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Concordance Among Bioelectrical Impedance Analysis Measures of Percent Body Fat in Athletic Young Adults

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ABSTRACT

International Journal of Exercise Science 12(4): 324-331, 2019. The purpose of this investigation was to determine the agreement among three bioelectrical impedance analysis devices (BIA) in athletic young adults. Fifty-one participants (26 men and 25 women) were assessed for percent body fat (PBF) using an arm-to-arm bipolar single-frequency device (ABIA), a leg-to-leg single-frequency device (LBIA), and an octopolar multi-frequency BIA device (MFBIA). PBF was measured with the three devices in a randomized, counterbalanced order. Repeated measures ANOVA revealed significant ($p < 0.001$) differences in PBF estimates among all devices (ABIA = 19.1 ± 7.2%, LBIA = 21.6 ±7.5%, and MFBIA = 22.9 ± 8.8%). Pearson's Correlations revealed a strong relationship between ABIA and MFBIA in both men ($r = 0.948$) and women ($r = 0.947$) and a moderately-strong relationship between LBIA and MFBIA ($r = 0.870$ and 0.679, respectively). Lin's concordance coefficient revealed moderately-strong concordance between ABIA and MFBIA in men ($\rho_c = 0.800$) and women ($\rho_c = 0.681$) and between LBIA and MFBIA ($\rho_c = 0.846$ and $\rho_c = 0.651$, respectively). These data indicate a strong agreement among all three devices, suggesting that any of them could be used to track changes in PBF over time. However, the significant differences in PBF values among devices imply that best practice for monitoring body composition should be to use one device consistently over time for a reliable assessment.

KEY WORDS: Inter-trial reliability, BIA, bipolar, octopolar, multi-frequency

INTRODUCTION

Bioelectrical impedance analysis (BIA) is a method to estimate body composition, and more specifically percent body fat (PBF). BIA measures the impedance, or resistance, to an electrical current that travels through the water in muscle and fat. Electrical properties of tissues, described since 1871 (12), indicate that the water content of humans varies between fat tissue (~10% water) and muscle tissue (~75% water). Thus, electrical current passing through the body encounters greater resistance traveling through compartments with higher amounts of fat tissue. BIA devices measure the strength and speed of an electrical signal sent through the body and calculate body composition by applying the resistance and impedance of this signal in propriety equations.

In the 1970s, the foundations of BIA were established using total body water (TBW) as a cornerstone for electrical impedance measurements, with the original measurements involving two subcutaneously-inserted needles for percent fat calculation, (12) which rendered the technique impractical for general use. Later, the four-surface electrode BIA technique was introduced, but problems occurred with the high current and voltage needed to get results, which could be painful for the client. Further research allowed the development of a method to send currents through small magnetic plates on a device, which could then produce results without any discomfort for the participant (12, 19).

There is an increasing demand for body composition analysis in personal use or homecare to monitor body mass, evaluate body mass loss therapy, or assess the outcome of strength or endurance exercise (21). Today, BIA consumer devices are easy to use for noninvasive, indirect assessment of body composition and offer a variety of additional values such as total body water, fat mass (FM), fat-free mass (FFM), and muscle mass (12). More accurate techniques such as isotope dilution, dual energy x-ray absorptiometry (DXA) and hydrodensitometry are not as commonly used due to their expense and poor economy for general use (1). Consumer BIA devices that are relatively cheap (< $100) and use a single frequency (50 kHz) current to calculate body composition are widely available (10).

Investigations of the accuracy of single-frequency BIA comparing the devices to criterion measures such as hydrostatic weighing, air displacement plethysmography, or DXA have found inconsistent results, with some studies indicating good accuracy (2, 21) while others reporting poor accuracy (23). The reasons behind inconsistent reports could be attributed to three factors. First, many single-frequency BIA use population-specific prediction techniques, meaning that the results are highly dependent on the agreement of physical characteristics such as body mass status, ethnicity, and age between the participant and the reference population used to generate the BIA algorithm (1, 10, 12).

Second, the market offers a wide variety of impedance devices which have expanded to include bipolar (two-electrodes), tetrapolar (four-electrodes), and octopolar devices (eight-electrodes). Bipolar devices are perhaps the most common and are produced in segmental forms: leg-to-leg and hand-to-hand. These segmental instruments are generally regarded as being less accurate than those used clinically or in nutritional and medical practice (1, 10). The traditional tetrapolar and more recently developed octopolar BIA devices measure the impedance throughout the whole body, and, in theory, should be the most accurate of the BIA techniques. Modern octopolar BIA devices permit whole-body scanning with multiple frequencies of electric current, which is thought to enhance their accuracy (1, 2, 10, 11, 21, 22). In addition to the different number of electrodes, the shape, conductivity, and arrangement of electrode may lead to different results among devices (12).

Since the electrical impulse travels through the water medium of the body, hydration may influence the validity and reliability of results. Dehydration is a recognized factor affecting BIA measurements because it increases the body's electrical resistance and has been shown to cause as much as a 5 kg underestimation of FFM (12).

With wide array of BIA devices on the market, it would helpful to determine how well some of these instruments measure body composition compared to a more sophisticated criterion. The purpose of this study was to analyze percent body fat results from two bipolar single-frequency BIA consumer devices, one leg-to leg (LBIA) and one arm-to-arm (ABIA), in comparison to an octopolar multi-frequency BIA medical device.

METHODS

Participants

Fifty-one participants (26 men and 25 women) completed this experiment (Table 1). All participants were tested between 0700-0900 hours and adhered to testing guidelines (Table 2) regarding food and fluid intake intended to enhance the reliability and accuracy of BIA measures. Participants were habitually highly active and thus able to meet the criteria of "athlete" as described by both ABIA (a score ≥ 60 on a brief survey of regular exercise duration, frequency, and intensity) and LBIA (≥ 10h · wk^{-1} of intense physical activity and resting HR ~60 bpm or less) devices. All procedures involving human participants were approved by the University's Institutional Review Board, and participants provided written informed consent prior to participating in the experiment. All experimental conditions met the requirements specified by the Declaration of Helsinki.

Table 1. Demographic characteristics of participants.

	Men (n = 26)		Women (n = 25)	
Variable	Mean ± SD	Range	Mean ± SD	Range
Age (yrs)	24.1 ± 8.3	19 - 49	23.6 ± 9.2	18 - 52
Height (cm)	179.1 ± 6.6	167.6 - 194.3	168.9 ± 9.2	154.9 - 198.8
Body Mass (kg)	83.8 ± 17.1	51.48 - 126.1	68.2 ± 8.4	53.8 - 88.9
BMI (kg/m^2)	25.97 ± 4.18	18.32 - 35.69	24.02 ± 3.38	12.93-31.16

Table 2. Testing guidelines.

Have you restricted your fluid intake in the last 24 hrs?
Have you consumed caffeine in the last 12 hrs?
Did you eat 3-4 hours prior to testing?
Did you exercise 6-12 hours prior to testing?
Did you get in a shower or sauna today?
Do you have a pacemaker installed?
Did you apply lotion/ointment on your hands today?
Have you consumed alcohol 24 hours prior to testing?

All participants were required to answer "No" to the following questions to continue participating in the experiment.

Protocol

Participants were asked to report to the laboratory wearing light athletic clothing, such as shorts and a t-shirt, to increase accuracy of results. Height was measured without shoes with a wall-mounted stadiometer, and body mass was determined using an electronic scale accurate to 0.1 kg.

Following the height and weight measurement, participants' percent body fat was assessed by three devices, in randomized, counterbalanced order: 1) Omron handheld impedance device (Omron model HBF-306, Hoffman Estates, IL) for bipolar arm-arm impedance, 2) Tanita device (Tanita model TBF300A, Arlington Heights, IL) for bipolar leg-leg impedance, 3) InBody 770 (InBody model 770, Cerritos, CA) for octopolar full-body multi-frequency impedance. Measurements with all devices were done in accordance with the manufacturer's instructions. Participants were asked to repeat any test if there were questions concerning the ability of a device to transmit results properly.

Statistical Analysis

All data are presented as means ± standard deviation. Agreement between each single-frequency BIA device's PBF values and the PBF derived from the InBody 770 were compared using Pearson Product-Moment Correlations (r) and Lin's concordance correlation coefficients (ρ_c). Differences in PBF values among the devices were tested using repeated measures ANOVA, with post-hoc analyses using the Bonferroni paired contrasts. Bland-Altman plots were constructed to illustrate level of agreement (LoA) between Omron and InBody, and Tanita and InBody, using InBody PBF as the reference value. Statistical significance was set at $p \leq .05$.

RESULTS

Mean values for PBF among the BIA values are displayed in Table 3. Repeated measures ANOVA revealed that all three BIA devices produced significantly different percent fat values ($p < 0.001$). Lin's concordance coefficient revealed similar, moderately strong concordances between Omron and InBody and between Tanita and InBody, while Pearson's r was notably higher between Omron and InBody than between Tanita and InBody (Table 4).

Table 3. Mean (± SD) values for percent body fat determined by three BIA devices.

	Omron	Tanita	InBody
Men (n = 25)	14.0 ± 5.6*	17.0 ± 5.6*	17.5 ± 7.0*
Women (n = 26)	24.3 ± 4.6*	26.3 ± 6.3*	28.6 ± 6.5*
Total (n = 51)	19.1 ± 7.38*	21.6 ± 7.5*	22.9 ± 8.8*

*Significantly different from other estimates ($p < 0.001$).

Table 4. Lin's concordance coefficient and Pearson product-moment correlations between bipolar and octopolar BIA devices.

	Lin p_c		Pearson r	
	Omron vs. InBody	Tanita vs. InBody	Omron vs. InBody	Tanita vs. InBody
Men (n = 25)	0.800	0.846	0.948	0.870
Women (n = 26)	0.681	0.651	0.947	0.697
Total (n = 51)	0.849	0.846	0.966	0.868

A Bland-Altman plot illustrates a mean bias between Omron and InBody PBF of -3.9%, with 49 of 51 samples falling within the 95% CI (Figure 1). Mean bias between Tanita and InBody BFP was -1.9%, with 48 of 51 samples falling within 95% CI (Figure 2). The LoA for the Omron (-8.9 to 1.1) was substantially smaller than for the Tanita (-9.9 to 7.1).

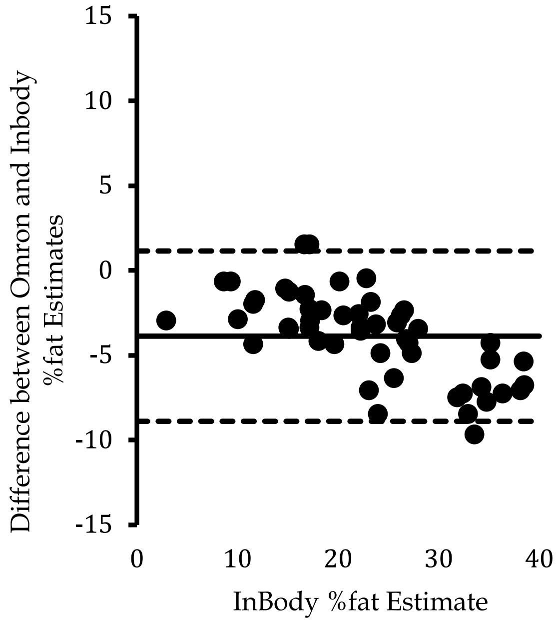

Figure 1. Bland-Altman Plot comparing Omron and InBody percent fat estimates.

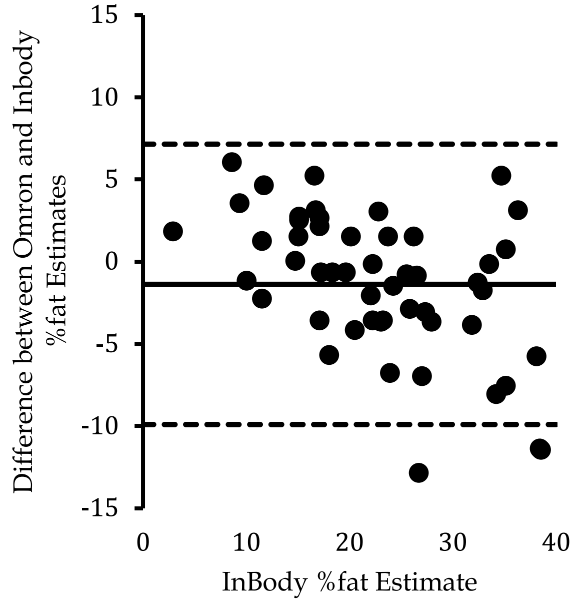

Figure 2. Bland-Altman Plot comparing Tanita and InBody percent fat estimates.

DISCUSSION

Part of the difficulty with studies evaluating single-frequency BIA devices is determining which criterion device is acceptable as a "gold" standard. Body plethysmography (BodPod), DXA, and research-grade multi-frequency BIA devices have all been accepted as "gold" standards against which to judge the validity of other body composition methods. Ling et al. (13) indicated that research-grade multi-frequency BIA devices are an acceptable standard by which to evaluate other, simpler devices. With the growing use of multi-frequency measurement, we felt it appropriate to compare simpler BIA devices with this clinically acceptable instrument.

Previous studies have generally found that limb-to-limb BIA devices correlate well with criterion measures but tend to underestimate percent body fat in active women. Pichard et al. (15) used reactance and resistance from a hand-to-foot BIA applied to 12 different formulae to estimate FM and FFM in 9 women distance runners and noted higher correlations between predicted and actual (DXA) FFM (r = 0.82 to 0.94) but suggested that BIA was not satisfactory for predicting FM. Fornetti et al. (9) also used the reactance and resistance from a similar BIA device to estimate FFM and found high correlations with DXA-estimated FFM (r = 0.96 to 0.98). Neither of these studies evaluated %fat predicted from BIA or calculated from FFM. Civar et al. (4) utilized a leg-to-leg BIA device to estimate %fat in highly active women compared to %fat from underwater weighing. They noted almost identical mean %fat values but relatively low correlation (r = 0.67) between the two techniques. Esco et al. (7) compared a hand-to-hand BIA device to DXA for estimating %fat in college female athletes. Although the correlation between the two procedures was r = 0.74, the BIA device underestimated DXA %fat by an average of 5.1%. They suggested that DXA was an ideal comparison standard for body composition in women because bone mineral density can vary substantially in this population and could affect estimates of other compartments. However, they noted the expense and inconvenience of DXA assessment and concluded that the standard error of estimate for BIA (± 6%) was within acceptable limits. A follow-up study by Esco et al. (8) comparing multi-frequency BIA measurement with DXA in female athletes noted a 3.3% lower average estimate of %fat from BIA but with a high correlation with DXA (r = 0.94). Miller, Chambers and Burns (15) compared a multi-frequency BIA device similar to the one utilized in the current study to DXA in recreationally-active college men and women and found a correlation between the two devices of r = 0.90 for men and r = 0.92 for women. BIA significantly underestimated in both men (-4.3%) and women (-5.2%). Recently, hand-to-hand and foot-to-foot BIA devices were used to track changes in %fat across a year in college women basketball players (16). Correlations between DXA and the BIA devices ranged from 0.62 to 0.82 throughout the year and were not consistent across the four times. Limits of agreement ranged from -10.0% to 2.8%, thus indicating a significant underestimation of %fat by either BIA device.

The same trends as noted for women between various BIA devices and criterion measures seem evident in active men. Oppliger et al. (16) found high correlations (r = 0.88 to 0.92) between three BIA devices and underwater weighing %fat in college football players, although the BIA device significantly overestimated %fat by 3.7% to 4.7% compared to the criterion. Interestingly, they found higher correlations (r = 0.94 to 0.96) and lower differences (0.5 to 1.7%) between skinfolds predicted %fat and underwater weighing %fat. Utter et al. (23) used a leg-to-leg BIA device similar to the one in the current study to compare with skinfold predicted %fat in collegiate wrestlers. They too found good agreement (r = 0.68 to 0.83) between the two techniques, with standard errors of estimate ranging from 2.1% to 3.5%. Dixon et al. (6) also found good agreement between underwater weighing and leg-to-leg BIA %fat (r = 0.80) but a significant underestimation (-2.2%) in college wrestlers. A later study by the same group (5) noted that the athletic mode of a leg-to-leg BIA device significantly underestimated %fat from underwater weighing and significantly overestimated %fat with the standard (normal) mode in college wrestlers. Despite finding high correlations between DXA and five single-frequency BIA devices, Loenneke et al. (14) noted that only a leg-to-leg BIA device had a nonsignificant difference of 4.6% in %fat estimate compared to the criterion in college baseball players. Svantesson et al. (20) compared bioelectric impedance spectroscopy (BIS) to DXA for measuring %fat in ice hockey and soccer players and concluded that BIS significantly underestimated %fat by an average of 2.8% ± 3.9%. Cheng et al. (3) reported good agreement between an eight-electrode BIA and DXA (r = 0.94) but noted a 5.2% limit of agreement between the two devices in young wrestlers.

In conclusion, the convenience, speed, and non-invasive nature of single-frequency BIA devices make them appealing for estimating body composition. Previous studies on the validity of BIA techniques in athletic individuals have generally found that single-frequency BIA devices may have adequate correlations with criterion methods but tend to overestimate or underestimate depending on the device and/or the population under investigation. The current results suggest that the Omron used in this study had a stronger concordance and better LoA in men than women, although both BIA devices had significantly different estimates of %fat from the multi-frequency criterion. Thus, caution might be advised in using BIA %fat values as absolute criteria for judging body composition in active young men and women.

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