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Validity of Two Commercial Grade Bioelectrical Impedance Analyzers for Measurement of Body Fat Percentage

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ABSTRACT

Dolezal BA, Lau MJ, Abrazado M, Storer T, Cooper, CB. Validity of Two Commercial Grade Bioelectrical Impedance Analyzers for Measurement of Body Fat Percentage. **JEPonline** 2013;16(4):74-83. The purpose of this study was to validate the assessment of %Fat measured by two commercial grade BIA devices against the gold standard of dual x-ray absorptiometry (DEXA). Twenty-one subjects were measured for %Fat using three devices: an octopolar, multi-frequency BIA device (BIA8, BioSpace InBody R20); a quadripolar, single frequency BIA device (BIA4, Tanita BC-590BT); and a whole body DEXA (Hologic 4500). Mean \pm SD differences in %Fat between the devices and DEXA were 0.14 ± 0.04 ($P=0.80$) (BIA8) and 1.77 ± 0.54 ($P=0.76$) (BIA4). Correlations with DEXA were $r=0.98$ (BIA8) and $r=0.92$ (BIA4). Bland-Altman analyses revealed a systematic bias for both BIA instruments vs. DEXA in which %Fat was underestimated in leaner subjects and overestimated in fatter subjects. All subjects had individual differences of $\leq \pm 3.0$ %Fat for BIA8 vs. DEXA while 43% had differences of ≤ 3.0 %Fat for BIA4 vs. DEXA. Our data suggest that the use of an octopolar BIA device yields more than twice as many subjects within a $\pm 3\%$ error compared with BIA4; a value that might be considered appropriate for clinical use.

Key Words: BIA, Body Composition, DEXA, Fat

INTRODUCTION

Body composition analysis is vital for understanding the proportions of fat and fat-free mass for healthy and unhealthy individuals. While computed tomography, magnetic resonance imaging, densitometry, and dual x-ray absorptiometry (DEXA) are commonly used reference methods to provide accurate body fat percentage (%Fat) measurements, they are expensive, time-consuming, and often inaccessible to the general population. They also require trained technician to complete the measurement (3). A shift to alternative, inexpensive, and more rapid measurement techniques (e.g., such as the bioelectrical impedance analysis (BIA) that uses conventional adhesive electrodes) have improved access to body composition measurements. However, the feasibility of these techniques still remains a barrier for widespread usage.

Some newer models of BIA instruments are in the form of a weight scale similar to a bathroom scale. They are based on contact electrodes that have become popular in health clubs, worksite health programs, commercial weight loss programs, and athletics owing to their safety, ease of use, relatively low cost, and portability. These instruments measure body composition by applying an alternating, imperceptible low-voltage current to electrodes in contact with various body parts. The aqueous tissues of the body (i.e., bone-fat-free mass) and their dissolved electrolytes are the major conductors of the electrical current while body fat and bone are relatively poor conductors (2). Resistance (i.e., impedance to the electric current) is directly related to the amount of fat-free mass in a given subject. Subsequently, %Fat is derived from the ratio of total body mass minus fat-free mass divided by total body mass.

The marketplace offers a wide range of consumer grade BIA devices. The differences between the devices are known to influence the validity of BIA results, especially when compared with DEXA and MRI (1,2,6,7,10,11,13,17,18). Over the years, improvements in the BIA devices from single-frequency to multi-frequency, accompanied with additional tactile electrodes placed at more body sites, have improved the accuracy of %Fat measurements (9,16). The recent advancements have focused on octopolar scales (i.e., hand-to-hand and foot-to-foot) over traditional quadripolar scales (i.e., hand-to-hand or foot-to-foot).

To date, given its high degree of accuracy, DEXA has been recognized as the preferred gold standard in the assessment of body composition and the measurement of fat content (5). Although progress in the technology that is used to assess body composition with BIA is linked to the increased accuracy of %Fat, there still remains a paucity of studies that have examined the newer multi-frequency and the multi-segmental instruments. This includes the devices that have wireless capabilities for added ease of use. Thus, the purpose of this study was to validate the assessment of %Fat as measured by two commercial grade BIA devices against DEXA.

METHODS

Subjects

Twenty-one subjects (15 men, aged 37.6 ± 16.8 yrs; BMI, 28.6 ± 1.5 kg·m⁻²) from the University of California, Los Angeles volunteered to participate in this study. Within a 20-min period, the subjects were measured for %Fat using the following devices and sequence: (a) an octopolar, multi-frequency, multi-segmental BIA device (BIA8, InBody R20 scale, Biospace, Inc. Seoul Korea; refer to Figure 1); (b) a quadripolar, single frequency, BIA device (BIA4, Tanita BC-590BT Bluetooth Wireless Body Composition Monitor, Tanita Corporation, Arlington Heights, IL); and (c) a whole body energy x-ray absorptiometry (DEXA, Hologic 4500A Hologic Inc., Bedford, MA). All subjects provided their informed consent. The study was approved by the Institutional

Review Board at the University of California Los Angeles. DEXA and BIA were performed after at least 3 hrs of fasting and voiding. Since hydration state has a marked influence on BIA results, the subjects were instructed to remain hydrated and not exercise during the 12-hr period before testing. Each subject's weight was measured to the nearest 0.1 kg in light indoor clothing with no shoes using the BIA8. Height was measured using a precision stadiometer to the nearest 0.01 m.

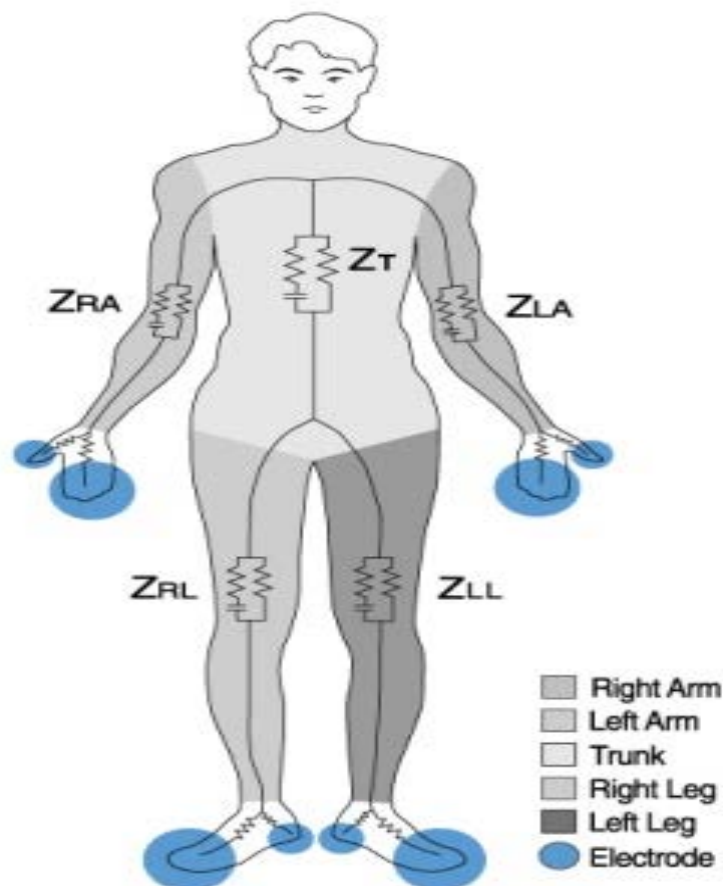


Figure 1. The 8-Point Tactile Electrode Method (i.e., Octopolar) Enabled BIA8 to Analyze the Impedance of Separate Segmental Body Fluid Distributions (Both Arms, Both Legs, and the Trunk).

The BIA measurements were carried out according to the manufacturer's instructions by a trained investigator (ML). After an explanation of the procedure, the subject stood upright with the ball and heel of each foot on two metallic footpads used on both the BIA4 and BIA8 scales. For BIA8, the subjects also held a hand grip in both hands with the upper limbs perpendicular to the floor. The hand grip was gripped completely with the palm on one electrode and the thumb resting on the top of the units other electrode. Anthropometric measurements were manually inputted into the instrument. Additionally, the subject body type (all were routinely classified as "standard") was entered for BIA4 per manufacturer's instructions. Each instrument measured resistance and reactance using proprietary algorithms. Each subject's %Fat was estimated using the prediction equations supplied by the manufacturers.

Following procedural recommendations, DEXA scans were performed by a licensed radiological technologist at the UCLA Gonda Diabetes Center. Whole body DEXA scans were used to assess body mass and fat soft tissue, subsequently calculating %Fat by use of software supplied by the manufacturer. During the 15-min scanning time, the subjects laid supine with arms and legs at their sides while instructed to remain still and silent. The DEXA instrument was calibrated daily for standard clinical densitometry testing using a lumbar spine phantom and weekly with a soft tissue phantom per the manufacturer's recommendations.

Statistical Analysis

Differences in %FAT between each BIA device and DEXA were determined using a one-way ANOVA. Levels of agreement were determined using Bland-Altman analysis. Correlations were determined using the Pearson Product-Moment correlation coefficient. Statistical significance was set at $P \leq 0.05$ with Bonferroni corrections for multiple comparisons.

RESULTS

Subject characteristics and %Fat measurements for the two BIA devices and DEXA are presented in Table 1. The mean values for %Fat between the three devices were not statistically significant. The differences (mean \pm SD) in %Fat between the two BIA devices and DEXA were 0.14 ± 0.04 for BIA8 ($P=0.80$) and 1.77 ± 0.54 for BIA4 ($P=0.76$). Mean errors for BIA8 and BIA4 vs.DEXA were 1.6 %Fat and 4.6 %Fat, respectively.

Table 1. Subject Characteristics and %Fat Between BIA Devices and DEXA.

	Mean	Standard Deviation	Range
Age (yrs)	38	16.8	19 to 70
Body weight (kg)	77.1	3.9	69 to 85
Height (m)	1.70	0.09	1.52 to 1.88
BMI (kg·m⁻²)	28.6	1.5	26 to 32
%Fat-BIA4	23.5	11.6	7 to 48
%Fat-BIA8	25.5	10.3	10 to 41
%Fat-DEXA	25.3	9.6	11 to 41

%Fat, percentage body fat; BIA, bioelectrical impedance

There were strong correlations between BIA8 and DEXA ($r=0.98$; $P<0.0001$) and between BIA4 and DEXA ($r=0.92$; $P<0.0001$) as shown in Figure 2.

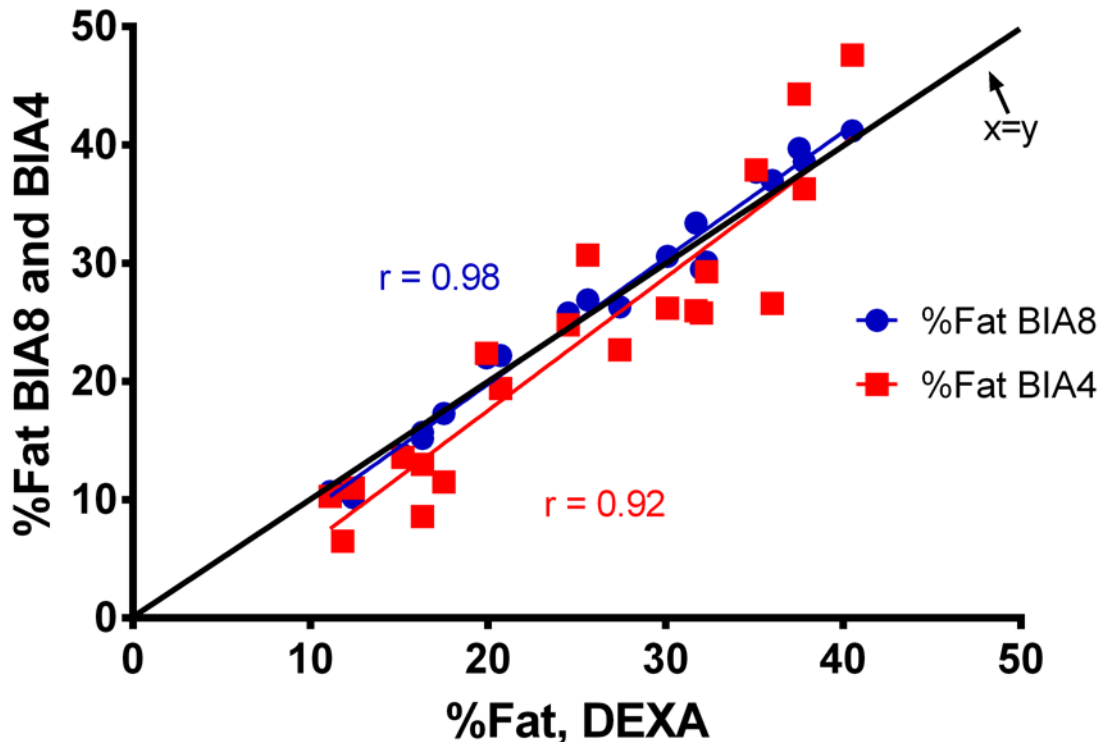


Figure 2. Correlations Between %Fat Determined by BIA8 and BIA4 vs. DEXA.

The Bland-Altman analysis revealed a systematic bias for both BIA instruments in which %Fat was underestimated in leaner subjects and overestimated in fatter subjects (Figure 3). The mean bias (95% CI) for agreement between BIA8 and DEXA was 0.14 %Fat (-2.91 to 3.19 %Fat) and -1.77 %Fat (-10.75 to 7.21 %Fat) between BIA4 and DEXA. Further analysis revealed that 100% of the subjects had individual differences of $\leq \pm 3.0\%$ between BIA8 and DEXA while only 43% had differences of $\leq \pm 3.0\%$ for BIA4 and DEXA.

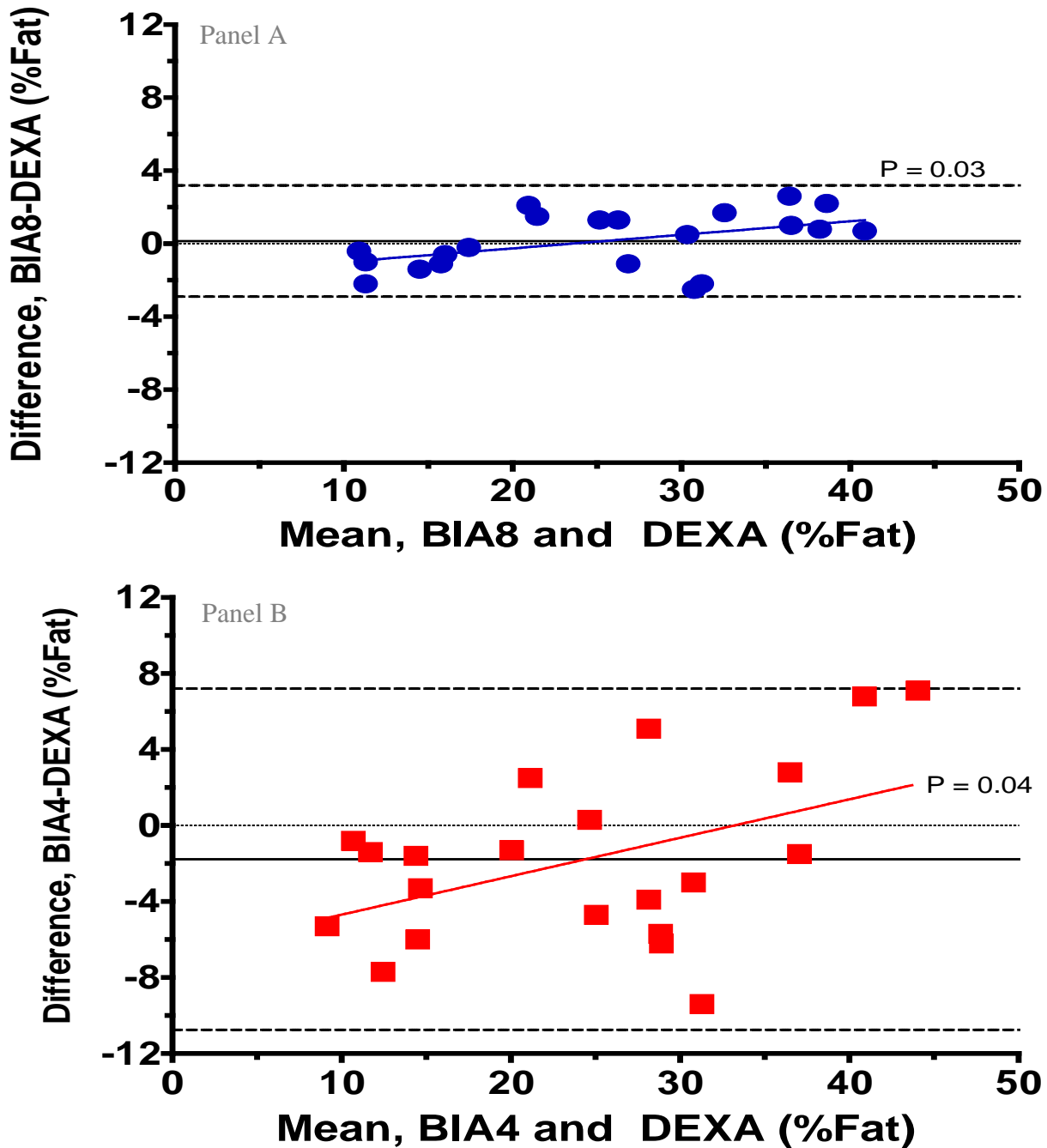


Figure 3. Bland-Altman Plots Depicting Individual Differences in %Fat Measurements Between DEXA and BIA8 (Panel A) and BIA4 (Panel B). The mean bias (95% limits of agreement) was +0.14 (-2.91 to +3.19)% for BIA8 and -1.77 (-10.75 to +7.21)% for BIA4. Analysis also revealed a systematic bias for both BIA4 and BIA8 in which %Fat was underestimated in leaner subjects and overestimated in fatter subjects. The diagonal lines are regression lines with significant P values indicating the slopes of the relationships were significantly greater than zero, therefore indicating a systematic bias

DISCUSSION

The search for a practical and accurate method to assess body composition continues to focus on BIA techniques. In the present study, we compared an octopolar, multi-frequency, multi-segmental BIA device (BIA8) and a quadripolar, single-frequency, BIA device (BIA4) against the gold standard criterion of DEXA. The results indicate that both BIA devices provide high relative agreement with DEXA as evidenced by strong correlation coefficients ($r > 0.90$) and the overall ANOVA that was not significant.

BIA is based on electrical impedance measurements as an index of total body water (TBW), which is the sum of extracellular and intracellular water. The differences in %Fat between the two BIA devices used in this study may be due, in part, to the electrical conduction paths of the two instruments. The BIA4 (and other previous two-to-four electrode instruments) estimates TBW from estimated extracellular water (ECW). It fails to distinguish trunk and extremity impedance since it is based on the postulate that the human body is a cylinder with constant resistivity (4). However, these limitations are overcome by recently developed whole-body, multi-frequency BIAs that directly calculate ECW and TBW from the impedance of low- and high-frequency signals with the higher frequencies penetrating the cell membrane for estimation of intracellular water (17). Moreover, the BIA8 is also a multi-segmental, octopolar device that recognizes that the human body is complex in shape and not represented by a single uniform cylinder but rather by five heterogeneous cylinders (i.e., both arms, both legs, and the trunk) with different resistivities over which resistances are separately measured (see Figure 1). By permitting a more comprehensive approach to body composition assessment through the measurement of components of impedance, with reactance and resistance across a range of frequencies, the BIA8 has been reported to improve the accuracy of %Fat estimates (9).

In this study, the narrow 95% confidence limits for agreement between BIA8 and DEXA (-2.91 to 3.19 %Fat) were less than half of those for BIA4 and DEXA (-10.75 to 7.21 %Fat). Furthermore, BIA8 measured more than twice as many subjects within a $\pm 3\%$ error compared with BIA4. Consistent with this finding, Bosy-Westphal and colleagues (2) found that the levels of agreement were -6.59 to 4.61 %Fat for a quadripolar BIA device and worse in three bipolar BIA devices (up to -14.51 to 8.58%). In contrast, Boneva-Asiova and Boyanov (1) and Linares et al. (11) found that levels of agreement for bipolar and quadripolar BIA devices were slightly narrower (-4.80 to 5.86% and -5.1 to 6.4%, respectively) when compared to the octopolar device (-3.81 to 8.31%) reported by Lim et al. (10).

Further analysis revealed a systematic bias for both BIA4 and BIA8 in which %Fat was underestimated in leaner subjects and overestimated in fatter subjects (refer to Figure 3). The systematic biases associated with BIA8 were significantly smaller than those exhibited by BIA4, indicating that the BIA8 may provide better accuracy in %Fat determination across %Fat values ranging between 10% and 40% Fat as compared to BIA4. For example, in individuals at the extreme ends of the distribution of %Fat scores, BIA8 underestimated %Fat by -.4 to -2.2; BIA4 underestimated %Fat in a range of +0.5 to -8.0 %Fat. Similarly, %Fat was overestimated by 0.7 to 2.6 %Fat for BIA8 and -1.5 to +7.1 %Fat for BIA4.

Both over- and underestimation of %Fat with BIA in comparison to DEXA have been reported in previous studies (9,10,12) due to the confounding effects of multiple variables such as age, sex, and ethnicity of the population, as well as the BIA instrumentation and regression equations used. Similar to our results, two studies (1,15) reported an underestimation of %Fat in leaner

subjects and an overestimation of %Fat in fatter subjects when compared to the DEXA measurements. In contrast, a more recent study by Bosy-Westphal et al. (2) who used a quadripolar BIA reported the opposite results (i.e., an overestimation of %Fat in leaner subjects and an underestimation of %Fat in fatter subjects. Yet, other investigations have shown a complete overestimation of %Fat (10) or underestimation of %Fat (14) compared to DEXA in both lean and fat subjects. The discrepancy in the varying accuracies for the assessment of %Fat in the literature highlights the challenge of accounting for the numerous confounding variables in BIA assessments.

Strengths and Limitations

The strengths of the present study include the short lag time between the measurements of the three devices for each subject, which minimized the potential within-subject measurement variability. While DEXA is widely accepted as the gold standard owing to its small error when used in standard conditions, it may be open to criticism due to its inability to accurately assess soft tissue: (a) in clinical conditions associated with fluid retention (e.g., renal failure, heart failure, or severe obesity); and (b) under non-steady state conditions (e.g., weight loss) (5).

Other limitations include the small sample size and restriction of the study population to slightly overweight subjects. The latter limited our ability to generalize the results to all populations. Finally, the accuracy of the BIA results is considerably dependent on the agreement of physical characteristics (such as age, sex, race, and weight between the subject and the reference population utilized in generating the algorithms for calculation of body composition with BIA). In many cases, BIA prediction equations have predominantly been validated in Caucasians with little information on the accuracy in other races or multi-ethnic populations. Variations in physique and body shape between races may confound the fundamental BIA model (e.g., quadripolar), which treats the body as a single cylinder (9).

CONCLUSIONS

Body composition measurements are frequently collected in hospitals, sports medicine, and nutrition clinics, commercial gyms, and other health-related facilities. Compared to other body composition techniques, BIA has certain advantages for assessing %Fat because of portable, relatively inexpensive equipment that requires minimal training in its use. However, these advantages of BIA may be offset by poorer accuracy in its estimation of %Fat in some BIA devices that use fewer body contacts (e.g., bipolar and quadripolar instruments), single frequencies, and analysis of a single body cylinder.

Our data suggest that the single frequency, quadripolar foot-to-foot BIA used in this study yields %Fat estimates that are significantly more discrepant with DEXA derived %Fat than the octopolar hand-to-foot BIA device with its multi-frequency and multi-segmental measures. In sum, based on our study design and the BIA instruments selected for study, we conclude that the BIA8 offers superior accuracy in assessing percent body fat as compared with the BIA4, both relative to DEXA derived %Fat.

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REFERENCES

1. Boneva-Asiova Z, Boyanov MA. Body composition analysis by leg-to-leg bioelectrical impedance and dual-energy x-ray absorptiometry in non-obese and obese individuals. *Diabetes Obes Metab.* 2008;10(11):1012-1018.
2. Bony-Westphal A, Later W, Hitze B, Sato T, Kossel E, Gluer C-C, Heller M, James M. Accuracy of bioelectrical impedance consumer devices for measurement of body composition in comparison to whole body magnetic resonance imaging and dual x-ray absorptiometry. *Obesity Facts.* 2008;1(6):319-324.
3. Dehghan M, Merchant A. Is bioelectrical impedance accurate for use in large epidemiological studies? *Nutr J.* 2008;7(1):26.
4. Demura S, Sato S. Prediction of visceral fat area at the umbilicus level using fat mass of the trunk: the validity of bioelectrical impedance analysis. *J Sports Sci.* 2007;25(7):823-833.
5. Glickman S, Marn C, Supiano M, Dengel D. Validity and reliability of dual-energy X-ray absorptiometry for the assessment of abdominal adiposity. *J Appl Physiol.* 2004:509-514.
6. Haroun D, Stephanie T, Russell MV, Rachel SH, Tegan SD, et al. Validation of bioelectrical impedance analysis in adolescents across different ethnic groups. *Obesity.* 2009:1252-1259.
7. Hemmingsson E, Joanna U, Martin N. No apparent progress in bioelectrical impedance accuracy: Validation against metabolic risk and DXA. *Obesity.* 2008;17(1):183-187.
8. Jensky-Squires NE, Dieli-Conwright CM, Rossuello A, Erceg DN, McCauley A, Schroeder ET. Validity and reliability of body composition analysers in children and adults. *Brit J Nutr.* 2008;100(04):859-865.
9. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, et al. Bioelectrical impedance

analysis-part I: Review of principles and methods. *Clin Nutr.* 2004;23:1226-1243.

10. Lim JS, Hwang JS, Lee JA, Kim DH, Park KD, et al. Cross-calibration of multi-frequency bioelectrical impedance analysis with Eight-point tactile electrodes and dual-energy x-ray absorptiometry for assessment of body composition in healthy children aged 6-18 years. *Pediatr Int.* 2009;51(2):263-268.
11. Linares CL, Cecile C, Jean-Luc B, Muriel C, Xavier D, et al. Validity of leg-to-leg bioelectrical impedance analysis to estimate body fat in obesity. *Obes Surg.* 2010;21(9):17-23.
12. Neovius M, Hemmingsson E, Freyschuss B, Uddén J. Bioelectrical impedance underestimates total and truncal fatness in abdominally obese women. *Obesity.* 2006;14(1):1731-1738.
13. Nichols J, Going S, Loftin M, Stewart D, Nowicki E, Pickrel J. Comparison of two bioelectrical impedance analysis instruments for determining body composition in adolescent girls. *Int J Body Compos Res.* 2006;4(4):153-160.
14. Sato S, Demura S, Kitabayashi T, Noguchi T. Segmental body composition assessment for obese japanese adults by single-frequency bioelectrical impedance analysis with 8-point contact electrodes. *J Phys Anthropol.* 2007;26(5):533-540.
15. Shafer KJ, Siders WA, Johnson LK, Lukaski HC. Validity of segmental multiple-frequency bioelectrical impedance analysis to estimate body composition of adults across a range of body mass indexes. *Nutrition.* 2009;25(1):25-32.
16. Sluyter JD, David S, Robert KS, Lindsay DP. Prediction of fatness by standing 8-electrode bioimpedance: a multiethnic adolescent population. *Obesity.* 2009:183-189.
17. Sun G, French, CR, Martin, GR, Younghusband, B, Green, RC, Xie, Y, Mathews M, Barron JR, Fitzpatrick, DG, Gulliver W, Zhang H. Comparison of multifrequency bioelectrical impedance analysis with dual-energy x-ray absorptiometry for assessment of percentage body fat in a large, healthy population. *Am J Clin Nutr.* 2005;81:74-78.
18. Thomson R, Brinkworth GD, Buckley JD, Noakes M, Clifton PM. Good agreement between bioelectrical impedance and dual-energy x-ray absorptiometry for estimating changes in body composition during weight loss in overweight young women. *Clin Nutr.* 2007;26(6):771-777.

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