43.83 ± 6.62	$p = 0.066$	−1.69 ± 5.75

Data are expressed as mean ± SD.

Table 4
Pearson's correlation coefficients between %BF determined by bioelectrical impedance and BAI, BMI, hip and waist circumference according to age-group.

		BAI	BMI	Hip circumference	Waist circumference
Age-group (years)	18–29	0.86	0.68	0.68	0.73
	30–59	0.81	0.62	0.61	0.61
	≥60	0.64	0.41	0.37	0.48

All reported correlation coefficients are significant at $p < 0.001$.

BMI and waist circumference had similar correlations with %BF. Previous studies using different methods to obtain %BF, such as BIA, magnetic resonance tomography or dual-energy X-ray absorptiometry, also found that correlations were different if men and women are investigated separately.[8,9,12] In general, these studies also showed that BAI is not more strongly correlated with %BF than BMI or waist circumference.

In this study we used bioelectrical impedance as the reference measure of adiposity. This field method of body composition assessment is safe, easy to use, noninvasive and relatively inexpensive. It has been validated by comparison with dual X-ray absorptiometry.[21–23]

In summary, we demonstrated that BAI can be a useful tool to predict PBF in this population, although it has some limitations especially in individuals with lower degrees of adiposity. However, it is not a better predictor than waist circumference in men or BMI and waist circumference in women. Our results are based on a large sample of an American native population.

Conflict of interest

The authors have no competing interests.

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All authors take public responsibility for the content of the article. PCK and RSM collected the data, conceived and designed the experiments, analyzed the data and wrote the manuscript. LJF collected the data, contributed with analysis tools. JPBVF, LF, ADF collected the data. All authors read and approved the final manuscript.

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