REVIEW

Validity of the Body Adiposity Index in Predicting Body Fat in Adults: A Systematic Review

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ABSTRACT

The Body Adiposity Index (BAI) is a practical anthropometric method used to measure body fat (BF) percentage (BF%). Recently developed, the validity and precision of BAI has been studied with adult samples of men and women, populations from different countries and ethnicities, varying amounts of BF, and sensitivity to detecting change over time. However, it is still necessary to determine its potential use in clinical practice and epidemiologic studies. Thus, our objective was to verify, through a systematic review, the validity of the BAI in predicting BF% in adults. Two independent researchers performed a search using PubMed, Web of Science, Science Direct, and Scopus databases. In order to be included, the studies had to use dual-energy X-ray absorptiometry (DXA) as a reference method. We excluded studies with samples from individuals with diseases or syndromes that alter the regional distribution of BF%. We included 19 studies with samples on individuals from different continents, varied ethnicities, both sexes, and a wide age range (18–83 y). The concordance of the BAI with DXA assessed by Lin's concordance correlation coefficient showed results classified as poor ($\rho_c < 0.90$). Bland-Altman plots showed that the BAI produced large individual errors when predicting BF% in all studies using this analysis. The studies were consistent in affirming that the BAI showed limited capacity to estimate BF% in adults. The BAI shows wide individual errors, in agreement with the reference method, and a lack of sensitivity in detecting change in BF% over time. The method presents a systematic error of BF% overestimation in individuals with ≤20% of BF, and underestimation in individuals with >30% of BF, regardless of sex, age, and ethnicity. The results of this systematic review show enough evidence that the BAI does not present satisfying results, and its use is not recommended for BF% determination in adults. *Adv Nutr* 2018;9:617–624.

Keywords: aged, male, female, body composition, anthropometry, DXA

Introduction

In 2011, an index based on anthropometric measures was proposed for assessing body fat (BF) percentage (BF%) in adults (1). The method, called the Body Adiposity Index (BAI), uses hip circumference and stature measurements in a simple mathematical equation [BAI = hip circumference (cm)/height (m)$^{1.5}$ – 18], and has proven to be practical, easy, fast, and low cost. The advantages of the method make it an interesting alternative to laboratory methods for evaluating body composition in epidemiologic studies or clinical practice, especially for identifying overweight or obesity in individuals, which is currently one of the most serious public health problems in the world. It is also worth noting that, in a short period of time, an article entitled "A better index of body adiposity" became the subject of a number of studies aiming to assess the validity of this method (2–5).

Although it has been validated in a sample of adults, the BAI has already been used in children and adolescents (6, 7). As a method of BF% evaluation, its ability to predict cardiovascular disease risk factors and metabolic syndrome has been verified in Chinese adults (8–10). The method was also used in individuals diagnosed with diseases and with some type of syndrome, such as familial partial lipodystrophy (11), HIV (12), amyotrophic lateral sclerosis (13), chronic kidney disease (14), and Down syndrome (15).

The method was developed with the use of a sample of Mexican Americans and validated in African Americans. According to the ethnicity of the sample, the authors believed that the method could be extrapolated to populations in Central and South America (1). They also reported evidence that the BAI might be useful in whites. However, the authors

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Abbreviations used: BAI, Body Adiposity Index; BF, body fat; BF%, body fat percentage.

TABLE 1 Description of the PIRO[1]

Component	Description
Population	Adults
Index	BAI
Reference	DXA
Outcome	Validity in the prediction of body fat percentage

[1] BAI, Body Adiposity Index; PIRO, population, index test, reference standard, outcomes.

emphasized the need to study the validity of the method in these ethnic groups as well as in Asians, in order to verify its generalizability. Thus, 7 y after its publication and with >100 published articles related to the method, there is enough evidence to confirm or reject the initial hypotheses of the authors.

Within this context it becomes of interest to know the ability of the method to predict BF%. Therefore, the objective of this study was to verify, through a systematic review, the validity of the BAI in predicting BF in adults and in people of different ethnicities by using DXA as the reference method. At this time, to our knowledge, this is the first systematic review involving this method.

Methods

For the development of this work, we followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology (16). The acronym PIRO ("P" = population; "I" = index test; "R" = reference standard; "O" = outcomes) was used to describe the inclusion criteria (Table 1), as indicated for diagnostic research questions (17).

The inclusion criteria were defined to follow the same procedures used for the BAI proposal (1): adult samples and DXA as the reference method. Another criterion for inclusion was that the statistical analysis should have a concordance method. We excluded studies with samples from individuals diagnosed with diseases or some type of syndrome that alters the regional distribution of BF, such as those diagnosed with HIV/AIDS, lipodystrophy, or Down syndrome.

Search strategy

Four databases—PubMed (https://www.ncbi.nlm.nih.gov/pubmed/), Web of Science (www.webofknowledge.com/), Scopus (https://www.scopus.com/home.uri), and Science Direct (https://www.sciencedirect.com)—were consulted until January 2018. The following keywords were applied in combination: "body adiposity index" AND (DXA OR DEXA OR Dual-Energy X-Ray Absorptiometry). In addition, the reference lists of the selected articles were analyzed (reverse search) to make the search as complete as possible.

After the definition of keywords and databases to be researched, 2 researchers independently searched for these, starting the screening by reading the title and abstract and selecting articles with potential relevance to compose the research. The selected articles were finally screened by a complete reading to verify if they met all of the inclusion criteria. After finalizing the selection of articles to be included, the searches were compared by a third reviewer to determine any inconsistencies. We assessed the methodologic quality of the selected articles by using the Quality Assessment of Diagnostic Accuracy Studies tool (18).

Results

Study selection

The initial search in the 4 databases totaled 162 articles. After the exclusion of duplicate articles, the screening was performed as shown in Figure 1 (19). The methodologic quality of the articles showed few cases of high risk of bias or applicability. Among 7 items assessed, 5 presented >75% low risk and in the 2 items that had a lower percentage (Flow and Time and Reference Pattern), this was caused by lack of information, which led to classification of the items as "unclear" (Figure 2).

Sample characteristics

Of the 19 selected studies, 8 had samples of only women and 11 included both sexes, totaling 5967 men and 10,942 women (Table 2). There were identified studies conducted in South (Brazil and Colombia), Central (Costa Rica) and North (United States and Canada) America, Europe (Norway and Poland), and Asia (China) involving Latin Americans, Asians, African descendants, and whites. The sample profile included athletes, healthy individuals, individuals with overweight and obesity, and pre- and postmenopausal women.

Statistical results

From the selected studies, the results of the total sample and/or stratified by sex or ethnicity are presented, totaling 40 analyses (Table 2). The statistical difference between the means of BF% determined by DXA and estimated by BAI was tested in 20 analyses, and only 2 analyses showed no significant difference. The correlation coefficient is a measure of association between 2 variables, in which zero (value) indicates no linear relation between the variables and value 1 or −1 indicates a perfect relation between them. Correlation coefficients were calculated in 36 analyses, in which the r values varied between 0.28 and 0.86, of which only 5 analyses had an $r \geq 0.80$. Lin's concordance correlation coefficient evaluates the agreement between 2 results from the same sample by measuring the variation from the 45° line through the origin (the concordance line). The closer to the line, the more perfect the agreement between the methods and the result is closer to 1. Lin's concordance correlation coefficient was performed in 15 analyses and they were all classified as poor ($p_c \geq 0.90$), according to the McBride (34) classification. The Bland-Altman technique is used when intending to evaluate the agreement between 2 methods that are proposed to measure the same item, presenting limits of agreement that may or not be clinically acceptable. When the limit of agreement is very large, it represents poor agreement among the methods. Analyses showed a mean difference between 0.3 and 9.2 BF%, with concordance limits being cited in 15

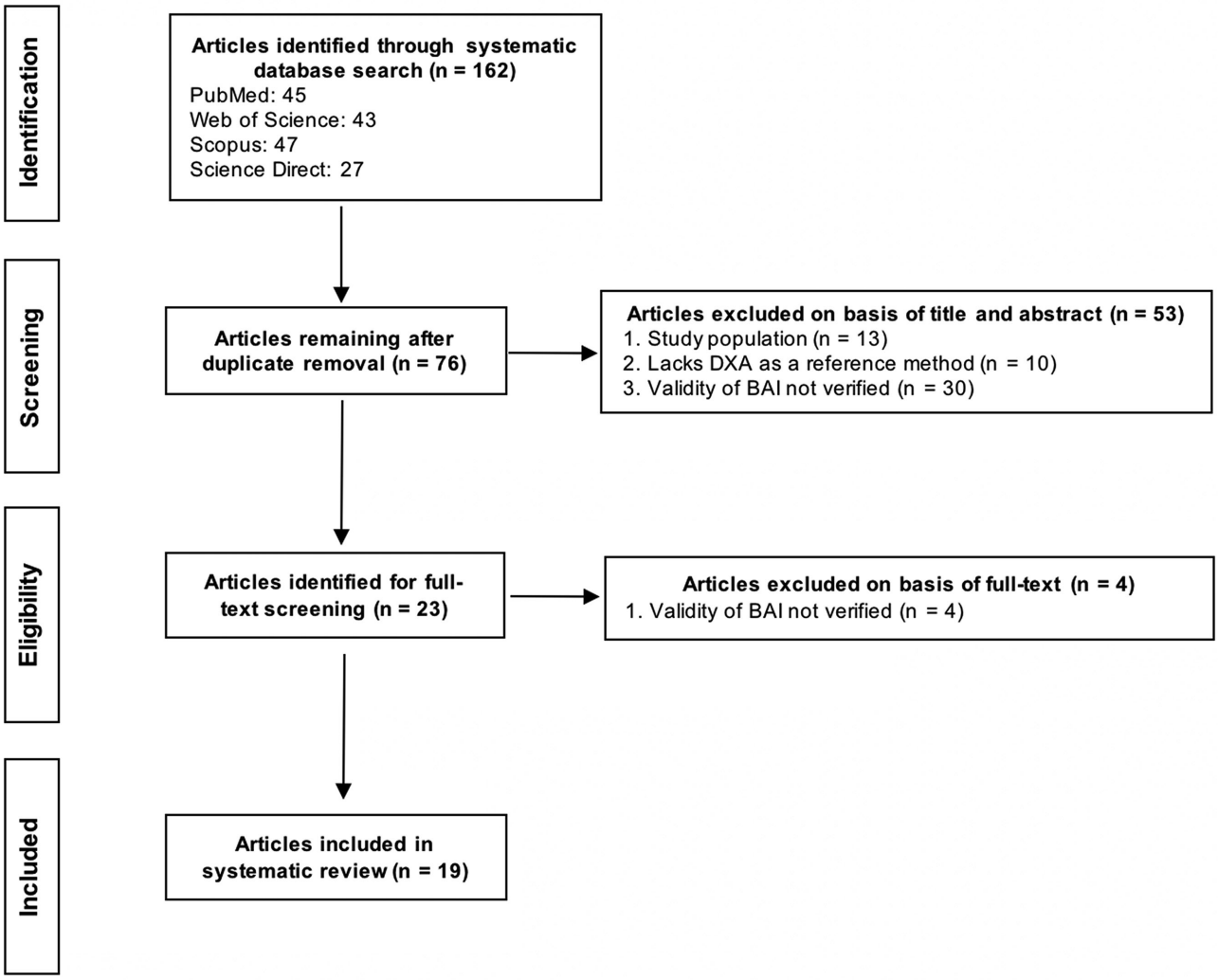

FIGURE 1 Flowchart summarizing the selection of studies for inclusion in the systematic review. BAI, Body Adiposity Index.

analyses, and in all cases the limits of concordance produced large individual errors.

Discussion

In this systematic review, the objective was to summarize the evidence on the BAI validity in estimating the BF% of adults. The literature until January 2018 was examined, and a total of 19 articles that met the eligibility criteria were selected. We conclude that the method presents many limitations from the equation formulation to the statistical analyses and shows limited concordance with the reference method for BF% estimation.

In the BAI formulation, the authors assessed the relation between BF% measured by DXA with age and anthropometric measurements of adult individuals analyzed in a single group, regardless of sex. Measurements of stature and hip circumference were those that showed the highest correlation with the BF measured by DXA and with no correlation with each other, contributing independently to the prediction of BF% in the equation that would be developed, thus being selected to compose the BAI equation (1). The fact that they used men and women together to compose the same equation, without considering sex differences, was discussed in several studies (21, 28–30), given that men and women present biological differences in BF distribution, stature, and hip circumference. Therefore, the use of such measures to predict BF without stratification by sex may result in distortions related to BF and consequently generate errors in an equation proposed in this manner. The correlation of BF% by DXA with anthropometric measurements presents very different results when analyzed together or separated by sex. In general, when the results of both sexes were analyzed together, the results of other studies were consistent with the findings by Bergman et al. (1) in the BAI formulation. However, when the analyses were conducted by sex, stature correlations are close to zero, body mass is strongly correlated, and the circumference of the abdomen in men is generally larger than the circumference of the hip, whereas for women the opposite occurs (30). On the basis of the data presented, a prediction equation of BF% by anthropometric measurements should be developed specifically by sex.

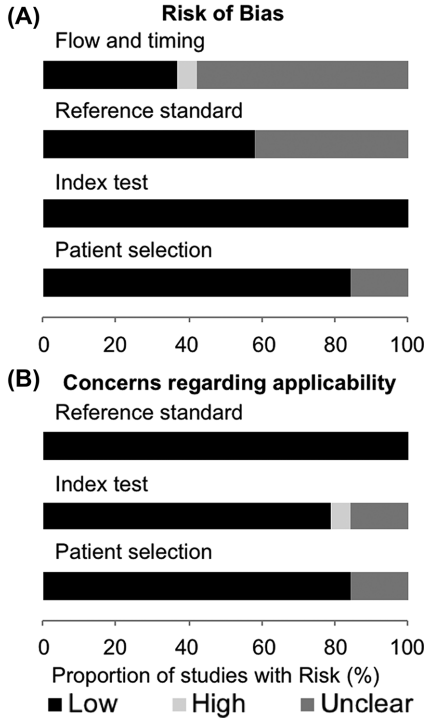

FIGURE 2 (A, B) Graphical display of the results of the methodologic analysis of the quality of included studies using the QUADAS-2 checklist. QUADAS-2, Quality Assessment tool for Diagnostic Accuracy Studies.

Relying on the knowledge of patterns of sex-specific anthropometric characteristics, called sexual dimorphism, Schulze and Stefan (35) did a critical analysis of the BAI in a Letter to the Editor, even before other publications on the method had been published and confirmed by the evidence cited above. Thus, on the basis of the basic premises of sexual dimorphism, a method of BF% estimation should not be developed in a single equation for both sexes. Because women show a better hip circumference correlation with the BF, and considering that the BAI proposal sample had a higher percentage of women, this factor may have favored hip circumference having a better correlation with DXA (35), which shows yet another limitation in the method's development. This superiority of women in the sample also resulted in the BAI showing a better correlation in women than in men (29), as shown in Table 2, in which all studies that presented correlation values with DXA in both sexes resulted in higher values for women than for men.

The statistical results of the BAI proposal were analyzed critically by some studies. The use of the bias correction factor is not a complete measure of concordance between 2 variables and is not the best measure to verify the concordance between methods (2, 22). In addition, although the limits of agreement in the BAI proposal have not been reported, it is possible to visually identify in the graph that these limits are approximately ±10%, which represents a poor and clinically unacceptable agreement (2, 25). The information presented in the articles that verified the validity of this index showed limited validity in the BF prediction. It was shown that there was a significant difference between the BF% determined by the BAI and DXA (2–4, 20, 22, 23, 26, 32, 33). Only 2 studies did not show this difference; however, the Bland-Altman analyses showed limited agreement between the methods (27, 31). Lin's concordance correlation coefficient showed an unsatisfactory result in all studies (2, 4, 20, 22, 28, 32, 33). Similarly, the Bland-Altman limits of agreement showed limited concordance between the methods (3, 5, 20, 23–25, 27, 32, 33).

The method also incurs a systematic error of overestimating BF% in individuals with low BF% and underestimating BF% in individuals with high BF%. Two studies analyzed the differences between BF% estimated by the BAI and that determined by DXA separated by BF% ranges, and showed similar results. In the first study, the BAI overestimated the value determined by DXA in individuals with ≤25% BF. In addition, the BAI overestimated BF values by more than double in individuals with ≤10% BF (DXA compared with BAI: 9.1% compared with 19.5%). For BF values between 25% and 30%, there was no significant difference between the methods, and from 30% of BF, the BAI underestimated the true value (2).

In the second study, for BF values of 20–30%, there was no difference between the BAI and DXA; at >30% of BF, the BAI underestimated the value determined by DXA in both men and women (33). These findings are consistent with the validation study of the method in which the authors reported that the BAI shows better results from 20% of BF and that below these values BF% is highly overestimated (1). The results presented were consistent in individuals of all age groups, both sexes analyzed together and separately, and in different ethnicities, highlighting that the main factor for the systematic error of BAI is the amount of BF%. Other studies, although they did not statistically determine the difference between the methods, showed that at <20% of BF determined by DXA, the BAI shows much higher averages; and at >30% of BF, the BAI shows much lower averages (4, 5, 29). It was also determined that for individuals grouped in the same ranges of BF% as determined by DXA, the mean BF% estimated by BAI was similar regardless of sex or ethnicity (4). This result confirms the findings of other studies (2, 33) that showed that the higher the BF%, the greater the underestimation of the BAI in relation to DXA.

In clinical practice and epidemiologic studies, systematic errors presented by BAI may represent a risk. Taking into consideration the proposal of BF% classification for men and women suggested by Heo et al. (36), the best BAI range performance (20–30%) is exactly the lowest health risk range, in which individuals are generally classified for BF% as appropriate. BAI overestimation for BF of <20% would inappropriately classify low-BF individuals as adequate, resulting in false-negative errors in individuals who may be at risk of malnutrition. However, the greatest public health risk is the underestimation that BAI generates for those with BF >30%, which may lead to nondetection of overweight or obese individuals (false-negative results for high BF%),

TABLE 2 Characteristics of studies that aimed to verify the validity of the BAI in predicting BF in adults and in people of different ethnicities using DXA as the reference method[1]

Study (ref) and study sample characteristics	Age, y	Sample, *n*	BF%		*P* (*t* test)	Correlation, *r*	Lin p_c	Bland-Altman	
			DXA	BAI				Bias	LoA
Bergman et al. (1)									
Mexican Americans (M and F)	35 (18–67)[2]	1733 (675 M)	33.2	—	—	0.790	—	NR	NR
African Americans (M and F)	35 (20–50)	223 (97 M)	29.7	—	—	0.849	—	NR	NR
Appelhans et al. (20)									
African Americans (F)	—	156	45.1	35.9	<0.001	0.74	0.39	9.2	−1.4 to 19.8[3,4]
White Americans (F)	—	196	41.4	33.2	<0.001	0.78	0.45	8.2	−2.7 to 19.0[3,4]
Total (F)	50.1 (42–60)	352	43.0	34.4	<0.001	0.77	0.44	8.6	−2.1 to 19.4[3,4]
Johnson et al. (2)									
European Americans (M)	Adults	291	22.2	24.3	<0.001	—	0.559	−1.9	—
European Americans (F)	Adults	332	33.7	31.2	<0.001	—	0.676	2.5	—
European Americans (M and F)	Adults	623	28.3	28.0	<0.001	—	0.752	0.3	—
Freedman et al. (21)									
Multiethnic (M)	45 ± 19[5]	383	20.5	24.4	—	0.77	—	−3.9	NR
Multiethnic (F)	48 ± 19	768	35.0	32.5	—	0.82	—	2.5	NR
Lemacks et al. (22)									
White Americans with overweight and obesity (F)	55.8 ± 3.3	187	45.9	38.3	<0.0001	0.78	0.39	7.6	—
Miazgowski et al. (23)									
White Polish normal-weight (F)	31.5 (22–40)	145	32.1	26.8	<0.01	0.455	—	5.3	−4.7 to 15.2[4]
Geliebter et al. (24)									
Multiethnic with severe obesity (F)	32.6 ± 7.7	19	58.7	48.9	—	0.42	—	9.8	−10.1 to 29.75[4]
Lam et al. (25)									
Chinese (M)	38.8 ± 11.3	53	33.6	29.5	—	0.74	—	3.9	−2.61 to 14.15[4]
Chinese (F)	39.9 ± 12.0	52	40.4	32.9	—	0.82	—	7.5	—
Chinese (M and F)	39.3 ± 11.6	105	37.0	31.2	—	0.81	—	5.8	—
Elisha et al. (26)									
Canadians postmenopausal with obesity (F)	57.2 ± 4.7	132	M1, 48.0	41.2	<0.001	0.54	—	6.8	NR
			M2, 45.5	38.5	<0.001	0.59	—	7.0	NR
Esco (27)									
American collegiate athletes (F)	20.0 ± 1.3	30	26.7	27.1	0.49	0.28	—	−0.4	−10.2 to 11.8[4]
Sun et al. (28)									
White Canadians (M)	39.5 ± 14.4	662	24.5	24.4	—	0.67	—	0.1	—
White Canadians (F)	43.3 ± 12.4	1939	37.3	30.8	—	0.74	—	6.5	—
White Canadians (M and F)	42.3 ± 13.1	2601	34.0	29.2	—	0.78	<0.9	4.8	—
Cerqueira et al. (3)									
Brazilians (F)	60.3 (35–83)	102	36.9	33.6	<0.0001	0.65	—	3.3	−5.9 to 12.5
Vinknes et al. (29)									
White Norwegians (M)	Adults	2204	25.8	24.9	—	0.57	—	0.9	NR
White Norwegians (F)	Adults	2989	38.1	30.0	—	0.72	—	8.1	NR
White Norwegians (M and F)	Adults	5193	32.9	27.9	—	0.78	—	5.0	NR

(*Continued*)

TABLE 2 *Continued*

Study (ref) and study sample characteristics	Age, y	Sample, *n*	BF%		*P* (*t* test)	Correlation, *r*	Lin p_c	Bland-Altman	
			DXA	BAI				Bias	LoA
Chang et al. (4)									
Multiethnic (M)	71.9 ± 9.2	483	29.8	26.8	<0.01	0.55	0.42	3.0	—
Multiethnic (F)	68.9 ± 9.6	471	40.0	32.5	<0.01	0.72	0.43	7.5	—
Multiethnic (M and F)	70.4 ± 9.5	954	34.8	29.6	<0.01	0.74	0.55	5.2	—
Zhang et al. (30)									
Chinese (M)	62.2 (51–77)	680	25.0	25.3	—	0.58	—	0.3	NR
Chinese (F)	59.6 (51–77)	1707	35.6	29.8	—	0.62	—	5.8	NR
Dias et al. (31)									
Brazilians (F)	24.5 ± 2.6	19	28.6	29.1	>0.05	0.627	—	−0.5	NR
Carpio-Rivera et al. (32)									
Costa Rican students (M)	19.2 ± 2.8	106	21.9	24.8	<0.001	0.53	0.35	−2.9	−17.3 to 11.5[4]
Costa Rican students (F)	18.6 ± 2.4	93	36.5	29.3	<0.001	0.74	0.36	7.2	−3.8 to 18.2[4]
Ramírez-Vélez et al. (33)									
Colombians with overweight and obesity (M)	39.3 ± 6.0	22	34.8	28.8	<0.001	0.677	0.803	6	−0.4 to 12.0[4]
Colombians with overweight and obesity (F)	41.0 ± 7.3	26	42.6	37.2	<0.001	0.763	0.882	5.4	−1.0 to 12.0[4]
Colombians with overweight and obesity (M and F)	42.3 ± 8.2	48	39.0	33.4	—	0.844	—	5.6	−1.0 to 12.0[4]
Segheto et al. (5)									
Brazilians (M)	34.3 ± 11.9	311	24.0	25.0	—	0.72	—	−1	−12.42 to 11.41
Brazilians (F)	37.4 ± 12.4	395	35.5	31.4	—	0.78	—	4.1	−6.77 to 12.82
Brazilians (M and F)	36.0 ± 12.8	706	30.4	28.6	—	—	—	1.8	—

[1] $n = 19$. BAI, Body Adiposity Index; BF, body fat; Lin p_c, Lin's concordance correlation coefficient; LoA, limits of agreement; M1, moment 1; M2, moment 2; NR, not reported; ref, reference.
[2] Mean; minimum–maximum in parentheses (all such values).
[3] Calculated from information in the study.
[4] LoA values quoted as BAI – DXA were reversed in DXA – BAI to standardize information.
[5] Mean ± SD (all such values).

hence impairing intervention may worsen obesity effects on an individual's health.

The sensitivity of the BAI to identify changes in BF% was verified in a group of women with obesity after a 6-mo intervention period for weight loss (26). The BF% pre- and postintervention was underestimated by the BAI, whereas the change in BF% was overestimated. This evidence shows a further limitation of the BAI, not only in estimating BF but also because of the low sensitivity in detecting changes after a process of BF% reduction.

Esco (27) verified the accuracy of the BAI in predicting the BF% of university athletes. Although it was the only study that did not show a significant difference between the methods, it was found that there was no significant relation between the methods ($r = 0.28$, $P = 0.14$), and the Bland-Altman analysis resulted in high limits of concordance, which represents very large differences between the methods in the individual analyses.

The validity of the BAI for the populations of Central and South America was suggested by the authors, because the sample selected to develop and validate the equation was composed of African and Mexican Americans, who have characteristics similar to the populations of those countries. The need to verify the validity of the BAI was also stated in whites and Asians. The generalizability of the BAI for other ethnicities can be widely verified in the present study because the articles selected included samples from populations of North (2, 20, 22, 26–28), Central (32), and South (3, 5, 31, 33) America; Europe (23, 29), Asia (25, 30), and multiethnic studies (4, 21, 24); and also included a wide age group and different body compositions. This wide diversity of population samples allows better conclusions on the BAI, because it was observed that in all assessed profiles, the method was limited.

Three studies to optimize the method results for the respective sample examined proposed modifications in the BAI equation. In a sample of European-Americans, the BAI for the Fels Longitudinal Study sample (BAI_{Fels}) was proposed, which, although more robust than the BAI, generated a more complex equation and still remained limited to estimate BF (2). The BAI in the population in the Hordaland Health Study (BAI_{HUSK}) is a derivative form of the BAI for white Europeans, which improved their BF% prediction, especially at higher adiposity levels, presented smaller mean differences in relation to DXA, but still presented some limitations of the BAI (29). In older adults with >40% BF as determined by DXA, the modified BAI was developed, which had better results than the BAI (4). However, this new method is not very effective, because its application is restricted only to individuals with >40% BF. In addition, the authors mention that individuals with a mean of 40% BF had a mean BMI (in kg/m^2) of 31.3, and thus, they would first have to calculate the BMI and, if it was greater than the value mentioned, they could apply the modified BAI. All 3 BAI modification proposals maintained the same premises of the original method, using the same anthropometric measures and developed from the data of men and women together, changing only the mathematical equation. Therefore, they maintained the same BAI limitations previously discussed, with the same potential for error as the original formula expected.

The main limitation of this systematic review is not to have performed a meta-analysis. However, the articles selected do not present enough information to conduct a meta-analysis. We could conduct a meta-analysis in 2 ways: *1*) by the information of the receiver operating characteristic curve of the studies, or *2*) by the information from the correlation coefficients. However, the following limits the realization of the meta-analysis: *1*) the heterogeneity of the samples (the age range of the surveyed studies was very wide); *2*) only 3 studies present information on SEs, which does not allow calculating the information from the meta-analysis; *3*) only 1 article used the receiver operating characteristic curve to verify the relation between BAI and DXA.

In conclusion, the articles selected in this systematic review were consistent in determining that the BAI had limitations to predict BF compared with DXA. These results were detected for both sexes and across different ethnicities, age groups, and BF levels. The BAI systematically underestimates BF in individuals with a high BF% and overestimates in individuals with a low BF%. The method presents wide individual errors in agreement with the reference method and lack of sensitivity in detecting change in BF% over time.

Future research aiming to develop new methods for estimating BF% from anthropometric measures should seek to overcome the limitations observed in the BAI, especially concerning sexual dimorphism, by selecting anthropometric measures that have a better association with BF, separated by sex. The proposal for other age groups, such as children and adolescents, is also interesting, considering the rising obesity prevalence in all ages and the need for useful methods for clinical assessment and population studies.

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