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Accuracy of Bioelectric Impedance Analysis Devices to Estimate Body Fat and Fat-Free Mass in College Women Athletes

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ABSTRACT

Background: Body composition is frequently measured in women athletes to evaluate training changes, assist in dietary planning, and avoid the female athlete triad. Measurements to monitor %fat and fat-free mass (FFM) can provide valuable information for coaches and athletes throughout the training process. However, questions remain concerning the accuracy of various methods used to measure %fat. The purpose of this study was to assess the accuracy of bioelectric impedance analysis (BIA) devices to estimate %fat and FFM compared to dual-energy X-ray absorptiometry (DXA) in college women athletes. **Methods:** A cross-section design was employed to assess %fat and FFM among college women athletes. Fifty-seven athletes (age = 20.0 ± 1.4 yrs, height = 179.2 ± 6.0 cm, weight = 74.3 ± 4.4 kg) from soccer (n = 29), basketball (n = 15), and swimming (n = 13) had %fat estimated from four single-frequency BIA devices. Two BIA devices had general population equations (BIA1 and BIA2) and two had athlete-specific equations (BIA3 and BIA4). Each device had proprietary equations for estimating %fat and was not capable of being updated. Each device had a 2-point electrode contact with either hands or feet. DXA %fat served as the criterion measurement. Percent fat was estimated directly by each device, and FFM was calculated as body mass minus fat mass. All measures were completed in single sessions for each athletic group with different sports groups being measured at the onset of their competitive season. Athletes were measured between 1400 and 1600 hours in a rested stated with hydration assumed and after voiding the bladder. A repeated-measures one-way analysis of variance (ANOVA) with Bonferroni *post hoc* testing was used to evaluate differences among measurement techniques with significance set at $p<0.05$. **Results:** Three arm-to-arm BIA devices (BIA1, BIA2, and BIA3) were not significantly different in %fat estimates (23.1 ± 5.0%, 23.7 ± 4.7%, and 23.6 ± 4.3%, respectively) but were significantly lower than DXA (29.5 ± 5.1%). The leg-to-leg athletic BIA (BIA4) had a significantly higher %fat estimate (24.6 ± 5.7%) than BIA1 but was not significantly different from BIA2 and BIA3. The correlation of DXA %fat with BIA1 (r = 0.84), BIA2 (r = 0.85), and BIA3 (r = 0.85) were significant but not statistically different across the 3 devices. BIA4 had a significantly lower correlation (r = 0.66) with DXA %fat. The lower estimates in %fat resulted in significantly higher calculated FFM values for BIA1 (51.1 ± 5.5 kg), BIA2 (50.8 ± 59 kg), BIA3 (50.9 ± 6.9 kg), and BIA4 (50.1 ± 5.8 kg) than for DXA (47.5 ± 5.9 kg). However, all BIA estimates of FFM were highly correlated with DXA FFM (r = 0.90-0.93). Limits of agreement analysis indicated the average bias ranged from 2.2 kg (BIA4) to 3.4 kg (BIA1). Conclusion: Single-frequency BIA devices utilized in this study tend to underestimate %fat and overestimate FFM compared to DXA in college women athletes. However, high correlations between predicted and actual FFM values indicate that single-frequency BIA devices may be useful for tracking changes in women athletes across seasons.

Keywords: body composition, single-frequency BIA.

INTRODUCTION

Body composition is an important metric in women athletes for evaluating training changes, assisting in dietary planning, and avoiding the female athlete triad. While many researchers and coaches focus on the percent fat (%fat) level of women athletes, estimates of fat-free mass (FFM) may be equally important.[1] Regular measurements to monitor %fat and FFM can provide valuable information for coaches and athletes regarding the need for diet manipulation, alterations in training intensity, and recovery throughout the training process. However, sophisticated body composition measurement techniques require expensive equipment, the need for trained technicians, and perhaps a significant time commitment away from sports skill development. These factors often exclude routine measurement of body composition for athletes engaged in your-round training and competition schedules. Studies that have tracked body composition changes over the course of a competitive season have noted variations in both %fat and FFM that may affect performance.[2-5]

Therefore, there is need for both time-efficient and accurate body composition measurement techniques for women athletes. Some of the most popular methods for estimating %fat among athletes include skinfolds, whole-body plethysmography (BODPOD), bioelectric impedance analysis (BIA), and dual energy X-ray absorptiometry (DXA). Skinfold measurement demands a certain level of expertise in order to insure accurate and consistent measurement.[6] BODPOD and multi-frequency BIA can be expensive and can require a certain level of expertise to achieve accurate measurement. Since its development, DXA has gained a reputation as a primary standard for determining body composition.[7] In addition to estimating %fat, this technique determines FFM directly as the sum of lean mass and bone mineral content. However, the high cost of this device and time frame for measurement mean this technique is not often available for use in many collegiate athletic settings.

Over the years, many inexpensive BIA devices using single frequency electrical impedance and propriety equations have been marketed to estimate %fat. Some of these devices differentiate between "normal" and "athlete" categories with difference based on the hours of vigorous activity per week. From the reported %fat, FFM can be estimated according to the equation FFM = weight- (weight x %fat/100). Despite the many inexpensive BIA models available, their accuracy for measuring %fat appears to vary depending on which device is used and the athletic population evaluated. Civar et al.[8] compared a leg-to-leg BIA to underwater weighing in women athletes and found no significant difference in %fat between the two methods (11.8 ± 2.4% vs 11.6 ± 2.4%, respectively) with a moderate correlation between them ($r = 0.67$). Using a hand-to-hand single-frequency BIA, Esco et al.[9] showed mean %fat for a group of women athletes to be 5.1% (±3.6%) lower than DXA, which caused FFM to be overestimated by an average of 3.4 kg (±2.5 kg) with a high correlation between the two methods ($r = 0.84$) but a fairly large limits of agreement (LoA) of -8.4 to 2.4 kg. Nickerson et al.[10] used a hand-to-foot single-frequency BIA device compared to DXA for determining %fat and FFM in 44 college women athletes. They noted a significantly lower %fat estimate using BIA compared to DXA with a correlation of $r = 0.71$ between techniques. They also found a large LoA (-10.2% to 6.4%) with a mean difference of -1.9% between the two devices. Rockermann et al.[11] concluded that the difference between a hand-held single-frequency BIA %fat values and DXA may be too great to allow the former to estimate the latter with sufficient accuracy in untrained college men and women. To the contrary, Carrion et al.[12] noted good concordance for hand-to-hand and leg-to leg BIA devices with air-displacement plethysmography in athletic college men and women.

Due to mixed results in studies utilizing single-frequency BIA devices, questions remain concerning their accuracy for measuring %fat and FFM in women athletes compared to a laboratory standard technique. If accurate assessments of %fat and/or FFM could be established in young women athletes, it might facilitate more routine measurement of body composition throughout the yearly training cycle to provide guidance for diet plans and indications of the outcome of various training programs. Therefore, the purpose of this study was to assess the accuracy of several single-frequency BIA devices for estimating %fat and FFM compared to DXA in college women athletes.

METHODS

Participants and study design

Fifty-seven NCAA Division-II college women athletes volunteered to participate after being informed of the processes of the study. The study was approved by the university institutional review board and complied with the Declaration of Helsinki. Sports represented were soccer (n = 29), basketball (n = 15), and swimming (n = 13). G-Power analysis indicated that 54 participants were required for a power of 0.80, effect size of 0.4, and α = 0.05[13]. Measurements were performed during the initial week of training for each sport in September. Participants were measured in the afternoon a minimum of 3 hours following a meal and at least 8 hours after any morning training session.[14] Immediately prior to testing, each participant voided their bladder. Each athlete was measured wearing shorts and T-shirt without shoes. All jewellery was removed before scanning.

Instruments

Body weight was assessed using a platform scale (Tanita BWB-800). Height was measured using a wall-mounted stadiometer (Hyssn Limnfog AB). BIA was measured with four single-frequency devices. The Omron model HBF-300 (BIA1) had one setting for all participants. All BIA devices used a two-electrode contact method. The Omron HBF-306 had setting designations for normal (BIA2) and athletes (BIA3). These 3 device required input of age, height and weight and had participants hold the device at arm's length in a standing position during measurement. The Tanita model TBF-521 (BIA4) was a leg-to-leg single-frequency device using an athletic setting and required the input of age and height before it assessed the athlete's weight in a standing position to complete measurement of %fat. Hands were dry at the time of measurement. Each device estimated %fat utilizing propriety equations that were not capable of updating or modification. Since each device did not provide an estimate of FFM, it was calculated using the formula: FFM = weight-(weight x %fat/100).

Criterion body composition measurements were performed using DXA (General Electric Lunar iDXA, Fairfield, CT). Each athlete was positioned on the scanning bed with arms at their side and hands in a prone position several inches lateral to the side. Each scan required seven minutes.

Statistical Analysis

Differences among sports groups for %fat and FFM were determined using repeated measures analysis of variance (ANOVA). Significance level was set at $p<0.05$ for all statistical procedures. Post hoc differences were assessed using the Bonferroni comparison. Pearson correlation coefficients were used to determine the strength of relationship among measurement techniques (.00-.30 = small, 0.30-0.49 = moderate, 0.50-0.99 = large). Limits of agreement (LoA) were constructed by comparing FFM residuals (BIA – DXA) to FFM measured for each BIA device. Typical error of measurement (TEM) was calculated as the standard deviation of the difference between each BIA device and DXA divided by √ 2. Bias was calculated as the mean difference between each BIA device estimation and DXA divided by the sample size.

RESULTS

Basketball players were significantly greater ($p<0.05$) in height, weight, and FFM than soccer players and swimmers, but the three sports groups were not significantly different ($p>0.05$) in %fat (Table 1). DXA presented a significantly higher %fat ($p<0.05$) than all BIA estimates (Table 2). The three arm-to-arm BIA devices (BIA1, BIA2, and BIA3) were not significantly different in their %fat estimates ($p>0.05$), while the leg-to-leg athletic BIA (BIA4) had a significantly lower %fat estimate ($p<0.05$) than BIA1 but was not significantly different ($p>0.05$) from BIA2 and BIA3 (Table 2). All four BIA devices produced significantly lower estimates of FFM than DXA ($p<0.05$).

Correlations of DXA %fat with %fat from all BIA devices were significant ($p<0.05$) but not statistically different ($p>0.05$) between BIA1, BIA2, BIA4 and DXA (Table 2). BIA3 %fat had a significantly lower correlation ($r = 0.66$, $p<0.05$) with DXA %fat than the other devices. Regression analysis to estimate DXA FFM from BIA FFM produced high correlations for each device (Table 2) but significantly overestimated ($p<0.05$) for each device (Figure 1). The lower %fat estimates from each BIA device resulted in significantly higher estimates of FFM ($p<0.05$) compared to DXA (Figure 1). However, correlations between BIA-determined FFM and DXA FFM were all significant (Table 2). BIA2 had the lowest bias (1.9 kg) and typical error (3.1 kg) when estimating FFM. Regression validity for estimating FFM using BIA devices was plotted against the residuals to identify limits of agreement according to the procedure suggested by Kiouwa15 (Figure 1).

DISCUSSION

The main objective of this study was to evaluate the agreement between commercially available single-frequency BIA devices to estimate %fat and FFM in college women athletes. All BIA models showed good agreement with DXA (r > 0.90) for FFM with small difference of 2.2 to 3.4 kg between DXA and these devices. Therefore, these BIA models appeared to have good potential for evaluating FFM in women athletes.

Nickerson et al.[10] previously suggested that use of hand-to-foot BIA-derived values for FFM did not appear to provide a suitable surrogate for DXA in women athletes. However, their small mean difference of 1.3 kg and a correlation of 0.89 between BIA and DXA FFM values might suggest better support than previously thought. A later study found that the same hand-to-foot BIA device (RJL Quantum IV) was better for estimating FFM than %fat in college-age women, offering support for use of BIA when more sophisticated techniques are not available[14]. Another study tracking FFM changes across a basketball season also found good agreement between several single-frequency BIA devices and DXA for estimating FFM.[5]

Moon[16] earlier noted that no generalized BIA equation had been developed using a 4-component body composition model. However, he did state that several studies using a 2-component model of body composition have supported the use of single-frequency BIA devices. Part of the discrepancy surrounding use of BIA in women may center on hydration fluctuations during the menstrual cycle. This may always be a potential confounding issue with women athletes in the timing of body composition evaluations across a training year. White et al.[17] reported that fluid retention was highest on the first day of the cycle and can return to normal levels by the 4th day. In their review, Carmichael et al.[18] suggested that fluid retention during a typical cycle tends to be low. Gleichuaf and Roe[19] suggest that monthly fluid fluctuation might be a confounding issue when measuring body composition. However, McKee and Camerron[20] and Comberledge et al.[21] found no difference in body composition measurement with several BIA devices across a monthly cycle. Thus, the fluid retention experienced by the average female athlete probably has very

Table 1. Physical characteristics of women athletes.

	Age (yrs)	Height (cm)	Weight (kg)	%fat	FFM (kg)
Basketball (n = 15)	20.4 ± 1.3	174.9 ± 5.8*	76.3 ± 15.0*	28.5 ± 5.7	52.8 ± 6.9*
Soccer (n = 29)	20.2 ± 1.7	164.5 ± 4.3	63.9 ± 7.9	29.8 ± 5.3	45.0 ± 3.5
Swimming (n = 13)	20.2 ± 1.5	166.4 ± 5.3	66.5 ± 8.6	29.9 ± 4.2	47.2 ± 5.2
Composite (n = 57)	20.2 ± 1.5	167.7 ± 6.6	67.0 ± 11.0	29.5 ± 5.1	47.5 ± 5.9

Abbreviations: FFM = fat-free mass.
**Significant difference from soccer & swimming (p<0.05).*

Table 2. Comparison of %fat, FFM, and fat-free-mass index between BIA and DXA in women athletes (n = 57).

	BIA1	BIA2	BIA3	BIA4	DXA
%fat	23.1 ± 5.0[1] r = 0.84*	23.7 ± 4.7[1] r = 0.85*	23.6 ± 4.3[1] r = 0.66*	24.6 ± 5.7[1,2] r = 0.85*	29.5 ± 5.1
FFM (kg)	51.1 ± 5.5[1] r = 0.93*	50.7 ± 5.9[1,2] r = 0.94*	50.9 ± 6.9[1] r = 0.90*	50.1 ± 5.8[1,3] r = 0.92*	47.5 ± 5.9
Bias[a] (kg)	2.2	1.9	2.8	2.2	
Typical Error[b] (kg)	3.4	3.1	3.2	5.9	
FFMI (kg)	18.15 ± 1.19[1] r = 0.81*	18.01 ± 1.25[1] r = 0.83*	18.06 ± 1.59[1] r = 0.76*	17.79 ± 1.25[1,2] r = 0.78*	16.86 ± 1.33

Abbreviations: FFMI = fat-free mass index. [a]Bias = Mean (BIA-DXA)/n [b]Tyical error = $SD_{(DXA-BIA)}/\sqrt{2}$.
**Correlation with DXA value (p<0.01).*
[1]Signficant difference from DXA (p<0.05). [2]Signficant difference from BIA1 (p<0.05).

little effect on BIA measurement of FFM.

The current study was not without some limitations. Although the athletes were assumed to be well hydrated, no measurement of urine specific gravity was determined to validate hydration level. Despite previous studies suggesting that menstrual cycle variations in fluid retention appears to play a minor role in BIA measurement,[19-21] charting menstrual cycles for each athlete may have been useful to assess the effect on the differences between BIA estimates and DXA values. In addition, attention should be given to the athlete's hydration and nutrition level prior to measurement as they may impact BIA measurement.

CONCLUSION

The high correlations, low bias, and small typical error between DXA FFM and FFM calculated from hand-to-hand single-frequency BIA devices noted in this study could provide support for adequately monitoring changes in FFM in women athletes across a yearly training cycle. Additional studies may be needed to assess the impact of training programs and diets variations on FFM and %fat in women athletes across the year's sports cycle when using

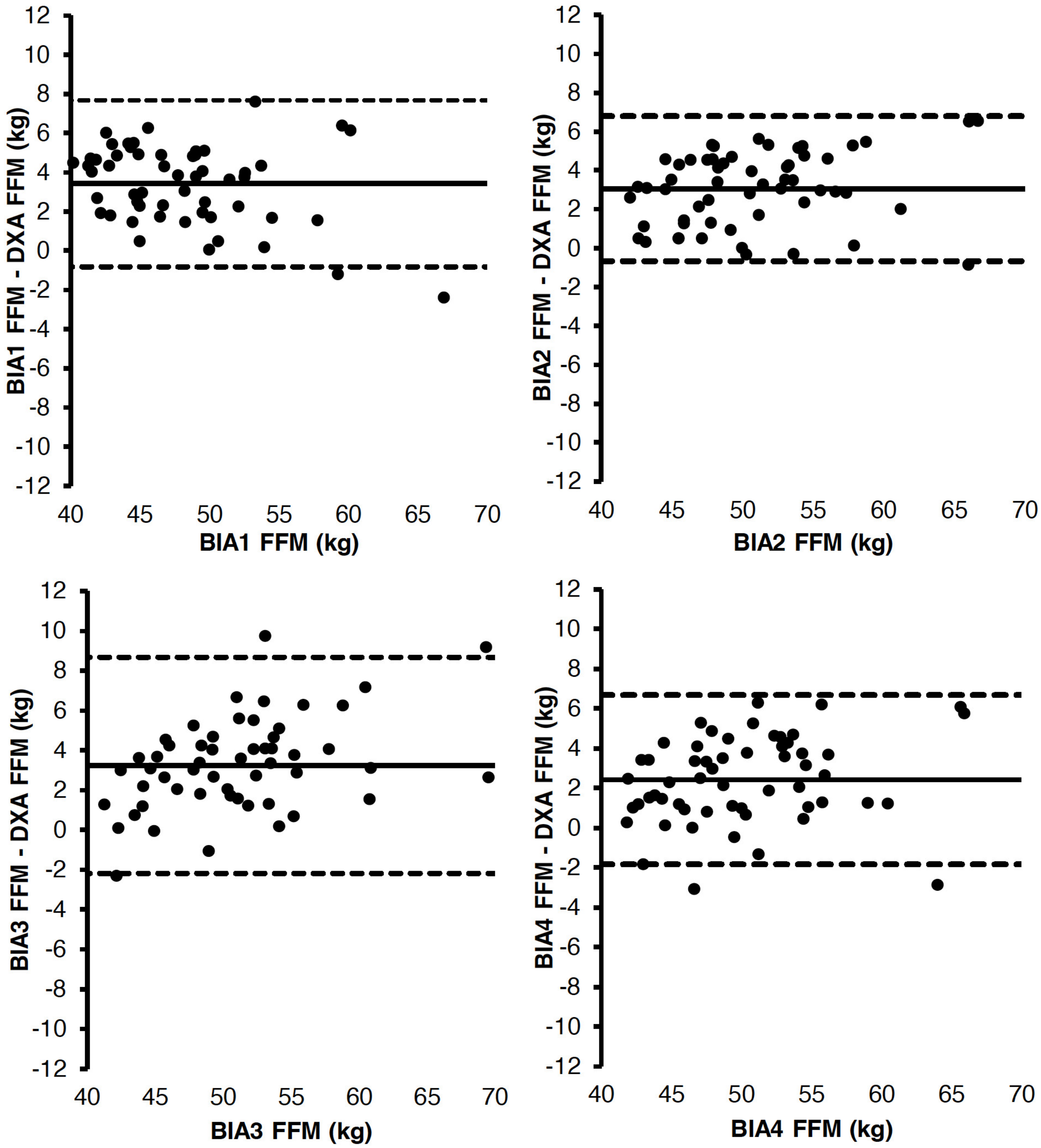

Figure 1. Bland-Altman plots for DXA BIA vs predicted-actual FFM.

different devices. However, as Moon[16] has pointed out, until more detail work is published on the use of BIA for assessing changes in body composition across a training cycle, selected BIA devices may provide useful estimates of FFM in women athletes.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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