



Original Research

Validity of Arm-to-Arm BIA Devices Compared to DXA for Estimating % Fat in College Men and Women

REBECCA A. ROCKAMANN*¹, EMILY K. DALTON*¹, JANA L. ARABAS*¹, LIZ JORN*¹, and JERRY L. MAYHEW*^{1,2}

¹Exercise Science Program, Truman State University, Kirksville, MO, USA;

²Physiology Department, A. T. Still University, Kirksville, MO, USA

*Denotes undergraduate, †Denotes professional author

ABSTRACT

International Journal of Exercise Science 10(7): 977-988, 2017. Bioelectric impedance analysis (BIA) devices are commonly used to estimate percent body fat (%fat), although validation of their accuracy varies widely. The purpose of this study was to assess the validity of four commonly used BIA devices compared to dual-energy X-ray absorptiometry (DXA). College-aged men ($n = 29$, age = 19.7 ± 1.2 y, weight = 76.9 ± 12.5 kg) and women ($n = 31$, age = 20.5 ± 0.8 y, weight = 61.5 ± 9.2 kg) were evaluated for %fat using four single-frequency (50 mHz) BIA devices and DXA. A gender \times device repeated measures ANOVA indicated some less expensive BIA devices produced %fat values that were not significantly different from DXA. A thumb-to-thumb BIA device produced the closest values in men ($21.9 \pm 6.6\%$) and women ($32.1 \pm 5.3\%$) compared to DXA ($20.6 \pm 6.1\%$ and $30.3 \pm 5.4\%$, respectively). The two more expensive BIA devices significantly underestimated in men ($14.7 \pm 5.8\%$ and $17.0 \pm 5.6\%$) and women ($23.3 \pm 4.2\%$ and $23.3 \pm 4.2\%$) compared to DXA. Interclass correlation coefficients with DXA were higher for the more expensive devices in men (ICC = 0.899 and 0.958) than the less expensive devices (ICC = 0.681 and 0.730). In women, all BIA devices showed moderate correlations with DXA (ICC = 0.537 to 0.658). Despite the convenience of simple BIA devices, their use in estimating body composition in young men and women might be questionable due to large variations in the differences between DXA and each device in this study.

KEY WORDS: Dual-energy x-ray absorptiometry, body composition, gender difference, bioelectric impedance analysis

INTRODUCTION

Bioelectric impedance analysis (BIA) has gained wide popularity as a convenient approach to estimate body composition. The most frequently used BIA devices are single-frequency (50 kHz) apparatuses that send a small, imperceptible electrical current through the water medium of the body to assess the resistance to current flow. Since the major portion of body water is located in muscle, less impedance implies more muscle mass for a given

body weight, which is translated into an estimate of fat-free mass (FFM) and back-calculated to determine %fat. These devices usually require the input of gender, age, height, and weight to allow estimation of %fat through proprietary equations specific to each device.

The simplicity of single-frequency BIA devices has resulted in the production of a multitude of models designed to measure impedance from hand-to-hand, foot-to-foot, or a combination of both. Due to this proliferation in the marketplace, these devices have a wide range of prices making them available to individuals or institutions desiring a quick and simple method of assessing body composition. Several studies have evaluated the performance of single-frequency BIA devices against accepted laboratory criterion measures. Peterson et al. (38) evaluated four low-cost consumer-grade BIA devices and noted significantly higher %fat values for two leg-to-leg models and a finger-to-finger model, although these devices had moderate correlations with air displacement plethysmography (ADP) %fat ($r > 0.765$). Their hand-to-hand device nonsignificantly underestimated ADP %fat by only $1.37 \pm 5.35\%$, with a moderate correlation ($r = 0.771$). Likewise, Gibson et al. (18) found that a hand-to-hand BIA device significantly underestimated %fat from hydrostatic weighting (HW) in men by 1.4% and in women nonsignificantly by 0.2%. Pribyl et al. (39) noted a hand-to-hand BIA device significantly overestimated ADP %fat in both men and women. Weaver et al. (50) also found a hand-to-hand device significantly underestimated women's %fat by an average of 2.4% compared to ADP, with a moderate validity coefficient ($r = 0.75$). Duz, Kocak, and Korkusuz (15) compared a hand-to-hand device to dual-energy X-ray absorptiometry (DXA) and noted the former to underestimate %fat in men by 4.8% and in women by 9.2%. Andreoli et al. (2) found that a leg-to-leg BIA device significantly underestimated adult women measured by DXA by an average of 5.2%. Unick et al. (48) likewise observed a leg-to-leg BIA device underestimated %fat in young women but not in men measured by HW. Dolezal et al. (14) noted that a hand-and-foot bioelectrical impedance spectroscopy (BIS) device underestimated lean men and overestimated obese men compared to DXA. Brown et al. (9) found that a hand-to-foot BIA device had a lower correlation with HW ($r = 0.587$) and ADP ($r = 0.627$) than did skinfold prediction equations ($r = 0.738$ to 0.783) in high school wrestlers. Brock et al. (8) observed a high correlation ($r = 0.94$) between a leg-to-leg BIA device and HW in college football players, with no systematic over- or under-estimation difference between the two methods. It appears from previous studies that various BIA devices have a wide range of agreement with standard laboratory measurement techniques. However, the variability among standard laboratory methods of body composition may add to the difficulty of judging the validity of BIA devices.

Over its short history, DXA has gain wide acceptance as a criterion measure of %fat (4, 6, 21, 35). Since few studies have compared low-cost, single-frequency BIA devices to this criterion, it would be beneficial to assess the validity of inexpensive, commercially available single-frequency BIA devices compared to DXA. Therefore, the purpose of this study was to determine the validity of four commonly used upper-body single-frequency BIA devices compared to DXA as the criterion measure.

METHODS

Participants

College-aged men (n = 29) and women (n = 31) volunteered to participate in this study (Table 1). All participants were healthy and moderately active according to the criteria given by Triano (46). Each participant was measured on each device on the same day in the afternoon (16:00 to 19:00 hrs) with no exercise within five hours of measurement or no liquid consumption within a minimum of an hour prior to measurement, which was confirmed verbally upon arrival at the testing facility. Also, there was no alcohol consumption within 24 hours prior to measurement. All participants were encouraged to be adequately hydrated. Although previous studies have discussed the effect of food and liquid intake prior to measurement and have noted trivial effects on body composition components (35), the current protocol may be more typical of procedures revolving around practical considerations of the schedule of college students and athletes (8,14,30,38,39,50). No participants under the age of 18 years were included in the study. The procedures for the study were approved by the Institutional Review Board for the Protection of Human Subjects at Truman State University, and all participants signed a consent document prior to testing.

Table 1. Descriptive characteristics of the participants.

	Men (n = 29) Mean \pm SD	Women (n = 31) Mean \pm SD
Age (yrs)	19.8 \pm 1.2	20.4 \pm 1.0*
Height (cm)	178.1 \pm 7.6	164.4 \pm 6.3*
Weight (kg)	76.6 \pm 12.6	60.9 \pm 8.7*
BMI (kg/m ²)	24.1 \pm 3.3	22.4 \pm 2.3*

*p<0.05

Protocol

Height was determined without shoes using a wall-mounted stadiometer (Pharmacia model, Hynnna Limforg, Sweden); weight was recorded using a digital scale accurate to 0.1 kg (Tanita, model BWB-800AS). Each participant was evaluated for %fat using four hand-held BIA devices in random order according to the directions given by each manufacturer. Each BIA devices was a single frequency (50 mHz) instrument ranging in price from \$9.95 to \$32.68: thumb-to-thumb (BIA1, Baseline, model 12-1140), small hand-to-hand (BIA2, Baseline, model 12-1122), and two larger hand-to-hand devices (BIA3, Omron, model HBF-306 and BIA4, model HBF-306C).

Criterion body composition was assessed by DXA (General Electric Lunar iDXA, Fairfield, CT, USA) running GE Encore software. It was calibrated daily using a standard block supplied by the manufacturer. Participants wore only sports shorts and T-shirt without any metal. They were also asked to remove all jewelry, glasses, shoes, and any other items that may interfere with the scan. Participants were then positioned on the scanning bed with body alignment adjusted with the head within 3 cm of the top of the scanning area, the body symmetrically aligned on either side of the center line, with arms at the side and

hands in a prone position (4). Once properly positioned, an ankle strap was applied to minimize movement, and a 7:16 or 13:16 minute scan was begun, depending on machine determination of participant thickness. Participants were instructed not to move or talk during scanning. All measurements were completed within a 20-minute time span for each participant.

To evaluate the impact on body composition and weight management on the difference between the criterion DXA measurement and each BIA assessment, ideal body weight (IBW) was estimated from the equation: $IBW = FFM / (1 - \%fat/100)$ (32,36). Ideal %fat was assumed to be the approximate midpoint of the desired range of body fat for men (10%) and women (20%) (32).

Statistical Analysis

Statistical analysis was performed with SPSS for Windows (Version 24, IBM Corp, Armonk, NY). A sex x device (2 x 5) ANOVA with repeated measures over the second factor was used to determine statistical differences between genders, among devices, and for interaction. If Mauchly's test for sphericity was significant, the Greenhouse-Geisser method was used to calculate the F-ratio. If significance was noted, the Bonferroni technique was used to assess significant differences among means. Intraclass correlation coefficients (ICC) between DXA and each BIA device were calculated according to the method detailed by Weir (51). Pearson correlations were utilized to evaluate the relationships of height, body mass, and body mass index (BMI) to %fat value from each measurement device. Rank-order correlations were utilized to assess the relative agreement of group position between devices. The 90% Limits of Agreement (LoA) was estimated for each BIA device using the Bland-Altman method (7). Total error (TE) was calculated as: $TE = \sqrt{\Sigma(BIA - DXA)^2/N}$ (29). Percent error for each device was calculated using the equation: $\%error = (BIA - DXA)/DXA \times 100$. Significance level was set at $p \leq 0.05$ for all analyses. Power exceeded 0.96 for all analyses.

RESULTS

The sex x device interaction was significant ($p < 0.001$); therefore, comparison among devices was analyzed separately for each sex. In men, BIA1 and BIA2 values were not significantly different from DXA ($p > 0.11$), while BIA3 and BIA4 significantly ($p < 0.001$) underestimated DXA %fat (Table 2). BIA4 was significantly lower than BIA3 ($p < 0.001$). The validity coefficients (ICC) were considered high for BIA3 and BIA4 and moderate for BIA1 and BIA2, with the latter two being significantly lower than the former two (Table 2). However, when considering the $\pm 3.5\%$ error limit on %fat prediction suggested by Lohman (18) for acceptable accuracy, BIA1 and BIA3 had most of their values within that error limit compared to DXA values (Table 2). Bland-Altman plots confirmed a bias and substantial LoA for all four BIA devices. Spearman rank-order correlations between DXA %fat and each BIA device were higher for BIA 4 ($\rho = 0.88$, $p < 0.01$) and BIA3 ($\rho = 0.78$, $p < 0.01$) than for BIA1 ($\rho = 0.48$, $p < 0.01$) and BIA2 ($\rho = 0.35$, $P = 0.06$), indicating that the former

two produce similar order of participants in the group despite between significantly different.

Table 2. Comparison of %fat values from BIA devices with DXA for assessing %fat in young men (n = 29).

	Mean ± SD	Diff ± SD ^a	SEE ^b	ES ^c	ICC ^d	90% LoA	TE ^e	Percent within ±3.5% ^f
BIA1	21.9 ± 6.6	1.3 ± 5.9	5.7	0.77	0.723*	-8.4 – 11.0	5.9	55%
BIA2	24.1 ± 8.1	3.6 ± 7.0	6.0	0.41	0.681*	-8.0 – 15.2	7.8	31%
BIA3	17.0 ± 5.7* [§]	-3.6 ± 3.6	5.7	1.57	0.899*	-9.5 – 2.3	5.0	45%
BIA4	14.7 ± 5.8* [§]	-5.8 ± 2.4	5.9	1.95	0.958*	-9.8 – -1.8	6.3	21%
DXA	20.6 ± 6.1							

BIA = bioelectric impedance analysis, DXA = dual-energy x-ray absorptiometry. *Significantly different from DXA (p<0.05). [§]Significantly different from BIA1 and BIA2. ^aDiff = BIA - DXA, ^bSEE = Standard Error of Estimate (%), ^cES = Effect Size, ^dICC = Intraclass Correlation Coefficient with DXA, ^eTE = total error, ^fAcceptable error for %fat determination (25).

In women, BIA1 and BIA2 values were not significantly different from DXA, while BIA3 and BIA4 significantly underestimated %fat (Table 3). When considering the ±3.5% error limit on %fat prediction (29), BIA1 was the only device to have more of the participants above 50% (Table 3). The validity coefficients (ICC) were considered moderate for all devices. Bland-Altman plots confirmed a bias and substantial LoA for all four BIA devices. Spearman rank-order correlations between DXA %fat and each BIA device were significant for BIA3 (rho = 0.48, P<0.01) and BIA4 (rho = 0.47, p<0.01) but not for BIA2 (rho = 0.19, p=0.30) and BIA1 (rho = 0.29, p=0.12). However, the moderate level of rank-order correlations of DXA %fat with BIA3 and BIA4 indicated a discoordination between the order of participants within the groups for each instrument.

Table 3. Comparison of %fat values from BIA devices with DXA for assessing %fat in young women (n = 31).

	Mean ± SD	Diff ± SD ^a	SEE ^b	ES ^c	ICC ^d	90% LoA	TE ^e	Percent within ±3.5% ^f
BIA1	32.1 ± 5.3	1.7 ± 5.8	4.6	0.32	0.591*	-7.9 – 11.3	5.9	52%
BIA2	28.4 ± 5.8	-1.9 ± 6.3	4.7	0.36	0.537*	-12.3 – 8.5	6.5	39%
BIA3	23.3 ± 4.2* [§]	-7.1 ± 4.9	4.0	1.31	0.643*	-15.2 – 1.0	8.6	19%
BIA4	23.0 ± 3.6* [§]	-7.2 ± 4.6	3.6	1.35	0.658*	-14.9 – 0.3	8.6	16%
DXA	30.3 ± 5.4							

BIA = bioelectric impedance analysis, DXA = dual-energy x-ray absorptiometry. *Significantly different from DXA (p<0.05). [§]Significantly different from BIA1 and BIA2. ^aDiff = BIA - DXA, ^bSEE = Standard Error of Estimate (%), ^cES = Effect Size, ^dICC = Intraclass Correlation Coefficient with DXA, ^eTE = total error, ^fAcceptable error for %fat determination (25).

Body mass and body mass index (BMI) were significantly correlated with %fat from each BIA device in both men and women (Table 4). Height was not significantly correlated with %fat estimates from any technique. The average correlation between BMI and the various %fat values was significant for women (r = 0.91, p<0.001) and men (r = 0.80, p<0.01), but not significantly different between the sexes. The correlations of either body mass or BMI with the difference between BIA %fat and DXA %fat for each device were significant only for BIA1 in men and women (r = 0.43 and r = 0.51, respectively) and BIA2 in women (r = 0.44 and r = 0.52). This would suggest that these BIA devices may be utilizing BMI as part of their proprietary algorithms to estimate %fat.

Table 4. Correlations of height, body mass, and BMI with %fat values from each device in men (n = 29) and women (n = 31).

	Body Mass (kg)		Height (cm)		BMI	
	Men	Women	Men	Women	Men	Women
BIA1†	0.58**	0.82**	-0.29	0.22	0.77**	0.99**
BIA2†	0.54**	0.80**	-0.10	0.21	0.73**	0.97**
BIA3†	0.82**	0.34*	0.21	-0.15	0.64**	0.61**
BIA4†	0.92**	0.36*	0.15	-0.19	0.71**	0.63**
DXA‡	0.64**	0.35	0.15	0.07	0.66**	0.43*

†Bioelectric Impedance Analysis, ‡Dual-energy x-ray absorptiometry kg = kilogram cm = centimeter *p<0.05, **p<0.01

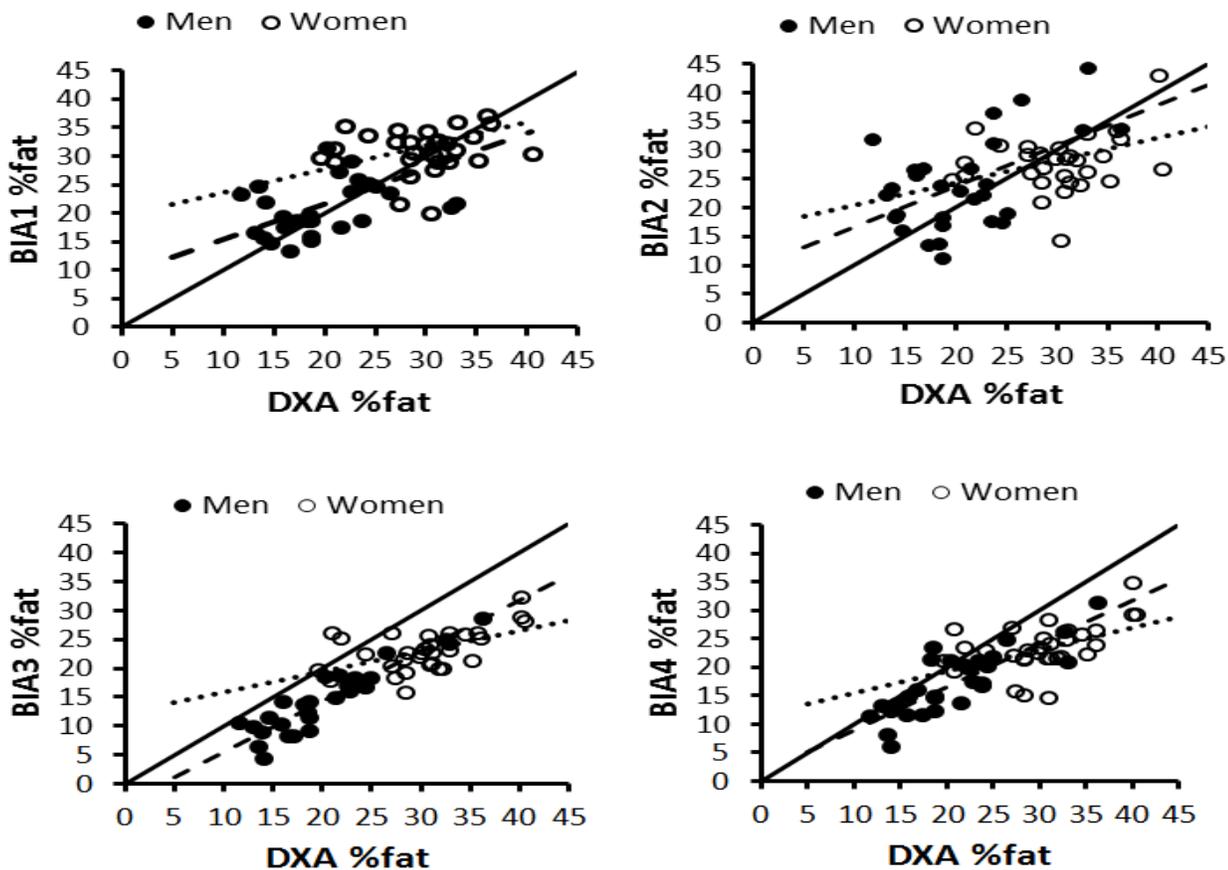


Figure 1. Validity of BIA devices compared to DXA for estimating %fat in men (● and dashed line) and women (○ and dotted line).

The relationship between DXA %fat and BIA %fat estimates in men and women had similar patterns for each device (Figure 1). BIA3 and BIA4 had a greater degree of underestimation of %fat than did BIA1 and BIA2 in both men and women. BIA2 had a greater spread around the regression line than did BIA1. The slopes and intercepts of the regression lines for BIA1, BIA2, and BIA4 were not significantly different between men and

women. The intercept for BIA3 was significantly greater for women than for men, with no significant difference between the slopes.

DISCUSSION

This study sought to evaluate the accuracy of several inexpensive BIA devices compared to the criterion measure of DXA for estimating %fat in young adults. The testing procedure utilized in this study more closely resembled what might typically occur in a school or commercial setting when the timing of food and liquid intake might be less rigorously controlled (30,44). In these settings, it may be difficult to require participants to be tested in the morning after an overnight fast. Further, while it might be recommended that participants be hydrated, the actual determination of euhydration using urine specific gravity would be impractical. Given those contingencies, the major finding of the study indicates that some inexpensive commercial-grade BIA devices may have differing abilities for accurately estimating %fat in average college men and women when compared to a sophisticated laboratory technique such as DXA. Major portions of men (45-79%) and women (48-84%) might be over- or under-estimated compared to the DXA criterion when considering an error of acceptance criterion of $\pm 3.5\%$ for %fat prediction (29).

The current results agreed with Loenneke et al. (27, 28) who found that single-frequency BIA device typically underestimated %fat in college athletes compared to DXA. The differences persisted regardless of whether a normal or athletic setting on the BIA device was used. Dixon et al. (13) found the athletic setting on a leg-to-leg BIA was more accurate compared to HW for wrestlers with BMI<25 while the normal setting was more accurate for those with BMI>30. That was not the case in the current study where only BIA2 showed a tendency to significant underestimate %fat compared to DXA in participants with BMI>25. De Lorenzo et al. (12) found high LoA between DXA and BIA estimates of %fat in athletes with a significant bias and noted that the two methods should not be used interchangeably. Using a BIA device similar to BIA3 and BIA4 used in the current study, Gibson et al. (18) found 72% of men and 65% of women had %fat values within $\pm 3.5\%$ compared to HW, which is substantially higher than noted in our results.

In the current study, statistical agreement between BIA devices and DXA was stronger in men (Table 2) than in women (Table 3). However, Mitsui et al. (33) suggest that the error of a method in comparison to a criterion might be more important than the correlation between them. In the current study, each BIA device had correlational support but a larger than desirable TE and LoA (Tables 2 and 3). Although there was a significant difference between two BIA devices and DXA %fat in men, the relative group position as indicated by Spearman rank-order correlations suggests that BIA3 and BIA4 might give comparable with-group ranking but different actual %fat values. This was not true for women where the variance accounted for was less than 23% for all devices. This could mean that 35% of the women in this study could have been told they were an average of 6.1 kg (± 2.1 kg) overweight when they were actually within the error of measurement for estimating %fat.

The fact that two widely used BIA devices (BIA3 and BIA4) significantly underestimated large portions of the current sample could impugn the advice given to college students concerning weight control. Previous research has indicated that college students tend to gain weight during the early years due to reduced activity levels and increased food consumption (10, 11, 19, 26, 37, 40, 53). Most of the weight gain tends to be as fat and not as muscle (10, 24, 31, 37). Previous comparisons between students who were given diet and exercise instruction showed less weight gain than a control group without feedback (19). However, if a large proportion of freshmen and sophomores received information that their body fat was significantly lower than it actually was, it is possible they may have a greater tendency to gain unwanted weight since many may feel weight gain is inevitable due to the widely circulated myth of the “freshmen 15” (19, 20).

Furthermore, a substantial body of information suggests that a large portion of college women have body image issues that provoke extremes in dieting behavior (3). Women who diet more tended to rebound to gain more weight (19,22,47). Since women might be more sensitive to body image issues (22, 47), misinformation concerning their body composition could trigger more disordered eating habits (1).

One factor which might qualify the current findings is the use of DXA as the criterion measure of body fat. Although it has been acclaimed as a prime criterion for assessing body composition (4, 6, 17, 21, 45), other sources have questioned it as a “gold” standard (23, 42). Some sources suggest that it yields higher estimates than other techniques (34). This may suggest that current standard of %fat values should be reassessed in order not to alarm individuals who guide their weight management program by the use of various body composition evaluation techniques. Some researchers support a multi-component model as the only means of accurate assessment (25, 34, 52). While several studies have found good agreement between various BIA devices and ADP (5, 30, 41), HW (8, 21, 49), and DXA (15,16), there is no concrete support that any indirect assessment of body composition is the most accurate, no matter how sophisticated the technique. Use of any sophisticated method would require considerable time and expense, which may not be feasible in most university or commercial settings. Perhaps this is what has given rise to the wide spread use of simple BIA devices to offer body composition advice. The current and other studies have brought into question the unqualified use of such devices in diverse populations. It is possible that quick, simple, and inexpensive methods of assessing body composition could do more harm than good.

One limitation of the current study was the small sample size of volunteers. In addition, these results may be limited to young adults in the 18-24 year old age group. However, since their basic demographics were similar to previous studies of college-aged students (37), the current outcomes could be similar to what might happen in a larger sample. Further investigation on a larger and more diverse population might provide additional information on the integrity of simple, single-frequency BIA devices to provide acceptable estimates of %fat.

In summary, these data indicate that some commercial BIA devices have limited potential to accurately measure %fat when DXA is used as the criterion measure. Furthermore, the wide spread use of such devices in college settings may pose a problem when the information is used to formulate weight control plans. A major drawback to these devices may be the proprietary algorithms used to calculate %fat from impedance since no information is available on the population on which they were derived. Since this is not likely to change in the near future, the use of most single-frequency BIA devices for estimating %fat should be viewed by skepticism.

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