International Journal of EXERCISE SCIENCE

ORIGINAL RESEARCH

Comparison of Body Composition Prediction Equations with Air Displacement Plethysmography in Overweight and Obese Caucasian Males

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ABSTRACT

International Journal of Exercise Science 12(4): 1034-1044, 2019. Body mass index (BMI) has been used for years by clinicians to approximate total body fat. However, the body adiposity index (BAI), body adiposity index from the FELS longitudinal study (BAIFELS), and an equation developed by Deurenberg et al. (BFD) were created recently to offset BMI's limitations and accurately estimate percent body fat (%BF). The prevalence of overweight and obese Caucasian men is increasing in the United States; currently, there is no established way to quickly and accurately predict their %BF. Purpose: To compare the existing %BF equations (BAI, BAIFELS, and BFD) to measured %BF via air displacement plethysmography (ADP) in order to determine the most accurate way to predict %BF in overweight and obese Caucasian men. Methods: Four hundred and fifty-two Caucasian men aged from 18 to 76, with a BMI of 25.0 to 42.4 kg/m2, participated in this study. Height, weight, waist circumference, hip circumference, and body composition using ADP were measured on each participant. These measurements were inserted into the three equations to determine any differences between the equations and the actual %BF measured by ADP. Results: Differences in %BF between ADP and the BAI ($p < 0.001$) and ADP and the BAIFELS ($p < 0.001$) were discovered. While no differences ($p = 1.00$) between ADP and BFD existed. Conclusion: In a population of overweight and obese Caucasian adults from the United States, the BAI and BAIFELS are not appropriate to predict %BF while the BFD prediction equation proved worthy of consideration.

KEY WORDS: Anthropometrics, Fat Distribution, Bod Pod

INTRODUCTION

The prevalence of obesity began increasing during the 1970s in the United States, and currently continues to show no signs of improvement (9). Obesity is becoming more common among adults, especially men, in the United States, and can be measured and diagnosed in multiple ways (9). There are many different techniques to assess body composition, total body mass, or total body fat such as: skinfolds, densitometry, hydrostatic weighing, dual-energy X-ray absorptiometry (DEXA), bioelectrical impedance, and body mass index (BMI). BMI is most commonly used in clinical settings and large groups due to administering ease for health care providers and simplicity when calculating total body mass (10, 19, 28). It has previously been reported that physician face-to-face time with patients averages about 19.7 minutes (27). Therefore, to estimate body fat using anything other than BMI (mass to height ratio) in clinical settings is not ideal.

BMI can be calculated after obtaining height and weight on an individual. It is calculated by dividing weight (kg) by height (m2). Once BMI is calculated, it can be assigned a classification. Those with a BMI between 25.0-29.9 kg/m2 are considered overweight, while those with a BMI greater than or equal to 30.0 kg/m2 are obese. Although BMI is commonly studied and used, it has significant limitations. While relying on height and weight allow for an easy measurement, it also creates the main source of error. BMI does not compartmentalize body weight, which means it cannot differentiate between lean and fat mass (11). This can lead to overestimations in a muscular athlete's total body fat as well as the inability to properly assess an obese individual's total body fat (11, 31, 32, 34, 39). BMI also does not take into account sex. Females tend to store more fat mass while males often have more lean mass, but both can have the same estimated body fatness when using BMI (13, 21, 36). Additionally, older individuals tend to carry more fat mass than younger individuals, but they can also both have the same estimated body fatness using BMI (34). There have been attempts to reduce these limitations in BMI by creating BMI equations which consider physical activity and ethnicity to predict %BF. However, other techniques, like skinfolds and the DEXA, have been found to predict %BF more accurately than the BMI equations can predict total body fatness (8, 30).

Therefore, to combat all of the BMI limitations, the Body Adiposity Index (BAI) was developed in 2012 (2). We previously found overestimations in percent body fat (%BF) when using the original BAI equation and a variation equation taken from the FELS longitudinal study (BAIFELS) (3). Alternative equations have been developed in attempts to accurately determine %BF. One such equation was developed by Deurenberg et al. (BFD). Although slightly overestimating %BF, the BFD equation considers age and sex, giving it the potential to be a more accurate way of predicting %BF (5).

Research has shown the BAI has demonstrated significant disagreements between predicted %BF and measured %BF via the DEXA and air displacement plethysmography (ADP) (3, 4, 15, 29, 33). BMI has even occasionally been shown to predict total body adiposity better than the BAI (20). However, many studies have concluded the BAI to be superior to BMI as a predictor of adiposity (18, 22, 37).

Therefore, the purpose of this study was to use ADP to determine which existing %BF equation (BAI, BAIFELS, and BFD) is the most suitable for a population of overweight and obese Caucasian men. By limiting the participants according to sex and a specific %BF range, we were able to accurately accomplish this. Based on our previous findings, we predicted all measures, from each prediction equation, would be significantly different from ADP (3).

METHODS

Participants

Four hundred and fifty-two (452) overweight and obese Caucasian males participated in this study. Participants included males aged 18 - 76 with a BMI that ranged between 25.0 to 42.4 kg/m2. Prior to testing, participants were asked to refrain from caffeine and alcohol for 24 hours. Participants were also asked to fast for two hours and only permitted to drink water ad libitum during this time. Mean participant characteristics are presented in Table 1. The exclusion criteria included being female, BMI less than 25 and greater than 50 kg/m2, being under the age of 18 yrs, clinically detectable edema, physical amputations, and refusal to give informed consent. The study was approved for completion by the local Institutional Review Board at The University of Utah. A minimum of 161 participant, determined by conducting a power analyses using G*power (Version 3.1.9.3), were required to identify a small effect (power = 0.80, alpha = 0.05).

Table 1. Descriptive statistics**.**

	Mean	SD
Age (yrs)	37.15	9.91
Height (m)	1.79	0.09
Weight (kg)	93.47	14.20
WC (cm)	94.99	10.52
HC (cm)	100.24	8.95
BF (%)	27.20	7.70
BAI	23.92	4.85
BAI_{FELS}	23.12	6.28
BMI (kg/m^2)	28.99	3.36
BF_D	27.13	4.85

yrs = years; m = meters; kg = kilograms; WC = waist circumference; HC = hip circumference; cm = centimeters; BF = body fat; % = percent; BAI = body adiposity index; BAI_{FELS} = body adiposity index FELS longitudinal study; BMI = body mass index; kg/m^2 = kilogram per meter squared; BF_D = percent body fat calculated from Deurenberg et al.

Protocol

This study used a repeated measures design to assess the difference in %BF using ADP, two prediction equations for BAI, and Deurenberg et al.'s BMI conversion equation (5). All participants underwent body composition analysis using ADP via the Bod Pod. Before entering the Bod Pod, waist circumference (WC) and hip circumference (HC) were measured. Visual inspection of Bland-Altman plots allowed for the determination of agreement between measurements.

Anthropometry: WC and HC were measured to the nearest mm 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, while having feet shoulder width apart (6). HC was measured at the maximum circumference of the buttocks while having both feet together (6). BMI (14), BAI (2), BAIFELS (22), and BFD (5) were calculated using the following equations:

Body Mass Index (14): weight (kg) / height (m2)
Body Adiposity Index (2): hip circumference (cm) / height (m) 1.5 - 18
Body Adiposity Index FELS (22): 1.26 * hip circumference (cm) / height (m) 1.4 - 32.8
Body Fat Deurenberg et al (5): 1.2 * BMI + 0.23*age - 10.8 * sex - 5.4
Note: For sex, male = 1 and female = 0

Air Displacement Plethysmography: Body composition was determined using the Bod Pod (Life Measurement Inc., Concord, CA, USA). The Bod Pod has demonstrated to be a valid and reliable tool for assessing body composition in overweight and obese individuals (16, 17, 24). For appropriate %BF measurements, 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 following the manufacturer's directions. Height was measured without shoes to the nearest mm using a stadiometer (Novel Products Inc., IL, USA). Weight was measured using an electronic scale which was calibrated according to manufacturer's directions (Life Measurement Inc., Concord, CA, USA). Body volume was measured a minimum of two times. However, a third measurement was taken if the first two measurements were not within 150 ml or 0.3% as instructed by the Bod Pod. Thoracic gas volume was estimated using the prediction equation provided by the Bod Pod software (26). Body density was converted to %BF using the two-compartment Siri equation (35). All calculations were performed by the Bod Pod's software (version 1.91).

Statistical Analysis
Data are reported as means ± standard error. All data were screened for outliers, multivariate normality, and sphericity before proceeding with Repeated Measures ANOVA. Differences in %BF between methods were compared using repeated measures ANOVA with Bonferroni post hoc analysis. Pearson correlation coefficients examined relationships between ADP and the BAI, BAIFELS, and BFD. Agreement of estimating %BF was assessed between the BAI equations and the Bod Pod using a Bland-Altman plot with 95% limits of agreement. Constant error (CE) was calculated as CE=gold standard – new measure. Standard error of measure (SEM) was calculated as the standard deviation divided by the square root of N. Data were exported from the Bod Pod software to Excel (Microsoft Office, USA), and analyzed using SPSS version 20 (IBM Corp., Armock, NY, USA) with alpha set a priori at $p < 0.05$.

RESULTS

A significant value for Mauchly's Test of Sphericity was found indicating the assumption of sphericity had been violated. Because the assumption of sphericity was violated, a repeated measures ANOVA with a Greenhouse-Geisser correction was utilized and determined the mean %BF were statistically different among the methods used to predict %BF (F(1.884, 849.717) =

107.769, (p < 0.001). Post hoc tests using the Bonferroni correction revealed a statistically significant difference in %BF between ADP and the BAI (p < 0.001) as well as ADP and the BAIFELS (p < 0.001). However, there was no significant difference (p = 1.00) between ADP and BFD. Pearson correlation coefficients were all statistically significant and are listed in Table 2. BFD (r = 0.51) had the strongest correlation with ADP, followed by BMI (r = 0.49) and WC (r = 0.48). Additionally, CE and SEM can be seen in Table 3. Tables 4, 5, and 6 show %BF for each equation (BAI, BAIFELS, and BFD) based on the participants' BMI.

Table 2. Pearson's correlation coefficients between %BF determined by ADP and different variable.

Measure	r	Level of Significance
BAI	0.43	p < 0.000
BAIFELS	0.43	p < 0.000
BFD	0.52	p < 0.000
BMI	0.49	p < 0.000
HC	0.33	p < 0.000
WC	0.49	p < 0.000
WHR	0.21	p < 0.000

BAI = body adiposity index; BAIFELS = body adiposity index FELS longitudinal study; BFD = percent body fat calculated from Deurenberg et al.; BMI = body mass index; HC = hip circumference; WC = waist circumference; WHR = waist to hip ratio.

Table 3. Constant error and standard error of measure for the different measures of %BF.

	BAI	BAI_{FELS}	BF_D
CE	-3.28	-4.08	-0.07
SEM	0.23	0.30	0.229

BAI = body adiposity index; BAI_{FELS} = body adiposity index FELS longitudinal study; BF_D = percent body fat calculated from Deurenberg et al.; CE = constant error; SEM = standard error of measure.

Table 4. Mean and SD body composition measures according to BMI of 25-29.99.

	BMI 25-29.99	%BF	BAI	BAI_{FELS}	BF_D
Average	27.10	24.91	23.12	22.05	24.69
SD	1.36	7.16	4.55	5.88	2.97

BMI = body mass index; %BF = percent body fat; BAI = body adiposity index; BAI_{FELS} = body adiposity index FELS longitudinal study; BF_D = percent body fat calculated from Deurenberg et al.; SD = standard deviation.

Table 5. Mean and SD body composition measures according to BMI of 30-39.99.

	BMI 30-39.99	%BF	BAI	BAI_{FELS}	BF_D
Average	32.96	32.14	25.63	25.40	32.34
SD	2.38	6.32	5.04	6.52	3.56

BMI = body mass index; %BF = percent body fat; BAI = body adiposity index; BAI_{FELS} = body adiposity index FELS longitudinal study; BF_D = percent body fat calculated from Deurenberg et al.; SD = standard deviation.

Table 6. Mean and SD body composition measures according to BMI of 40-50.

	BMI 40-49.99	%BF	BAI	BAI_{FELS}	BF_D
Average	41.48	37.17	27.96	28.73	40.63
SD	0.80	4.21	3.59	4.79	1.22

BMI = body mass index; %BF = percent body fat; BAI = body adiposity index; BAI_{FELS} = body adiposity index FELS longitudinal study; BF_D = percent body fat calculated from Deurenberg et al.; SD = standard deviation.

Bland-Altman plots were also created to show the differences between ADP and each of the three equations. ADP versus BAI is depicted in Figure 1, ADP verses BAIFELS is depicted in Figure 2, and ADP verses BFD is depicted in Figure 3.

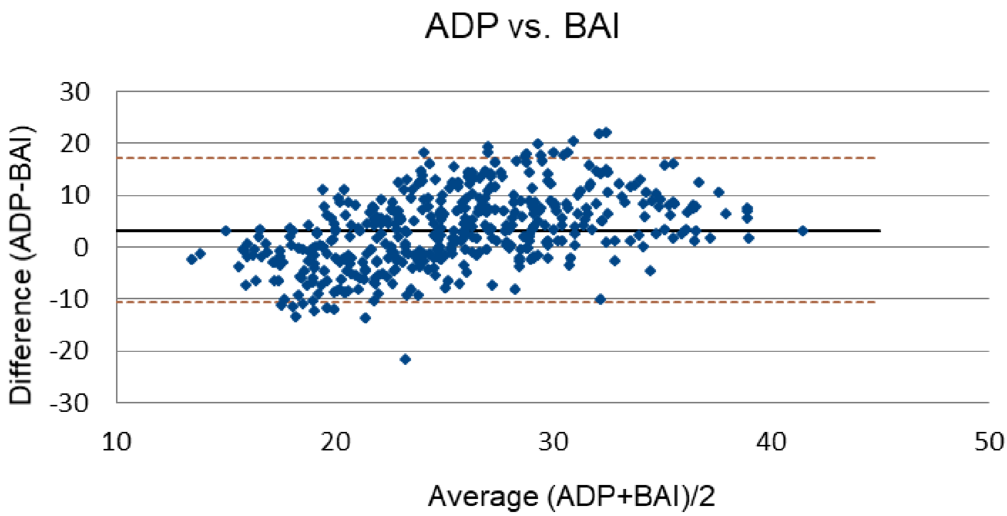

Figure 1. Bland-Altman plot depicting the difference and average between air displacement plethysmography (ADP) and the body adiposity index (BAI).

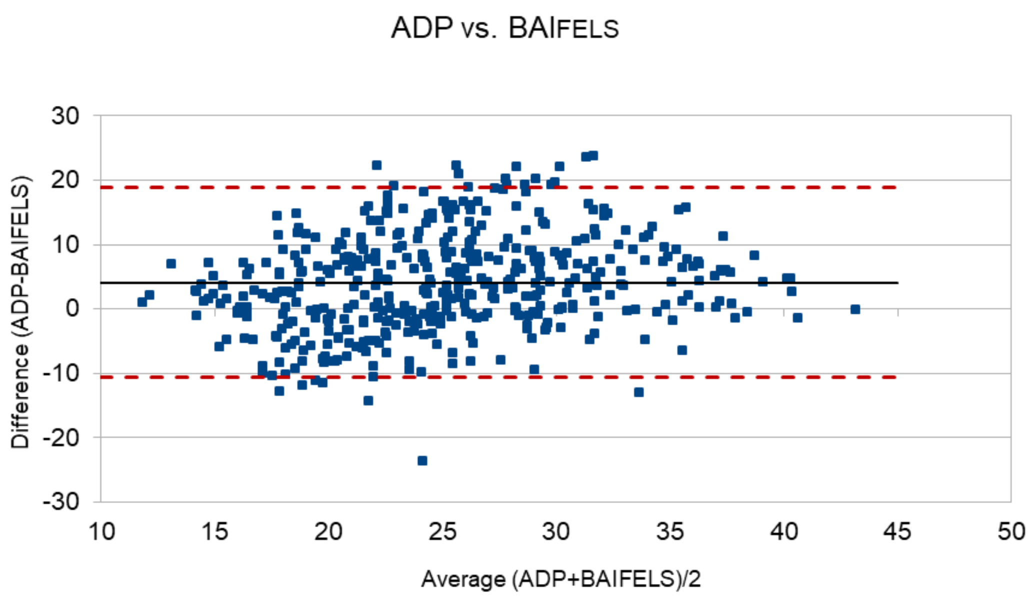

Figure 2. Bland-Altman plot depicting the difference and average between air displacement plethysmography (ADP) and the body adiposity index FELS longitudinal study (BAI_{FELS}).

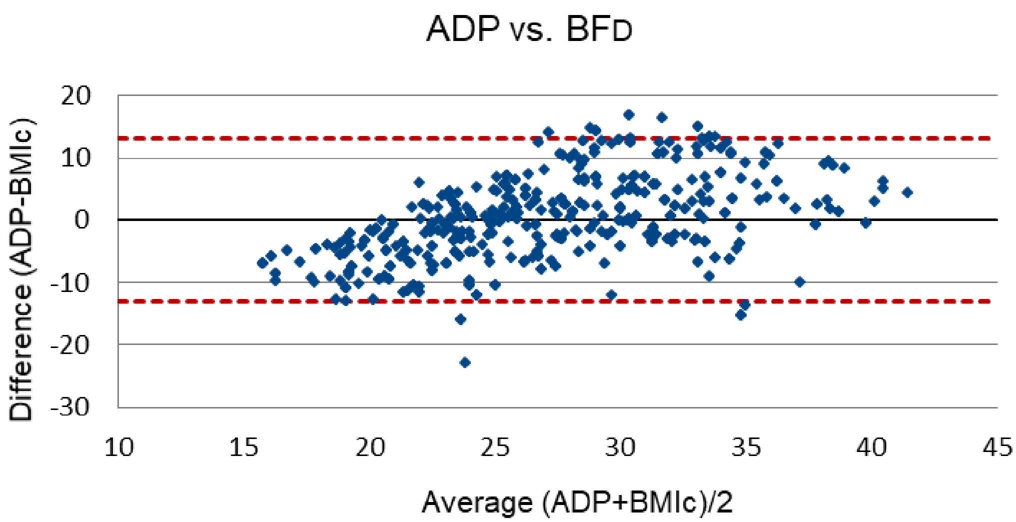

Figure 3. Bland-Altman plot depicting the difference and average between air displacement plethysmography (ADP) and the percent body fat as calculated from Deurenberg et al. (BF_D).

DISCUSSION

The purpose of this study was to compare predicted %BF from two different BAI prediction equations and BFD equation to the measured %BF via ADP in a sample of overweight and obese Caucasian men. The results from our study found all measures, except for the BFD equation, to be significantly different from the measured %BF via ADP. This was unexpected as Deurenberg et al. found their equation slightly overestimated %BF in obese participants (5). These findings may be the result of using a population of both overweight and obese participants, with BMIs ranging from 13.9 to 40.9 kg/m2. In addition, Deurenberg et al. used a sample with both sexes while our sample consisted of only male participants (5).

When formulating our prediction in this study, the measurements in each %BF equation were considered. When Bergman et al. originally developed the BAI, they looked at Mexican and African Americans of both genders and found HC to be a better predictor of %BF than WC (2). Therefore, HC was included in the original BAI equation (2). However, this is problematic because men store fat around the trunk whereas women store fat around the hips (23). This means, using HC in the BAI prediction equation may not be suitable for both genders. Therefore, we predicted the original BAI equation would be significantly different than the %BF measured via ADP, which did occur and is supported by one of our previous studies conducted with a mixed sex sample (3).

The inaccuracy in predicting %BF with the BAI can be seen further in other studies. In a study conducted with severely obese adults, the BAI exhibited to be a poor predictor of %BF (1). Likewise, in a sample of overweight and obese postmenopausal Caucasian women the BAI underestimated %BF by 7.56% (23). In a sample of collegiate female athletes, BAI was found to be an inaccurate measurement of %BF when compared to the DEXA, by overestimating %BF levels (7). Additionally, in a group of middle aged and elderly participants from Norway, the BAI underestimated %BF at higher BMI levels (38).

Our next prediction that the BAIFELS equation would also produce significantly different results for %BF than the measure taken by ADP did occur in our Caucasian male participants. This finding was also seen in our previous research with a mixed sex sample (3). The BAIFELS equation was originally created using European-American adults from the FELS longitudinal study (22). In this study, it was determined that both BAI equations, the original BAI and BAIFELS, differed significantly from the DXA; however, they did note the BAIFELS performed better at high levels of adiposity (22). This study along with another that found the BAI to be an inaccurate choice for assessing severely obese Caucasian women (15), helped develop our sample and prediction. We elected to limit our sample to adult Caucasian men with a BMI of 25 to 39.9 kg/m2 to attempt to get the most accurate results. Additionally, we elected to use an equation previously developed by Deurenberg et al. to consider sex and discard HC (5) because the BAI equation has been found to be a less accurate measure of %BF when compared to BMI, HC, and WC (12).

When assessing the Bland Altman plots and CE for this study, the BFD equation is suggested to be the best for predicting %BF when compared with the BAI and BAIFELS equations. The limited agreement on the Bland Altman plots suggest large individual differences from %BF measure by ADP. Based upon our findings, we believe the BFD is the best equation out of the three to predict %BF. We conclude that both the BAI and BAIFELS are not suitable for predicting %BF in overweight and obese Caucasian men. Clinicians should utilize other existing methods to assess body fat in order to avoid large errors associated with either BAI equation.

This study does have limitations. This study had few (n = 29) participants with a BMI above 35.0 kg/m2. Additionally, the results from this study can only be applied to overweight and obese Caucasian men from the United States. However, with the large sample size and use of ADP, we feel that this limitation is acceptable.

In conclusion, the BAI and BAIFELS are not appropriate to predict %BF in a population of overweight and obese Caucasian adults from the United States, while the BFD prediction equation is appropriate. Future studies should evaluate the differences in body fat using the BFD equation in multiple ethnic groups.

ACKNOWLEDGEMENTS

The authors would like to thank all of the volunteers for their time and efforts. No funding or contributions were received for this study.

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