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ORIGINAL RESEARCH

ACCURACY OF THE BODY ADIPOSITY INDEX AND BODY ADIPOSITY INDEX FELS COMPARED WITH AIR DISPLACEMENT PLETHYSMOGRAPHY

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ABSTRACT

The Body Adiposity Index (BAI) estimates a person's percent body fatusing hip circumference and height. A slight variation of the BAI from the FELS longitudinal study (BAI_{FELS}) has more recently proposed to estimate percent body fat better than the BAI.

Purpose: Assess criterion validity of the BAI and BAI_{FELS} with air displacement plethysmography (ADP).

Methods: Percent body fat was estimated for 1636 volunteer healthy adults (881M; 755F, age: 36.9 ± 10.5 yrs; BMI: 25.4 ± 4.6 kg/m^2) using ADP and BAI and BAI_{FELS}.Differences in percent body fat between ADP, BAI, and BAI_{FELS} were tested using an repeated measure ANOVA with post hoc analyses. Agreement between methods was tested using Bland-Altman plots.

Results: Differences in percent body fat between each method were statistically significant ($p<.05$).Percent body fat assessed by ADP correlated moderately with BAI ($r=0.534$, $p<0.001$), BAI_{FELS} ($r=0.526$, $p<0.001$), and BMI ($r=0.476$, $p<0.001$).BAI and BAI_{FELS} underestimated percent body fat compared to ADP on average 2.1% and 1.1% respectively. BAI equations overestimated percent body fat for lean persons and overestimated percent body fat for overweight or obese persons.Agreement between BAI, BAI_{FELS} was poor with wide limits of agreement.

Conclusion: BAI and BAI_{FELS} are easier and less expensive alternatives to estimate percent body fat in humans compared to ADP. However, health risk due to body fat will be better estimated using either ADP or waist circumference and waist-to-hip ration in addition to an BAI.BAI would be most suitable where resources for estimating percent body fat are most limited.

Key Words: body composition, body fat percentage, health risk, body adiposity, prediction equations

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INTRODUCTION

Various techniques have been established and employed by exercise physiologists and fitness professionals to estimate body composition including hydrostatic weighing, skinfold thickness, bioelectrical impedance, air displacement plethysmography (ADP), and body mass index (BMI). BMI is widely used due to low costs and it is quick to administer. BMI is often criticised because it does not account for age, race and levels of muscularity[1-3]; however, it has shown strong relationships with numerous health risks, such as metabolic syndrome[4], cardiovascular disease[5,6], joint pain[7], and decreased mortality.[8,9]

Because of the limitations associated with BMI Bergman et al. (2012)[10] developed the Body Adiposity Index (BAI) as a method of predicting percent body fat (PBF). Using a sample of 1,733 Mexican-American adults, the authors developed an equation using height and hip circumference which was validated against dual-energy X-ray absorptiometry (DXA). They determined the BAI was a valid predictor of PBF and demonstrated a stronger correlation between BAI and PBF than between BMI and PBF. Those results, however, are specific to Mexican-Americans and cannot be generalised to other ethnicities.

The original investigation by Bergman et al. (2011)[10] included Hispanic adults from the BetaGene study in southern California. That study also utilised African-American adults from the TARA study in Bethesda Maryland. Although Bergman et al. states the BMI range was similar (29.5 and 30.0 kg/m^2) between groups the PBF obtained from DXA was higher for the Mexican-American adults (33.2 vs. 29.7%). Those populations represent a sample taken from the east and west coast and represent specific race and ethnicity. Since that initial investigation, BAI has been assessed using various populations such as overweight and obese postmenopausal women[11], a Spanish Mediterraneanpopulation[12], women with familial partial lipodystrophy[13], obese Brazilian adults[14], European-American adults[15], and Chinese adults.[16,17] Despite the growing research supporting the BAI it has not been shown to be valid in other populations.[18]The purpose of this study was to assess criterion validity of the BAI and BAI_{FELS} with air displacement plethysmography (ADP).We hypothesised PBF measured using the ADP would be significantly different than PBF estimated by the BAI and BAI_{FELS}. Additionally, we hypothesised that both BAI equations would have stronger correlations with PBF than BMI. We believe there would be significant differences in PBF among measures based on research illustrating large variations using the BAI.

METHODS AND PROCEDURES

Participants

Participants were male and female Caucasians residing in the state of Utah. Participants were not restricted from participation based on health status. The subjects included in analysis were not missing data for any of the measured variables. Descriptive characteristic (n = 881 male, 755 female) of the participants are presented in Table 1. Participants were fully informed of this study's purposes and potential risks prior to volunteering. Verbal as well as written informed consent was obtained from each participant. Participants younger than 18 years gave assent and their legal guardians signed informed consent forms. Participants were asked to refrain from caffeine and alcohol for 24 h prior to testing. Participants were also instructed to present for the testing following a 2 h fast, while being allowed to drink water ad libitum. The study was approved for completion by the Institutional Review Board of The University of Utah.

Air Displacement Plethysmography - Bod Pod

Body composition was determined using the Bod Pod and was used as our criterion measure (Life Measurement Inc., Concord, CA, USA). Prior to entering the chamber, participants were instructed to change into form fitting clothing including spandex shorts, a sports bra for females, and a swim cap in concordance with the manufacturer's directions for reliable PBF measurements. Height was measured to the nearest 0.1 cm using a stadiometer (Novel Products Inc., IL, USA) without shoes. Weight was measured using an electronic scale which was calibrated according to manufacturer's directions

Table 1. Participant characteristics and body composition according to gender and as group total.

	Male	Female	Total
N	881	755	1636
Age (years)	36.83 ± 10.43	37.00 ± 10.67	36.91 ± 10.53
Height (m)	1.77 ± 0.10	1.69 ± 0.10	1.73 ± 0.10
Weight (kg)	81.82 ± 18.22	71.58 ± 16.99	77.10 ± 18.38
WC (cm)	87.07 ± 12.66	81.15 ± 12.58	84.34 ± 12.96
HC (cm)	95.88 ± 9.78	94.88 ± 11.41	95.42 ± 10.57
PBF	23.66 ± 8.44	26.75 ± 9.08	25.09 ± 8.88*
BMI (kg/m^2)	25.88 ± 4.57	24.86 ± 4.58	25.41 ± 4.60
BAI	22.82 ± 4.92	25.25 ± 5.27	23.94 ± 5.22*
BAI_{FELS}	21.58 ± 6.39	24.56 ± 6.88	22.96 ± 6.78*

WC, waist circumference; HC, hip circumference; PBF, percent body fat; BMI, body mass index; BAI, body adiposity index; BAI_{FELS}, body adiposity index FELS; m, meters; cm, centimeters; kg/m^2, kilogram per meter squared.

Table 2. Pearson correlation coefficients among PBF, BAI, BAI_{FELS}, and BMI.

	PBF	BAI	BAI_{FELS}
BAI	0.534	-	-
BAI_{FELS}	0.526	0.999	-
BMI	0.476	0.379	0.398

PBF, percent body fat; BMI, body mass index; BAI, body adiposity index; BAI_{FELS}, body adiposity index FELS.

Table 3. Pearson correlation coefficients according to sex between PBF, BAI, BAI_{FELS}, and BMI.

	PBF and BAI	PBF and BAI_{FELS}	PBF and BMI
Males	0.5	0.5	0.57
Females	0.68	0.67	0.48

PBF, percent body fat; BMI, body mass index; BAI, body adiposity index; BAI_{FELS}, body adiposity index FELS.

(Life Measurement Inc., Concord, CA, USA). Body volume was measured at least twice and three times if the first two measurements were not within 150 ml or 0.3%. Thoracic gas volume was estimated using the prediction equation provided by the Bod Pod software.[19] Body density was converted to % fat using the two-compartment Siri equation.[20] All calculations were performed by the Bod Pod's software (version 1.91).

Anthropometry

Waist circumference (WC) and hip circumference (HC) were measured to the nearest 0.1 cm using an anthropometric measuring tape (Creative Health Products, Ann Arbor, MI, USA). WC was measured at the smallest portion of the midsection between the xiphoid process and iliac crest[21]; HC was measured at the maximum circumference of the buttocks.[21] BAI, and BAI_{FELS} were calculated using the following equations[10,15]:

Body Adiposity Index: hip circumference (cm)/ height (m) 1.5 - 18

Body Adiposity Index FELS: 1.26*hip circumference (cm)/height (m) 1.4 - 32.8

Statistical Analyses

Data are reported as means ± standard error. All data were screened for outliers, normality was examined using the Shapiro-Wilk test of normality, and sphericity was examined using Mauchly's test of sphericity. Differences in PBF between methods were compared using repeated measures ANOVA with Bonferroni post hoc analyses. Correlation between BMI, BAI, BAI_{FELS}, ADP, and WC was examined by Pearson correlation coefficients. Agreement estimating PBF was assessed between the BAI equations and the ADP using a Bland-Altman plot with 95% limits of agreement.[22] Data were exported from ADP software to Excel (Microsoft Office, USA) and analysed using SPSS version 20 (IBM, NY, USA) and STATA version 11 (StataCorp, TX, USA) with alpha at $p < 0.05$.

RESULTS

Descriptive characteristics of the sample are shown in Table 1. Age ranged from 13 to 76 years with a mean age of 36.91 years. In addition, 11.32% of participants were obese (BMI > 30 kg/m^2), 32.45% were overweight (BMI 25 – 29.9 kg/m^2), and 56.2% were normal weight (BMI 18.5 – 24.9 kg/m^2). Mauchly's test indicated sphericity was violated, $\chi2$ (5) = 3105.6, $p < 0.001$. Consequently, the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\chi = 0.54$). Differences in mean PBF measured by ADP, BAI, and BAI_{FELS} were statistically different (F (1, 1632.5) = 61.10, $p < 0.0001$). Bonferroni corrections identified statistically significant differences between each pair of methods measuring body fat percentage (See Table 1). Correlations are displayed in Table 2. In our sample, BAI had the strongest correlation with PBF ($r = 0.53$, $p < 0.001$) followed by BAI_{FELS} ($r = 0.53$, $p < 0.001$) and BMI ($r = 0.48$, $p < 0.001$) (See Table 2).

Figure 1 A and B are Bland-Altman plots of the averaged PBF estimates by ADP and BAI, against the differences of PBF estimated by ADP and BAI. The ADP has an inherent error range of 2.7%. Figure 2 A and B are Bland-Altman plots of the averaged PBF estimates by ADP and BAI_{FELS} against the differences of PBF estimated by ADP and BAI_{FELS} for male participants. Figure 3 A and B are Bland-Altman plots of the averaged PBF estimates by ADP and BAI_{FELS} against the differences of PBF estimated by ADP and BAI_{FELS} for female participants. The bias between the BAI equation and ADP was low at 2.13% compared to 1.15% between BAI_{FELS} and ADP. Limits of agreement were within 95% of differences in PBF and were underestimated by the BAI equation up to 15.05% or overestimated by as much as 12.76%. Limits of agreement were within 95% of differences in PBF and were also underestimated by the BAI_{FELS} equation up to 16.30% or overestimated by as much as 12.04%. Both BAI and BAI_{FELS} overestimated PBF when ADP measurement was less than approximately 25% and increasingly underestimated PBF when measurement exceeded 25%. PBF measured by the BAI equation agreed notably more with PBF by the ADP than did the BAI_{FELS} equation.

DISCUSSION

To date additional research regarding the BAI and various populations has emerged[10, 11, 15, 23-29] since the development of the BAI. Our primary purpose was to compare PBF using the BIA, BAI_{FELS}, and ADP using a sample of Caucasian adults located in the rocky mountain region of Utah. We observed significant differences in PBF among all measures (Table 1). This confirms our hypothesis that all measures would be different. In our study the ADP yielded the highest PBF followed by the BAI and BAI_{FELS}. Furthermore, Bland-Altman plots indicated a negative systematic bias which was exhibited by BAI and BAI_{FELS}. In addition to the bias we noted large limits of agreement. This bias and large limits of agreement were noted for the group total as well as results that are specific to participant gender. Finally, the BAI and BAI_{FELS} demonstrated stronger correlations with PBF than BMI did for the entire sample. When results were stratified according to gender BMI correlated more strongly with PBF for

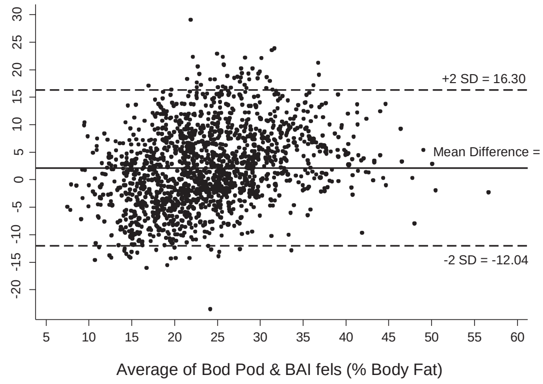

Figure 1A. Bland-Altman plot illustrating the level of agreement between the ADP and Body Adiposity Index.

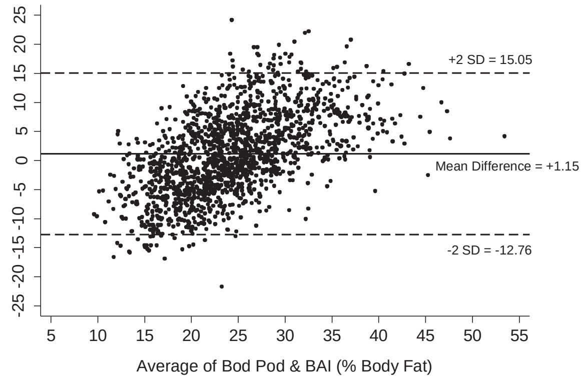

Figure 1B. Bland-Altman plot illustrating the level of agreement between the ADP and BAI_{FELS}.

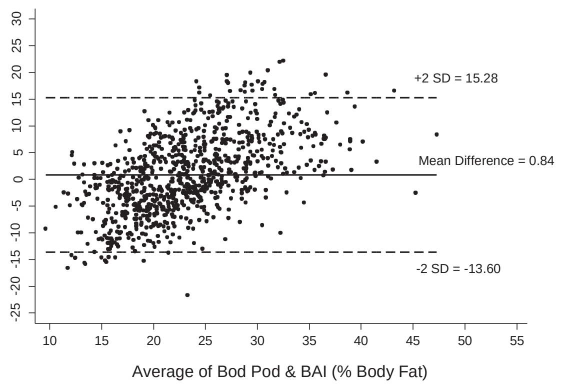

Figure 2A. Bland-Altman plots illustrating the mean difference and limits of agreement for males participants using the Bod Pod and BAI.

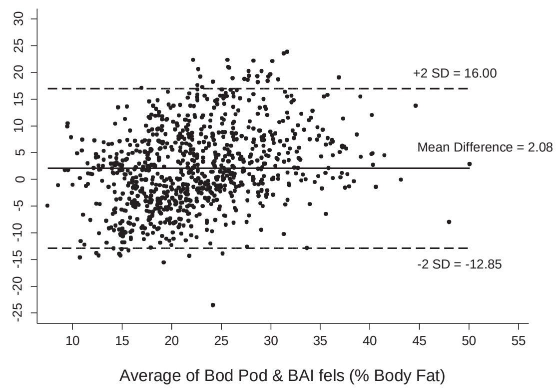

Figure 2B. Bland-Altman plots illustrating the mean difference and limits of agreement for males participants using the Bod Pod and BAI_{FELS}.

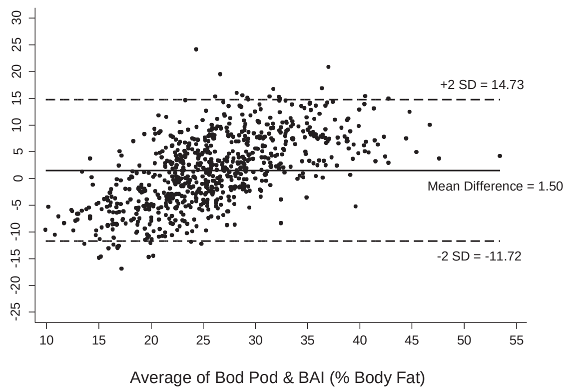

Figure 3A. Bland-Altman plots illustrating the mean difference and limits of agreement for female participants using the Bod Pod and BAI.

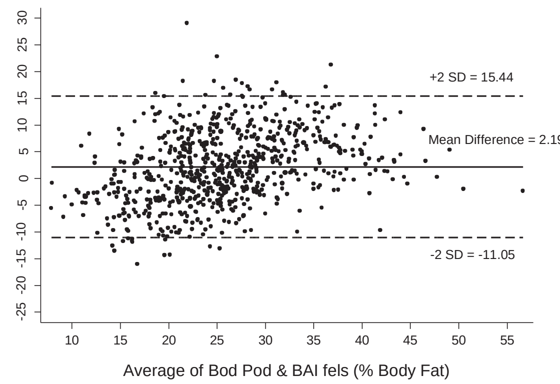

Figure 3B. Bland-Altman plots illustrating the mean difference and limits of agreement for female participants using the Bod Pod and BAI_{FELS}.

the male subjects. Females, however, continued to have stronger correlations between BAI and PBF and BAI_{FELS} and PBF.

Johnson et al. (2012)[15] developed a revised version of the BAI called the BAI_{FELS} by examining a sample of 623 adult's ages 20-50 years from southeast Ohio. They found significant differences in PBF measured from DXA and BAI. Furthermore, they found significant differences between DXA and the BAI_{FELS}. The authors did note that the BAI provides the best estimates between 20-35% PBF while overestimating PBF at lower levels of adiposity and underestimating PBF at higher levels of adiposity. Our results noticed the same trend and confirm the findings of Johnson et al. This study differs as it had a larger sample size (n = 1636), has a larger age range (13-76), and a greater PBF (25.1 ± 8.9% vs. 28.3 ± 9.3%). Both studies did however have a similar BMI (25.4 ± 4.6 vs. 25.7 ± 5.1 kg/m^2).

We also examined the relationship between the methods to estimate body composition and found a moderate correlation between PBF and BAI (r = 0.53), PBF and BAI_{FELS} (r= 0.53), and PBF and BMI (r = 0.48). Both BAI and BAI_{FELS} presented lower correlations than reported by Bergman et al. (2012)[10] (r = 0.79). Cerqueira et al. (2013)[23] reported a smaller correlation between BAI and PBF (r = 0.65) in a group of Brazilian Women. Our study differed from Cerqueira et al. (2013)[23] by having a larger number of female participants who were taller, heavier while having a lower HC, BMI and BAI. Research from Vinknes et al. (2013)[30] reported a correlation (r = 0.78) very similar to Berman et al. (2012)[10] using a population of Caucasian adults from Norway. When correlations were used to examine the relationships between the different age groups (middle aged 47 to 49 years and elderly 71 to 74 years) they found little change. However, when they stratified according to gender the correlations between BAI and PBF decreased for males and females (r = 0.57 and r = 0.72) and increased between BMI and PBF (r = 0.76 and r = 0.81). Lam et al. (2013)[16] reported a larger correlation for Chinese adults (r = 0.81) and when analysed according to gender, males (r = 0.74) had lower correlation versus females (r = 0.82). Our correlations when analysed according to gender demonstrated lower correlations between PBF and BAI (males, r = 0.50 and females, r = 0.68) and between PBF and BAI_{FELS} (males, r = 0.50 vs. females, r = 0.67). We also observed a stronger correlation between PBF and BMI for males compared to females (r = 0.57 vs. r = 0.48) which would support the use of BMI rather than BAI or BAI_{FELS}. Differences between studies might be explained by differences in study demographics such as age, gender, race and ethnicity. It is also likely that gender differences in anthropometric measurements and gender specific fat distribution could be responsible for the changes in relationships when stratified according to gender. It is well known that men carry excess fat around the waist and women carry excess fat around the hips. Schulz et al. (2012)[31] demonstrated this when they reported WC in men had a stronger correlation with PBF than HC. In addition, women had stronger correlation between HC and PBF than WC and PBF. Our sample represented Caucasian men and women from the Rocky Mountain area in the Western United States. We also allowed for a larger age range, whereas others were of different races from the Southern United States and other nations where obesity may differ.

Bland-Altman plots were used to examine bias (i.e. mean difference in PBF) between methods to estimate PBF and limits of agreement for estimating PBF. We found the BAI had a smaller bias when compared with BAI_{FELS} (1.15 vs. 2.13%) and smaller limits of agreement (-12.76 to 15.05% vs. -12.04 to 16.30%). Our plots suggest poor agreement between the PBF and the BAI prediction equations. Similarly, Geliebter et al. (2013)[32] noted large limits of agreement in a population of clinically severe obese women. Those results had a range of 11.3 to -13.63 between BIA and BAI and from 8.49 to -18.47 between the ADP and BAI. Likewise, Silva et al. (2013)[33] demonstrated the limits of agreement between BAI and DXA ranged from 7.7 to -14.4 in chronic kidney disease patients. Although Esco found no significant difference in PBF obtained from BAI and DXA, Bland-Altman plots from that study revealed large limits of agreement (-10.2 to 11.8%). Like Esco (2013)[25], our results demonstrated large limits of agreement. We likewise suggest using alternative methods to assess body composition. Bland-Altman plots were also created according to gender (Figure 2A and 2B). When males were removed from the population sample we saw a small increase in bias for BAI (1.15 to 1.50%) and BAI_{FELS} (2.13 to 2.19%) as well as a decrease in limits of agreement. When females (Figure 3A and 3B) were removed we observed a decrease in bias for BAI (1.15 to 0.84%) and BAI_{FELS} (2.13 to 2.08%); however, unlike the female population, we saw the limits of agreement increase when examining the male population. Schulze et al. (2012)[31] demonstrated large limits of agreement for 360 white Europeans. For men, the limits of agreement ranged from approximately 7 to -13% and 10 to -9% for women respectively. Miagzgowski et al. (2012)[27] found a range of 4.7 to -15.2% in normal weight premenopausal Caucasian women, suggesting poor agreement regardless of gender. This study differed from Schulze et al. (2012)[31] and Miagzgowski et al. (2012)[27] in a number of ways. Schulze et al. (2012)[31] utilised data collected from three other studies (TULIP study, EPIC-Potsdam study, and KORA study). Those studies collected data between 14 and 26 years ago and included adults residing in Germany. Miagzowski et al. (2012)[27] examined premenopausal Caucasian women from Poland with a normal BMI and an age range of 20 to 40 years. Although not part of the data collection, it is likely our sample consisted of both premenopausal and postmenopausal women with a larger age range. Despite these differences each study illustrates large limits of agreement using the BAI.

One limitation of this study might include using a two-compartment model ADP, rather than the three-compartment model. Two-compartment models are less accurate than three or even the four-compartment models; however, the ADP has shown considerable accuracy compared to DXA[34-36] and also has demonstrated good reliability[37,38] so we think this concession is reasonable. In addition, we predicted rather than measured thoracic gas volume. McCrory et al. (1998)[19] found no significant difference between measured and predicted thoracic gas volumes (3.591 ± 0.102 vs. 3.537 ± 0.068) and consequently no significant difference in PBF (23.8 ± 1.3% vs. 23.6 ± 1.3%) and in this light we think this is a reasonable limitation. We also acknowledge that allowing participants to drink water *ad libitum* may have increased the biological error in this study. The consumption of fluids in amounts of 1000 mL or more have shown to significantly increase body weight, volume, and PBF[39, 40]. Because we did not measure fluid intake or ask participants to report fluid intake prior to assessment we cannot rule this out as a limitation. Furthermore, our sample consisted of only Caucasian males and females residing in the state of Utah thus, these data can only be inferred to those individuals who are within this population.

We conclude that the BAI and BAI_{FELS} provide significantly different measures of PBF. Despite the stronger correlations with PBF than BMI those correlations were only moderate. When stratified according to sex BMI became more strongly correlated with PBF. In addition, the limits of agreement were quite large suggesting large differences between measures. We suggest using other measures rather than the BAI equations because of the differences as well as the large limits of agreements. If the BAI equations are used, we recommend using WC and BMI as they have stronger relationships and have shown to be better predictors of risk.[41-44]

The BAI equations do not appear to be valid because of the wide limits of agreement and statistically significant differences with the criterion measure. Furthermore, our data indicate that BMI has a stronger association with PBF when the sex of the participants is homogenous. This trend has been indicated in previous studies and supports the use of BMI rather than using BAI equations. The benefit of the BAI is similar to BMI including the ease of measurement, cost effectiveness. In order to further investigate the utility of BAI equations, we recommend assessing the sensitivity and specificity of the BAI to identify person's weight classifications in comparison with weight classifications identified using BMI. In addition, the authors recommend assessing the repeated agreement, or reliability, of estimates of PBF by BAI equations.

PRACTICAL APPLICATIONS

The BAI and BAI_{FELS} are simple methods of estimating PBF by measuring hip circumference and height. Because of the simplicity of the equations they are likely to be used in settings that require fast and cost effective estimates of PBF. Although the bias is relatively small the large limits of agreement are troubling and urge caution to practitioners using BAI or BAI_{FELS}. We also observe PBF overestimated at lower PBF and underestimated at higher PBF. This may cause misclassifications of health risk associated with either low or high PBF. If practitioners are to use the BAI or BAIFELS, we suggest using additional measures such as waist circumference or waist to hip ratio to better assess health risk.

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