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SHORT REPORT OPEN ACCESS

COMPARISON OF BIA AND DXA FOR ESTIMATING BODY COMPOSITION IN COLLEGIATE FEMALE ATHLETES

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ABSTRACT

Purpose: The purpose of this investigation was to compare bioelectrical impedance analysis (BIA) to dual-energy x-ray absorptiometry (DXA) for predicting body fat percentage (BF%) and fat-free mass (FFM) in collegiate female athletes. **Methods:** Forty-four collegiate female athletes (age = 21.1 ± 2.0 years; height = 166.5 ± 6.9 cm; weight = 63.9 ± 10.0 kg) volunteered to participate in the study. Each participant's BF% and FFM was determined via BIA and DXA. **Results:** The mean (± SD) BF% determined by DXA was 27.7 ± 5.9% and by BIA was 25.8 ± 3.2%, which was significantly different ($p < 0.05$). BIA significantly correlated with DXA ($r = 0.71$, $p < 0.05$) for BF% and yielded a SEE of 4.21%. The limits of agreement (i.e., 95% confidence intervals) for BF% ranged from 10.2% below to 6.4% above the mean difference of -1.9%. The mean FFM (+/- SD) determined by DXA was 46.2 ± 6.1 kg and by HF-BIA was 47.5 ± 6.0 kg, which was also significantly different ($p < 0.05$). BIA significantly correlated with DXA ($r = 0.89$, $p < 0.001$) for FFM with a SEE of 2.8 kg. The limits of agreement for FFM ranged from 4.0 kg below to 6.6 kg above the mean difference of 1.3 kg. **Conclusion:** Due to significant mean differences and large individual error, BIA does not appear to serve as a suitable surrogate to DXA for evaluating BF% and FFM in collegiate female athletes. Sport practitioners should be aware of the study's results and use caution when interpreting BIA analyses within this population.

Keywords: Women, Body Fat, Fat-Free Mass, Dual Energy X-Ray Absorptiometry

INTRODUCTION

Body fat percentage (BF%) and fat-free mass (FFM) are often evaluated among athletes due to their influence on health and performance (16,19). For example, excessive adiposity has been shown to negatively impact aerobic power, running speed, and explosive strength (26,29), while extremely low body weight, BF%, and FFM values have been linked to eating and body image issues associated with the female athlete triad (31). Therefore, BF% and FFM are often evaluated in sporting populations for assessing the outcomes of strength and conditioning programs, evaluating overall physical fitness, and providing important information for sport nutrition experts related to estimating daily energy requirements (3,10,11,12,34).

Dual energy x-ray absorptiometry (DXA) is a criterion method that is commonly utilized in scientific investigations to evaluate body composition (10,11,13,16,24), especially with female athletes due to the variation in bone mineral density (6,16). Though an acceptable laboratory measure of BF% and FFM (33), DXA scans can be time consuming and expensive, and are only found in clinical and research laboratories. Unfortunately, DXA scans are therefore not particularly accessible to athletes. Instead, simplified field techniques such as bioelectrical impedance analysis (BIA) are more commonly utilized in field settings. BIA is often used for determining BF% and FFM among athletes due to its portability, ease of use, and quick administration (29). Additionally, the procedure is highly reliable (25) and does not require an experienced operator, hence reducing the chance of technician error.

BIA passes an electrical current through the body while determining resistance and reactance (i.e., impedance) (29). It is based on the principle that electrical conductivity of lean tissue is far greater than that of fat because of relatively higher water and electrolyte content in lean tissue (25). In other words, BIA assumes that skeletal muscle provides a good electrical pathway, while adipose tissue produces a poor pathway of conduction (5). After identifying the levels of resistance and reactance to the electrical current, a BIA analyzer algorithmically converts the speed into total body water (TBW), which is subsequently calculated into FFM and BF% (27,35).

Common single frequency BIA conducts a painless, imperceptible electrical current (500 to 800 μA) at a fixed frequency of 50 kHz through the body. The polarity distribution of hand-to-foot BIA entails four leads being attached to surface electrodes placed on the hand and foot (considered distal poles) and wrist and ankle (proximal electrodes). The fall in voltage is provoked by impedance and captured by the sensor (proximal) electrodes (27).

Recently, RJL Systems, a manufacturer of BIA devices, created a hand-to foot model that is considered the company's flagship standard for body composition analysis. No studies to date have compared RJL Systems' new hand-to-foot BIA model to DXA in collegiate female athletes. Thus, the precision of the device remains uncertain for usage within this population. This is an important area of research because certain sport environments may heighten body and weight concerns in women due to factors such as pressure from coaches, social comparisons with teammates, team weigh-ins, physique-revealing uniforms, and judging criteria (18). Consequently, body composition methods that provide inaccurate results could negatively intensify these concerns. Therefore, the purpose of this investigation was to compare hand-to-foot BIA to DXA for predicting BF% and FFM in collegiate female athletes. Based on previous research that found significant differences between DXA and other BIA devices (13,21,22), it was hypothesized the BIA device used in this study would not provide comparable results to those of DXA.

METHODS

Subjects

Forty-four collegiate female athletes (age 21.1 ± 2.0 yr; height 166.5 ± 6.9 cm; weight 63.9 ± 10.0 kg;) from the National Association for Intercollegiate Athletics participated in the study and provided written informed consent. Athletes were recruited from the soccer (n = 20), tennis (n = 6), cross-country (n = 10), and basketball (n = 8) teams at the host university. According to health history questionnaires, all participants were apparently healthy, free from cardiopulmonary, metabolic, and orthopedic disorders, and were not pregnant. All data was collected on one visit to the laboratory between the hours of 7:00 – 9:00 am, as close as possible to the participants' awakening from sleep. The participants were instructed to fast overnight, and not to exercise or consume alcohol 24 hours before testing. However, they were encouraged to drink approximately between 1 and 1.5 cups of water before entering the laboratory.

Procedures

BF% and FFM were estimated by hand-to-foot BIA (Quantum IV, RJL systems, Clinton MI). This procedure required entry of the following variables into the BIA device: subjects' height (as measured by a wall-mounted stadiometer [SECA 220, Seca Ltd., Hamburg, Germany], weight (as measured by a calibrated digital scale [Tanita BWB-800A, Tanita Corporation, Tokyo, Japan], age, sex, and physical activity level (very light, light, moderate, heavy, exceptional). Subjects removed the right shoe and sock and were instructed to lie supine on a comfortable examination table. Before placement of electrodes, each of the sites described in the subsequent sentences were cleaned with an alcohol wipe. Two electrodes each were placed on the right hand and foot. One electrode was placed on the right wrist beside the ulnar head and another on the first joint of the middle finger. A third electrode was placed on the right foot beside the medial malleolus and the fourth electrode was placed on the base of the second toe. Red leads were attached to proximal electrodes which were located on the right wrist and right ankle, while black leads were connected to the distal electrodes located at the first joint of the middle finger and base of the second toe. Estimated BF% data was derived from the manufacturer's equation, which was selected within the software of the BIA device. FFM (kg) was determined as fat mass subtracted from total body weight. The equation used to determine BF% was as follows: (9):

$$FFM = -9.529 + 0.168 \times weight + 0.696 \times stature^2 / Resistance$$

$$BF\% = ([Body\ weight - FFM] / body\ weight) \times 100$$

DXA was also used to measure BF% and FFM of subjects (GE Lunar Prodigy, Software version 10.50.086, GE Lunar Corporation, Madison, WI). A whole-body DXA scan was conducted on each participant. Before each scan, the DXA was calibrated according to the manufacturer's instructions using the standard calibration block. The participants wore light clothing (T-shirt and shorts) and removed shoes and all metal (e.g., jewelry) from the body. The participants were instructed to lie supine and motionless with their arms held to the side, while Velcro straps were situated around the ankles and knees. Once the proper position of the participant was ensured, the scan was initiated and lasted approximately 6 minutes. The same investigator conducted all testing measurements.

Statistical Analyses

Data were analyzed with SPSS/PASW Statistics version 22.0 (Chicago, IL). The constant error (CE) was determined as the difference between the criterion and predicted BF% and FFM values (CE = criterion [DXA]

– predicted [BIA]). A Paired-Samples T-Test was used to determine significance of the mean difference of BF% and FFM. Effect size of mean differences between DXA and BIA was determined using Cohen's *d*. A regression procedure was used to ascertain the correlation coefficient *(r)* and standard error of estimate (*SEE*) of BIA compared to DXA (20). The Bland-Altman method was used to identify the 95% limits of agreement between BIA and DXA (8). A priori statistical significance was set at $p < 0.05$.

RESULTS

Paired t-test revealed the mean ± SD BF% determined by DXA was 27.7 ± 5.9% and by HF-BIA was 25.8 ± 3.2%, which was significantly different ($p < 0.05$, Cohen's *d* = .40). BIA correlated with DXA ($r = 0.71$, $p < 0.05$) for BF% and yielded a SEE of 4.2%. The limits of agreement (i.e., 95% confidence intervals) for BF% ranged from 10.2% below to 6.4% above the mean difference of -1.9 BF% resulting in a negative trend between both methods (Figure 1).

The mean FFM +/- SD determined by DXA was 46.2 ± 6.1 kg and by BIA was 47.5 ± 6.0 kg, which was also significantly different ($p < 0.05$, Cohen's *d* = .21). BIA correlated with DXA ($r = 0.89$, $p < 0.001$) for FFM with a SEE of 2.8 kg. The limits of agreement for FFM ranged from 4.0 kg below to 6.6 kg above the mean difference of 1.3 kg and also resulted in a negative trend between both methods (Figure 2). Statistical values are presented in Table 1.

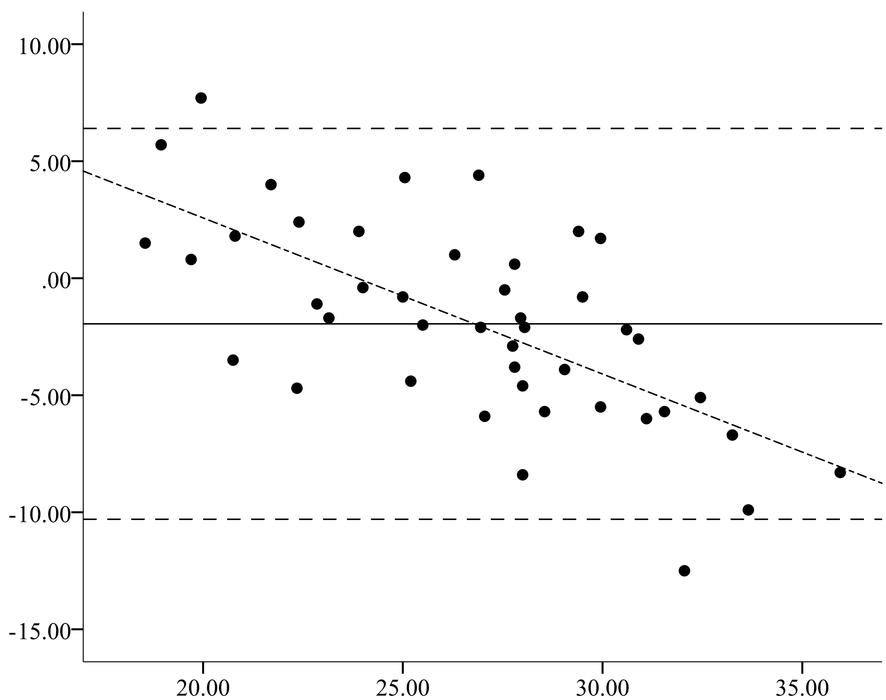

Figure 1: Bland-Altman plot comparing the differences in BF% estimated by DXA and BIA (n=44). The middle solid line indicates the constant error between predicted and the actual BF% values. The 2 outside dashed lines indicate the 95% confidence interval of the difference. The dashed regression line represents the trend between the difference of methods and the mean of both methods.

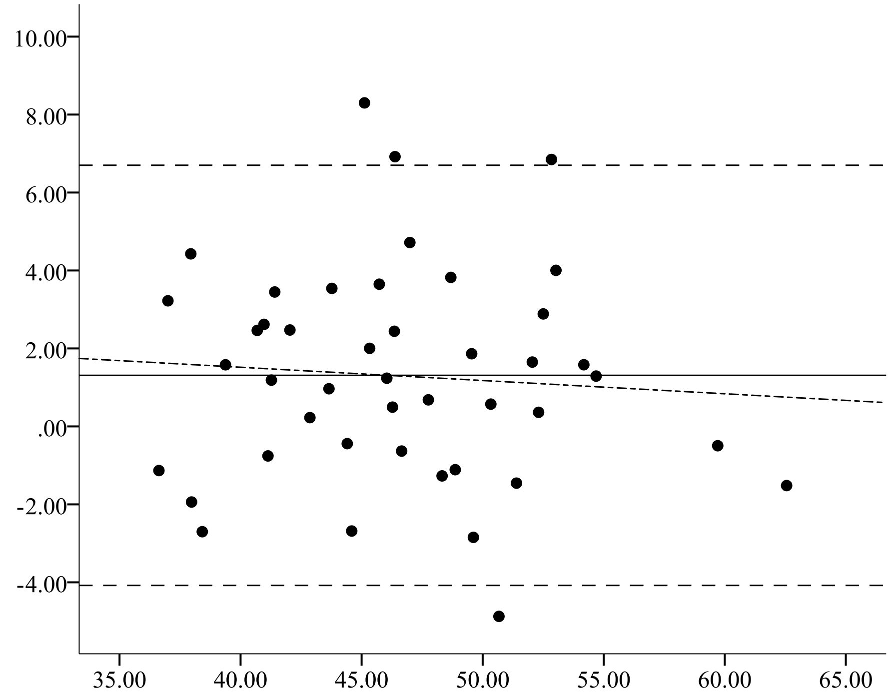

Figure 2: Bland-Altman plot comparing the differences in FFM estimated by DXA and BIA (n=44). The middle solid line indicates the constant error between predicted and the actual FFM values. The 2 outside dashed lines indicate the 95% confidence interval of the difference. The dashed regression line represents the trend between the difference of methods and the mean of both methods.

Table 1: Comparison of body composition values between BIA and DXA (n = 44).

						Limits of Agreement			
Value	(Mean ± SD)	Cohen's *d*	r	R^2	SEE	CE ± 1.96 SD	Upper	Lower	Trend
DXA BF%	27.74 ± 5.88								
BIA BF%	25.79 ± 3.25*	0.41	0.71	0.50	4.26	-1.95 ± 8.35	6.4	-10.30	-0.67*
DXA FFM	45.89 ± 6.14								
BIA FFM	47.20 ± 5.95*	0.22	0.90	0.81	2.75	1.31 ± 5.39	6.7	-4.08	-0.07

BF% = body fat percentage; FFM = fat-free mass; SEE = standard error of estimate; CE = constant error.

DISCUSSION

BIA is an affordable and easy to use body composition device making it ideal for collegiate strength programs to use to monitor athletes' body composition. Research on recent BIA devices (i.e. Quantum IV) is scarce in the collegiate female population. This study determined the agreements between the Quantum IV and DXA for measuring BF% and FFM in collegiate female athletes. The results indicated that on average, the Quantum IV significantly underestimated BF% by 1.9% and significantly overestimated FFM by 1.3 kg. There were significant correlations found between both methods for predicting BF% and FFM. The SEE for predicting BF% was 4.2%, which is within the reported range of SEE (i.e. ±3.5% to ±5%) for other BIA devices compared to reference methods (4). These results suggest the Quantum IV may consistently provide lower BF% and higher FFM values compared to DXA in college-age female athletes. Additionally, the Bland-Altman method showed the limits of agreement for each body composition variable were relatively wide. This finding indicates that the Quantum IV may provide a wide range of disparities for BF% and FFM when compared to DXA in individual female athletes.

Body Fat Percentage

Results of this study are similar to those of previous studies, which found BIA to be an unsuitable alternative to DXA for estimating BF% in female subjects (7,14). For instance, Bedgoni et al. (2013) found BIA significantly underpredicted BF% by 1.7% compared to DXA in a group of morbidly obese women. Likewise, Newton Jr. et al. (2005) compared hand-to-foot BIA to DXA using 7 different equations in a group of obese African-American adolescent girls and found only 1 equation to not be affected by body fat. Moreover, a majority of equations used underestimated BF% as body fat increased.

Mitsui et al. (2006) compared foot-to-foot BIA to DXA in a group of Japanese middle-aged and older females (40-70 yrs), and found BIA to overestimate BF% in low body fat groups and underestimate BF% in high body fat groups, similar to what Newton et al. found in a group of obese participants. In contrast, Aandstad et al. (2014) compared numerous BIA equations to DXA in a group of female military personnel and found equations to both underestimate and overestimate BF%. In the study it was noted that a majority of female participants had a BF% <30%, similar to that found in our study, and that no single BIA equation stood out superior to other equations. Understandably, researchers concluded that choosing the right BIA equation is crucial for assessing BF% in specific populations.

In the general population, arguments can be made that BIA overestimates BF% in lean individuals and underestimates BF% in overweight individuals (7,32,36). Additionally, it can be debated that the BIA model (i.e. hand-to-hand, foot-to-foot, etc.) used affects the outcome of BF% based upon the distribution of BF% in the individual being measured. Unfortunately, evidence is not as clear for females who have an athletic body composition. Esco et al. (2011) found hand-to-hand BIA to underestimate BF% in a group of collegiate female athletes using DXA as a criterion, which is similar to the findings of this this study. Yet, as previously cited, Aandstad et al. (2014) found hand-to-foot BIA to overestimate and underestimate BF% compared to DXA using various BIA equations in a group of athletic female military personnel. In the present study, researchers used the built in algorithm to determine BF% of female athletes. A majority of BIA prediction equations are based on limited samples and two-component models that describe BF% and FFM (9). Therefore, using three-compartment criterion methods such as DXA for comparison, which accounts for bone mineral density, might yield different results.

The findings in our study could be related to the simple fact that the chosen algorithm is not comparable to DXA for the assessment of BF% in collegiate female athletes. As a result, precise equations in the female athletic population are necessary for practitioners seeking equations that can serve as an alternative to DXA. Due to the findings of this study, the BIA equation selected should not be used in place of DXA for estimating BF% in collegiate female athletes. Individuals interested in using BIA as an alternative to DXA should use prediction equations developed from DXA as a criterion. Furthermore, equations developed from DXA as a criterion should be developed and examined in the future for collegiate female athletes in various sports.

Fat-Free Mass

This study found FFM to be significantly different between BIA and DXA, which is similar to findings of previous studies in female subjects (7,13,15,17). In a group of obese females, Faria et al. (2014) found multi-frequency BIA to significantly overestimate FFM compared to DXA. BIA has also been shown to not be a suitable alternative to DXA for measuring FFM in a group of healthy adult females (23).

There are conflicting results of BIA and DXA in the general population. However, there are also indefinite factors for both methods in the estimation of FFM for female athletes. What little research is available seems to be in disagreement (6,13,16). For example, Esco et al. (2011) found hand-to-hand BIA to significantly overpredict FFM by 3.39 kg in a group of collegiate females, which is equivalent to the findings of this study. However, others have found BIA to be an acceptable alternative to DXA for determining FFM in the female athletic population (6,16).

Fornetti et al. (1999) found non-significant differences in FFM between hand-to-foot BIA and DXA in a group of collegiate females athletes. Additionally, researchers were able to develop a BIA equation for estimating body composition of female athletes (16). Noticeably, the BIA equation was developed utilizing DXA as the criterion on participants. As a result, Bauer et al. (2006) compared the Fornetti et al. equation to DXA on a group of elite adolescent female gymnasts to determine if the equation could be generalized to a younger population of female athletes. In addition to the Fornetti et al. equation, Bauer et al. (2006) examined two other BIA equations, which were developed using hydrodensitometry as the criterion measure. The study concluded that the Fornetti et al. equation had the highest validity and lowest prediction error for estimating FFM of the three equations examined and could be used as an alternative in adolescent female gymnasts (6).

The findings of Bauer et al. (2006) are likely due to the fact that the Fornetti et al. equation was validated using DXA as a criterion, while the other two equations were developed using underwater weighing as a reference method. As previously mentioned, a majority of BIA equations have been developed using a two-compartment model such as hydrodensitometry as the reference method. Therefore, the differences in FFM between BIA and DXA found in the current study might be explained by the reference method used to develop the built-in equation utilized in the Quantum IV BIA device.

Criterion methods used in studies should be accurate and precise so that the indirect method is compared against values that are truly representative of the subjects' body composition. Unfortunately, there is no universally accepted "gold standard" methodology within body composition research (1). One limitation of DXA is the DXA algorithm assumes a constant hydration of FFM, which is not always true (37). Furthermore, DXA machines and software can vary in the results provided for body composition components (2).

When compared to a five-compartment model, DXA has been shown to overestimate BF% by 3.71% and have a wide range of individual error ± 6.3% (30). The individual error associated with DXA, when compared to multi-compartment models, is larger than the individual error of the BIA device found in the current study. The significant difference found in this study could simply be attributed to the large individual error associated with DXA and tendency of the method to overpredict BF% when compared to multi-compartment models. Thus, the BIA device utilized in this study should be compared to other reference methods, such as underwater weighing, in the future to determine if methods are interchangeable. Also, the Quantum IV could be used to compare BIA prediction equations developed from DXA, such as the Fornetti et al. model, to determine if BIA and DXA provide more equivalent results in female athletes than what was found in the current study.

In addition, this study used a sample of collegiate female athletes. We also only compared one hand-to-foot BIA device and equation to DXA. Due to these limitations, results should only be generalized to the specific population. Furthermore, we cannot conclude our findings apply to male athletes or men/women outside the age ranges of those found in the study. Thirdly, we did not fully control for hydration status of subjects. This could have affected results since hydration status has been found to impact the speed of the electrical current from BIA (25). However, the hand-to-foot BIA device examined is often used field settings where controlling for hydration is not always manageable.

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