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ORIGINAL ARTICLE

Which index best correlates with body fat mass: BAI, BMI, waist or WHR?

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Abstract

OBJECTIVES: The body mass index (BMI) has been the most commonly applied clinical measure to characterise body composition in individuals. However, the BMI has been criticised as being an inaccurate measure of body fatness. Recently, a new index reflecting body composition, the Body Adiposity Index (BAI) was proposed. The BAI was calculated using the equation BAI=((hip circumference)/((height)$^{1.5}$) – 18).
AIM: The aim of this study was to compare estimates of body fat content, i.e., body adiposity index (BAI), BMI, waist-hip ratio (WHR) and waist and hip circumferences, with respect to their ability to predict the percentage of body fat (PBF).
RESULTS: To select an optimal surrogate for adiposity, we examined the correlation between body adiposity percentage as measured by BIA and several variables, including BAI, BMI and WHR. Correlations ranged from a high of 0.78 for BMI, 0.67 for BAI and 0.66 for waist circumference to a low value of 0.39 for the WHR index. The correlation between PBF and BAI (R=0.67, R^2=0.45, p<0.001) and the correlation between PBF and BMI (R=0.78, R^2=0.60, p<0.001) were of similar magnitude.
CONCLUSION: Based on our results and those of other studies, we can say that the BAI index is not a universally valid index that could be used in the place of the BMI index in a Caucasian population; indeed, it would not accurately reflect body fat mass and thus could lead to an increased risk of obesity. Further, WHR index is not a suitable for an estimation of body fat.

Abbreviations:

BMI	- Body mass index
BAI	- Body Adiposity Index
WHR	- Waist-hip ratio
PBF	- Percentage of body fat
BIA	- Bioelectrical Impedance Analysis
DXA	- Dual-energy X-ray absortiometry

INTRODUCTION

According to the World Health Organisation, overweight and obesity are increasing in prevalence and rank fifth as worldwide causes of death behind high blood pressure, tobacco use, high glucose and physical inactivity (Flegal *et al.* 2012; Adamkova *et al.* 2011; Stamatakis *et al.* 2010). Although knowledge of and publications about the typical and less common causes of obesity (Suchanek *et al.* 2011a,b; Hubacek 2009) have grown exponentially in recent years, many ambiguities remain. Obesity and excess weight are among the primary risk factors for the development of insulin resistance, hypertension and dyslipidemia, which may increase the risk of cardiovascular diseases and type 2 diabetes (Stranska *et al.* 2011). An increased accumulation of body fat is accompanied by increased total body mass in both men and women. Thus, indices of relative weight are commonly used to diagnose obesity. It is important to target efforts to reduce adiposity for groups at risk of obesity-related chronic disease.

The body mass index (BMI) is the most commonly applied clinical measure to characterise obesity in individuals. This measure was introduced in the 19th century by Quetelet (Eknoyan 2008), who recognised that it is necessary to correct for differences in body size when comparing adiposity among individual patients. Because growth is linear, weight cannot be increased as the cube of height, but as the square, and the human represents a cylinder more than a sphere. The Quetelet index was renamed the BMI by Ancel Keys and is the ratio of weight to height squared (Keys *et al.* 1972).

The BMI is now routinely applied to estimate body fat. However, in clinical practice, given that at a constant BMI the relative composition of fat mass vs. lean body mass depends on age, sex, physical activity etc., the BMI has been criticised as being an inaccurate measure of body fitness and therefore inadequate for the assessment of percentage body fat (PBF). The BMI is particularly inaccurate in athletes, who typically present with a high lean body mass. Furthermore, the BMI does not consider the differences between men and women, and cannot be generalised among different ethnic groups (Rahman *et al.* 2010; Garrido-Chamorro *et al.* 2009). In addition, taking into account the child growth standards (McCarthy *et al.* 2006), the BMI is not a good method to classify children according to their fat content; the most prevalent approach for children is to use BMI normalised by age, however, this method involves complex mathematical calculations.

These and other reasons have prompted the introduction of a new index, the BAI (Body Adiposity Index), which is related to hip circumference and height (weight is not needed). The BAI is calculated using the equation suggested by Bergman and colleagues: BAI=((hip circumference)/((height)$^{1.5}$) – 18). The BAI measurement requires very simple instrumentation, which is very useful in under-developed or remote places where accurate measurement of weight can be difficult or scales are not available. This could constitute an important advantage for the BAI over BMI.

The BAI index showed a high correlation with body fat measured with DXA (the dual-energy X-ray absorptiometry) (Bergman *et al.* 2010), which is the gold-standard method developed to measure percentage body fat (PBF) in clinical methods. However, this method is expensive and not practical in a routine clinical setting or for large epidemiological studies. Furthermore, Bergman *et al.* (2012) study was conducted only in two U.S. ethnic populations (African Americans and Mexican Americans) and not in Caucasians.

In our study, we used the method of measuring body fat by bioelectrical impedance analysis (BIA). Bioelectrical impedance analysis is a non-invasive and simple method that has also been used for the measurement of percentage body fat (PBF). The introduction of bioelectrical impedance could provide a significant improvement in the methodology developed for assessing body fat. In addition, BIA has been validated against reference methods (Jensky-Squires *et al.* 2008). Several studies have reported contradictory results on the accuracy of BIA for the measurement of percentage body fat (PBF) compared with the use of DXA in adults and children (Lazzer *et al.* 2008).

MATERIAL AND METHODS

Subjects

A population of 395 healthy adult Czech Caucasian sedentary females aged between 18 and 75 years (41.0±11.4) with BMIs up to 18.5 (29.8±5.8) were recruited via an advertisement on a lifestyle web site and in a women‘s journal. We subsequently excluded a total of 5 volunteers, 3 with extremely low percentage body fat and 2 with extremely high percentage body fat. All volunteers were examined in a medical research centre, signed declarations of informed consent and of agreement to participate in the study, which was approved by the institutional ethic committee. Exclusion criteria consisted of known inflammatory or metabolic diseases (diabetes, thyroid gland disease, any other endocrine disorders, autoimmune diseases, any chronic inflammation and neoplastic disease).

Anthropometric measurements

Body weight was measured with an electronic weight scale (scaled to the nearest 100 g) that was placed horizontally and calibrated before each weighting session. Height was measured with a stadiometer to the nearest 0.5 cm. Waist (defined as narrowest diameter between xiphoid process and iliac crest) and hip (defined as widest diameter over the greater trochanters) circumferences were measured to an accuracy of 0.5 cm. The waist-to-hip ratio (WHR) and BMI were calculated from obtained measurements. Percentage body fat (PBF) was measured by bioelectrical impedance analysis (BIA) with

Bodystat analyser (1500 MDD; Bodystat, Isle of Man, UK). A trained nurse performed all measurements.

Statistical analyses

The Pearson correlation coefficient was used as a measure of the association between PBF and BMI, BAI, waist and WHR. The t-test for the difference between two non-independent Pearson correlations was calculated and Bonferroni correction of significance levels was applied. All data are presented as the mean±SD. Differences are considered to be statistically significant if $p<0.05$.

RESULTS

Anthropometrical characteristics of the 395 study participants are summarised in Table 1. To select an optimal surrogate for adiposity, we examined the correlation between percentage body adiposity as measured by BIA and several easily measured variables: BAI, BMI and WHR (Table 2). Interestingly, correlations ranged from a high of 0.78 for BMI, 0.67 for BAI and 0.67 for waist to a low value of 0.39 for WHR index. Figures 1–3 plot the relationship between BIA-measured percentage body fat and BAI index, between BAI-measured percentage body fat and BMI, and between BAI-measured percentage body fat and WHR index, respectively. Correlation between PBF and BAI (R=0.67, R^2=0.45, $p<0.001$) and between PBF and BMI (R=0.78, R^2=0.60, $p<0.001$) were of similar magnitude; subsequent statistical analyses may be required to determine whether there is no statistically significant difference between the measured correlations.

Tab. 1. Characteristics of the study participants (mean ± SD).

n=395	(Mean ± SD)
Age, years	41.0±11.4
BMI, kg/m^2	29.8±5.8
Weight, kg	85.6±15.1
Waist, cm	96.8±13.1
Hip, cm	109.1±9.8
Waist-to-hip ratio	0.89±0.08
Percental body fat, %	39.5±6.7

Tab. 2. Corporal correlation matrix among PBF from BAI, BMI, weight, hip, waist, WHR.

n=395	PBF (39.5±6.7)
BAI	0.673
BMI, kg/m2	0.776
Waist, cm	0.666
Waist-to-hip ratio	0.392

Pearson correlation with Bonferroni correction of significance levels

DISCUSSION

While nutritionists tend to trust and take interest in a new index, according to recent literary references, Body Adiposity Index (BAI) is not a sufficient indicator of BPF and is not as accurate as DXA or electrical bio-

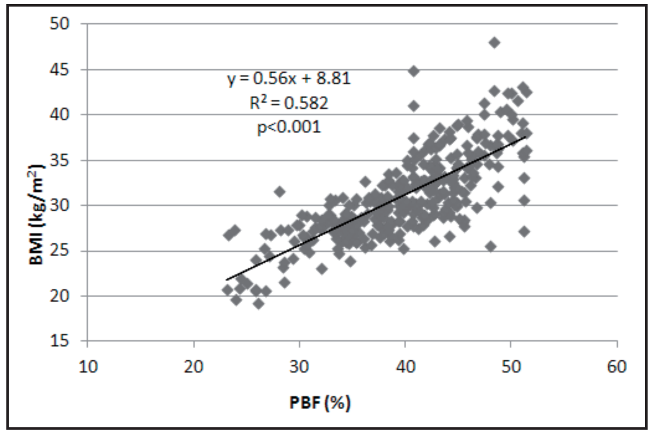

Fig. 1. Relationship between BIA-measured percentage body fat (PBF) and BMI index.

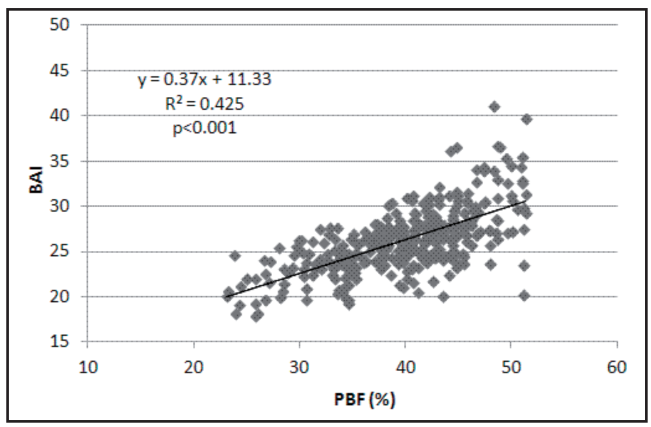

Fig. 2. Relationship between BIA-measured percentage body fat (PBF) and BAI index.

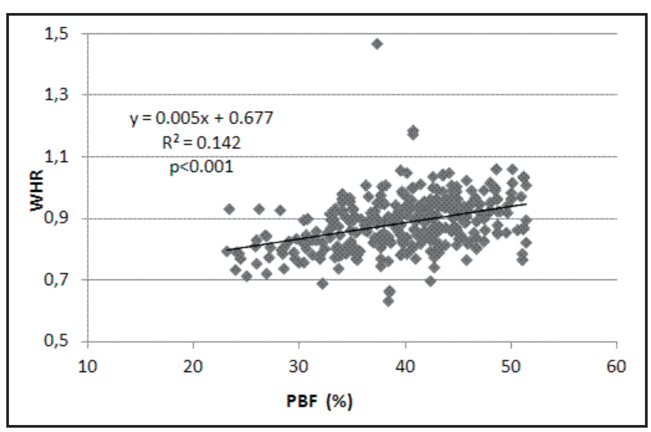

Fig. 3. Relationship between BIA-measured percentage body fat (PBF) and WHR index.

impendance. Recommended body fat mass is relatively difficult to calculate using the BMI index or the newly introduced BAI index. There are two reasons for this.

Firstly, body fat mass methods do not take into account the age factor. It is to be expected that that the recommended body fat mass would be different for a young woman in her 20's compared to an older woman in her 70's. Therefore, we recommend that this issue be resolved using charts (diagrams) with different age categories, as are used for weight monitoring of children.

Secondly, another problem occurs in the BAI method during the measurement of hip circumference. This measurement is performed manually and therefore subject to error. It was said in the literature that different results were obtained by two nurses for the same patient. The variability of results is caused by a human factor. In addition, it was shown that not only is there a connection between BMI (above 25) and lower risk of some diseases, but also between higher BMI and life duration. It is therefore complicated to set an optimal range of normal fit body index within the interval 18.5–24.9 while respecting current knowledge.

Overall, there are many methods available to measure BPF. We suggest, however, that it problematic to set a recommended body fat mass regardless of which method is used. Our team worked with magnetic resonance as well, but this method is too expensive, time-consuming, expensive and uncomfortable for patients. Therefore, it has not been applied in population studies.

Another issue to consider is the process of setting the parameters used for BAI calculation or determination. In contrast to BMI, BAI calculation uses an anthropometric parameter (measurement of hip circumference) that is influenced by sex.

Perhaps the most essential problem encountered in our study is that the BAI index does not address the difference in body fat allocation risk. It has been known for several years that abdominal obesity and abdominal allocation of body fat are associated with significantly higher risks of cardiovascular diseases, diabetes etc., than body fat allocation in the thighs and backsides. Therefore, while it would be of interest to take into account the sex difference when considering the hip circumference parameter within the BAI index, the BAI still does not take into account the increased risk associated with abdominal body fat allocation. Another body index which would address this issue would be of more use.

Both our study and that of Geliebter *et al.* (2012) indicate that the measurement of body fat mass by BAI method is not accurate enough. In certain sub-populations, the BAI method does not produce results comparable with those of DXA or electric bio-impendance methods. While very close correlation between BAI and percentage body fat was shown (even closer than the correlation between BMI and percentage body fat), the applicability of the BAI was nevertheless demonstrated in only two ethnic groups (Mexican Americans and African Americans) (Bergman *et al.* 2010). We have found that the BAI index is not applicable to Caucasian women (Lopez *et al.* 2012) because there is no statistically significant difference between the correlations registered for percentage body fat and BMI, BAI or hip circumference. Another important result of our study was the fact that WHR is wholly inapplicable for an estimation of body fat.

Based on our results and those of other studies, we conclude that the BAI method is not a universally valid index to be used in the place of the BMI index in a Caucasian population; indeed, it could provide inaccurate measurements of body fat mass and thus lead to obesity risks. In addition, the BAI index provides differential results based on various ethnic groups.

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