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The Stayhealthy bioelectrical impedance analyzer predicts body fat in children and adults

David N. Erceg, Christina M. Dieli-Conwright, Amerigo E. Rossuello, Nicole E. Jensky, Stephanie Sun, E. Todd Schroeder*

Division of Biokinesiology and Physical Therapy at the School of Dentistry, The Clinical Exercise Research Center, University of Southern California, Los Angeles, CA 90033, USA

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Abstract

Bioelectrical impedance analysis (BIA) is a time-efficient and cost-effective method for estimating body composition. We hypothesized that there would be no significant difference between the Stayhealthy BC1 BIA and the selected reference methods when determining body composition. Thus, the purpose of the present study was to determine the validity of estimating percent body fat (%BF) using the Stayhealthy BIA with its most recently updated algorithms compared to the reference methods of dual-energy x-ray absorptiometry for adults and hydrostatic weighing for children. We measured %BF in 245 adults aged 18 to 80 years and 115 children aged 10 to 17 years. Body fat by BIA was determined using a single 50 kHz frequency handheld impedance device and proprietary software. Agreement between BIA and reference methods was assessed by Bland and Altman plots. Bland and Altman analysis for men, women, and children revealed good agreement between the reference methods and BIA. There was no significant difference by *t* tests between mean %BF by BIA for men, women, or children when compared to the respective reference method. Significant correlation values between BIA, and reference methods for all men, women, and children were 0.85, 0.88, and 0.79, respectively. Reliability (test-retest) was assessed by intraclass correlation coefficient and coefficient of variation. Intraclass correlation coefficient values were greater than 0.99 ($P < .001$) for men, women, and children with coefficient of variation values 3.3%, 1.8%, and 1.7%, respectively. The Stayhealthy BIA device demonstrated good agreement between reference methods using Bland and Altman analyses.

Keywords: Bioelectrical impedance analysis; Body composition; Fat percentage; DXA; Hydrostatic weighing

Abbreviations: BCA, body composition analyzer; BIA, bioelectrical impedance analysis; %BF, percent body fat; CV, coefficient of variation; DXA, dual-energy x-ray absorptiometry; FM, fat mass; FFM, fat free mass; HW, hydrostatic weighing; ICC, intraclass correlation coefficient.

1. Introduction

With the increased prevalence of overweight and obese people in the United States [1], there is a need to accurately determine body composition to assess the risk of morbidity in children and adults and also a need to offer a reliable way that individuals can track their own body composition. Currently, there are many methods available for obtaining body composition measures such as summation of skinfolds [2], bioelectrical impedance analysis (BIA) [3], bioelectrical impedance spectroscopy [4], air displacement plethysmography [5], hydrostatic weighing (HW) [6], magnetic resonance imaging [7], and dual energy x-ray absorptiometry (DXA) [8]. Because these measures of body composition provide an estimate of body fat percentage,

* Corresponding author. Tel.: +1 323 442 2498; fax: +1 323 442 1515.
E-mail address: eschroed@usc.edu (E.T. Schroeder).

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cadaveric analysis has been used to validate reference methods such as HW and DXA by which other methods may be compared. However, HW and DXA are not always practical and can be relatively time consuming, expensive, and limited to clinical settings.

Bioelectrical impedance devices are convenient for estimating body composition and a popular choice for investigators because they can be used in both clinical and field settings. In addition, they are becoming popular for use by individuals who want to track progress when on diet and exercise regimens. Bioelectrical impedance analysis measures the body's resistance to flow of electric current between points of contact on the body and correlates well with measures of total body water [9]. Assuming that the hydration fraction for fat-free mass (FFM) is a constant, it is possible to calculate FFM from total body water and subsequently fat mass (FM) from total body weight. By incorporating variables to the measured impedance value such as body weight, height, sex, and age, prediction equations have been developed using regression analysis to better estimate body composition when compared to reference methods.

The accuracy and reliability of bioelectrical impedance devices have been validated against reference methods such as HW [10], DXA [8], and isotope dilution methods [11]. Although many studies have examined the validity of BIA for specific populations, such as children [2,4], adults [12], athletes [6,13], and clinical patients [11,14], few studies have examined the validity of BIA in a large diverse population.

Traditionally, body composition methods assess the body in 2 compartments: FFM and FM. Hydrostatic weighing was developed using cadaveric analysis of FM and FFM components [15] and is considered to be a reference criterion or "gold standard" [16] by which other methods for estimating body composition are compared. Hydrostatic weighing is a 2-compartment model that measures underwater body mass from which body density is calculated and subsequently entered into an equation to determine percent body fat (%BF). Previous studies have used HW to validate bioelectrical impedance devices in children and demonstrated strong correlations (r >0.90) [6,10].

Dual-energy x-ray absorptiometry is traditionally used for measuring changes in bone density and is increasingly being used for assessing body composition. Unlike 2-component models (FM and FFM), DXA uses a 3-component model of fat, mineral, and lean tissue mass [17] but has the limitation of high cost and radiation exposure, making it inappropriate for multiple measures and not practical for individual use at home or in physician offices.

Because DXA and HW methods are limited to a clinical setting and can be relatively time consuming and expensive, BIA may be a more practical method for measuring body composition. We hypothesized that there would be good agreement between the Stayhealthy BC1 BIA and the selected reference methods when determining body composition. Therefore, the purpose of the present study was to determine the validity and reliability of the Stayhealthy body composition analyzer BC1 using the new proprietary equation compared to HW measurements in children and DXA measurements in adults for a large diverse population.

2. Methods and materials

2.1. Participants

Two hundred forty-five adults, 18 to 80 years old (117 men and 128 women), and 115 children, 10 to 17 years old (51 boys and 64 girls), volunteered to participate in this study conducted at the University of Southern California's Clinical Exercise Research Center, Los Angeles, Calif. Men and women were analyzed separately because of inherent sex differences in body composition and further divided into the following age groups: 18 to 35, 36 to 50, 51 to 60, 61 to 70, and 71 to 80 years. Before study enrollment, we obtained university institutional review board–approved informed consent from all participants and child participants' parents or legal guardians. Before obtaining the anthropometric variables of height and body weight, each subject was asked to remove footwear, jewelry, and bulky clothing. Height was measured to the nearest 1 cm on a standardized wall-mounted height board, and weight was electronically calculated to the nearest 0.05 kg.

2.2. Bioelectrical impedance analysis

After the anthropometric variables were measured, BIA was performed using the commercially available Stayhealthy body composition analyzer BC1 (Stayhealthy, Inc, Monrovia, CA). The body composition analyzer (BCA) uses a single-frequency, 50-kHz oscillating current of 800 μA to determine impedance (Ohms). The subject's data (age, sex, weight, and height) were entered into the BCA software program before analysis. Body fat percentage was calculated using a proprietary prediction equation. All participants were required to stand comfortably, holding the BCA device with arms fully extended and held approximately 90° to their body. Three consecutive readings were obtained for each subject with the average of the 3 used for statistical analysis. Between readings, subjects rested their arms by their sides for approximately 90 seconds.

2.3. Hydrostatic weighing

In accordance with the University Radiation Safety Committee, children are to avoid unnecessary radiation exposure; therefore, HW was performed for all child participants in a custom-designed plexiglass tank (122 × 122 × 152 cm). Underwater weight was measured by having subjects sit in a chair suspended from a spring-loaded Chatillion 9-kg scale fixed to an overhead metal bar. Underwater weight was attained within 3 to 10 trials. To calculate body density, underwater weight was determined by averaging 3 trials within 100 g. Body density was adjusted for residual volume, estimated from a child-adjusted prediction equation [18] using an assumed constant gastrointestinal gas volume of 115 mL. Water temperature was recorded before each participant entered the tank. After body density was calculated, Lohman's age and sex adjusted equations were used to calculate %BF for children [19].

2.4. Dual-energy x-ray absorptiometry

All adult participants underwent a 10- to 15-minute total body DXA scan (model DPX-IQ 2288; Lunar Radiation Corporation, Madison, Wis) to assess FM. The Lunar DXA uses a constant potential x-ray source and a K-edge filter to achieve a congruent beam of stable dual-energy radiation. To assess body composition, a series of transverse 1-cm scans were performed beginning at the subject's head and progressing toward the feet. The average of 4 scans of a Bio-Imaging Inc, phantom (VCP-057) was used to determine the accuracy of the Lunar model to measure body fat [20]. The phantom consisted of 4 stacked acrylic blocks, which were used in conjunction with sheets of vinyl and PVC. The acrylic blocks acted to simulate FM, whereas the PVC and vinyl sheets acted to simulate lean tissue. By adjusting the number of PVC and vinyl sheets that are laid over the acrylic block, 3 differing levels of tissue density were simulated to give a high, medium, and low percent-fat reading. The percent-fat readings for the phantom and the DPX-IQ for 3 predetermined levels of tissue density were high percent fat (44.2, 42.4%), medium percent fat (23.4, 20.0%), and low percent fat (8.6, 6.1%), respectively. For the 3 tissue density settings, the DPX-IQ tended to underestimate fat by 1.8%, 3.4%, and 2.5%. Quality assurance was performed daily using a single acrylic block to confirm accuracy and precision of the DXA system. The same experienced investigator was responsible for analyzing all scans. The coefficient of variation (CV) for analysis of total body fat by DXA in our laboratory was less than 1%.

2.5. Statistical analyses

All statistical analyses were performed using Statistical Package for the Social Sciences version 14.0 (SPSS Inc, Chicago, Ill). Descriptive statistics (means and standard deviations) for %BF were calculated and tested for statistical significance between methods by independent *t* tests. Association between methods was assessed using the Pearson correlation coefficient to evaluate %BF between HW-BIA and DXA-BIA techniques. To determine the reliability of measure for the BCA, intraclass correlation coefficient (ICC) and CV analyses were performed. Coefficient of variation was calculated via log transforming the differences of the raw scores. Bland and Altman [21] plots were used to determine concordance between techniques with the limits of agreement defined as the mean of the difference ±1.96 standard deviations. Statistical significance was set at $P < .05$. A power analysis using SigmaStat 3.5 software was conducted to calculate sample size. Using previously published data for adults [12], a mean difference of 2 %BF, SD of 7.5 with the power of the test set to 0.8, and significance level at .05 resulted in sample size 222.

3. Results

Data from 245 adults, 18 to 80 years old (117 men and 128 women), and 115 children, 10 to 17 years old, (51 boys and 64 girls) were included in the analyses. A total of 4 men and 7 women were excluded from the analyses for not having completed all tests. Six children were excluded from analyses because they were unable to successfully perform the HW test. The girls' and boys' data were combined for analyses. Tables 1 and 2 summarize anthropometric and mean values for %BF as measured by the respective devices.

3.1. Validity

Estimated mean total %BF by BIA compared to HW values for children was not significantly different as shown in Table 1. In addition, for the adult group, all means were not significantly different when comparing BIA to DXA for %BF for men and women or when stratified by age groups (Tables 1 and 2).

Significant correlations were demonstrated between %BF by BIA and HW for children ($r = 0.79$, $P < .001$) (Table 3). For adults, significant correlations between BIA and DXA for men ($r = 0.85$, $P < .001$) and women ($r = 0.88$, $P < .001$) are reported in Table 3. Adults revealed significant correlations for all 5 age groups of r = 0.69-0.89, and 0.70-0.94 for men and women, respectively (Table 2).

3.2. Bioelectrical impedance analysis bias

Bland and Altman analyses were performed to determine concordance between percent fat by BIA and DXA (men and women) and between BIA and HW (children). The dashed lines in Figs. 1, 2, and 3 represent the limits of agreement between the 2 measures as being the mean difference

Table 1
Anthropometrics and mean values for %BF measured by BIA, HW for children, and DXA in adults [a]

	Children (10-17 y) (n = 117)		Adults (18-80 y)			
			Men (n = 117)		Women (n = 128)	
	Mean	SD	Mean	SD	Mean	SD
Age (y)	14.9	1.7	45.7	17.4	45.1	16.1
Height (cm)	164.5	11.0	178.2	7.4	164.6	6.4
Weight (kg)	59.5	13.1	80.9	11.8	65.3	13.8
BMI (kg/m^2)	21.9	3.9	25.5	3.4	24.1	4.8
	(14.7, 35.7)		(19.8, 37.4)		(16.0, 37.5)	
% Fat						
BIA	18.4	8.4	20.3	5.3	32.8	9.1
HW	18.8	8.3	–	–	–	–
DXA	–	–	20.4	5.6	33.4	9.6

BMI, body mass index.

[a] Includes %BF values that were not significantly different to reference methods as determined by *t* tests ($P > .05$). Data are mean values and standard deviations with minimum and maximum values in parentheses.

Table 2
Estimated %BF for adults by age group and sex for each body composition device

Adults	No.	Age (y)		Height (cm)		Weight (kg)		BIA (% fat)		DXA (% fat)		r
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Men (y)	117											
18-35	38	26.2	3.1	176.1	6.9	76.4	9.2	16.3	4.2	16.9	5.0	0.79 [a]
36-50	34	42.5	4.7	181.4	6.3	84.0	9.6	18.9	3.5	19.4	4.9	0.81 [a]
51-60	20	56.4	2.2	179.4	7.1	87.2	15.0	24.4	3.9	25.0	4.1	0.84 [a]
61-70	9	63.3	2.5	176.5	12.2	86.3	16.1	24.8	4.8	23.4	4.4	0.89 [a]
71-80	16	75.3	2.8	175.4	5.1	74.5	8.2	25.3	3.3	23.7	3.9	0.69 [a]
Women (y)	128											
18-35	41	26.6	4.2	163.9	6.1	58.3	8.3	26.2	3.1	26.6	5.7	0.70 [a]
36-50	35	41.5	4.6	165.0	6.4	64.7	11.9	31.6	7.1	32.5	9.2	0.81 [a]
51-60	23	56.0	2.8	163.2	6.9	62.5	10.4	33.2	5.1	34.7	6.5	0.84 [a]
61-70	19	63.7	2.6	164.6	5.6	76.5	16.4	42.4	10.4	42.1	9.6	0.87 [a]
71-80	10	72.3	1.3	169.4	6.5	81.2	15.3	45.7	8.1	44.7	5.7	0.94 [a]

Data shown are mean values and standard deviations. Percent body fat values for all age groups and sex were not significantly different to reference methods as determined by *t* tests ($P > .05$). *r* indicates Pearson correlation coefficients.

[a] Significant correlation coefficient for BIA and DXA ($P < .01$).

±1.96SD. The mean difference for percent fat for children was −0.4%, with limits of agreement ranging from −11.0% to 10.2% (Fig. 1). Men alone demonstrated a mean difference of 0.3%, with limits of agreement between percent fat by BIA being 6.3% higher or 5.8% lower when measured by DXA (Fig. 2). For the women, the mean difference for percent fat between BIA and HW was −0.6%. The limits of agreement between percent fat by BIA and percent fat by HW ranged from −9.6% to 8.4% (Fig. 3). Mean difference bias as determined by a 1 sample *t* test was not significantly different for all plots.

To determine over- or underestimations of %BF by BIA, linear regression analyses were performed for all Bland and Altman plots. Results demonstrate that there were no significant biases between the mean and differences by BIA and the reference methods for children ($r = 0.02$, $P = .87$), men ($r = 0.06$, $P = .55$), and women ($r = 0.12$, $P = .17$).

3.3. Reliability

The repeatability of measure by the BIA method is expressed by the ICC and CV in Table 3. Intraclass correlation coefficients for men, women, and children were greater than 0.99. The CV for the BIA system for men, women, and children were 3.3%, 1.8%, and 1.7%, respectively.

4. Discussion

Bioelectrical impedance analyzers are simple and cost-effective, and the technique is a noninvasive method to determine %BF. Investigators have reported reliable and valid BIA devices [6,14,22-23]; however, many of these have been shown not to be interchangeable with reference methods [8,11,24-25]. The purpose of the present study was to examine the hypothesis that the Stayhealthy BCA, a single-frequency, 50-kHz bioelectrical impedance device is a valid measure of %BF when compared to the reference methods of HW for children and DXA for adults. The main findings of this study suggest that Stayhealthy BCA is a valid measure for %BF when comparing to the selected reference methods.

Contrary to reports by other investigators [3,12], the mean %BF by BIA did not differ significantly from DXA measurements for adults. When comparing BIA to the DXA for adults, BIA was strongly correlated to DXA for both men and women and moderately to strongly ($r = 0.65$-0.90) correlated when stratified by age group. These findings are in agreement with previous studies [3,11,25]. However, a strong correlation does not necessarily indicate that the device is a valid measure [21].

To further determine device validity, Bland and Altman plots were used to assess agreement between methods for

Table 3
Pearson correlation coefficients (*r*) and ICC and CV for %BF [a]

	No.	r (intermethod)	Linear regression equation	P	ICC	P	BIA CV%
Children	115	0.79	$y = 3.4 + 0.8x$	<.001	1.00	<.001	1.7
Men	117	0.85	$y = 2.8 + 0.9x$	<.001	>0.99	<.001	3.3
Women	128	0.88	$y = 5.1 + 0.8x$	<.001	>0.99	<.001	1.8

Intermethod (*r*) correlation coefficient and linear regression equation ($P < .001$) for BIA vs DXA (men and women) or HW (children). The BIA repeatability (test-retest) of data indicated by ICC ($P < .001$) and CV.

[a] Significance set at $P < .05$.

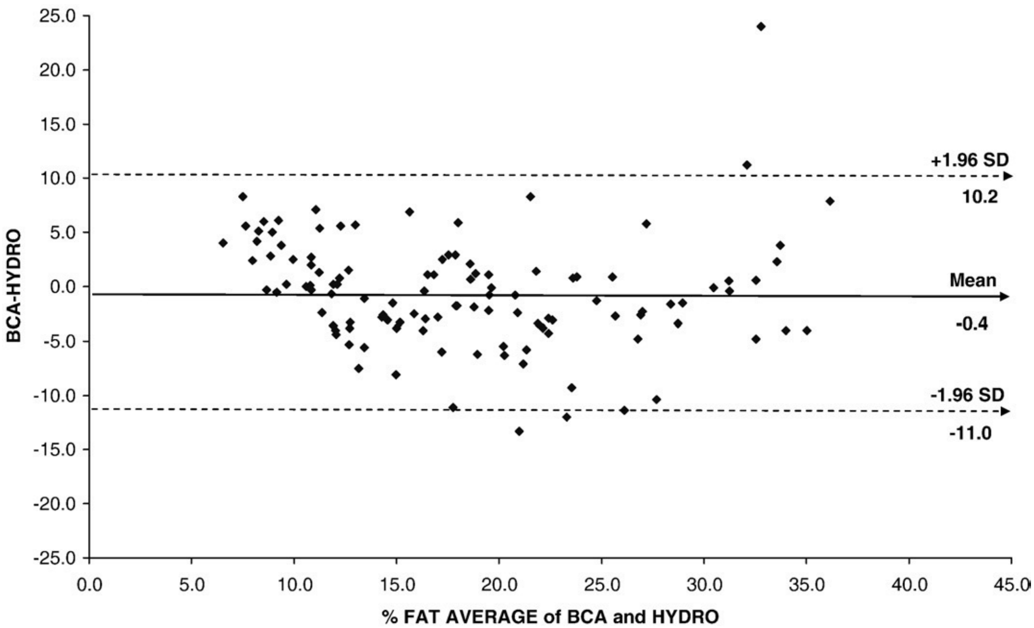

Fig. 1. Bland-Altman plot showing difference between %BF measured by the bioelectrical composition analyzer (BCA) and HW vs mean percent fat of BCA and HW for children 10 to 17 years old. The solid line represents mean %BF difference between methods, with the dotted lines representing the limits of agreement (±2SD). No significant difference was observed for mean difference (−0.4, P = .45) between methods, and no bias was found between the mean and difference (r = 0.02, P = .87).

estimating %BF. The nonsignificant mean difference bias was near zero for men and women demonstrating minimal bias by BIA to over- or underestimate when compared to DXA. A linear regression for the Bland and Altman plots was conducted to determine if BIA under- or overestimated %BF for the extreme ranges of lower or higher fat values. The linear regression for the Bland and Altman plots were not significant for both men (r = 0.06, P = .59) and women

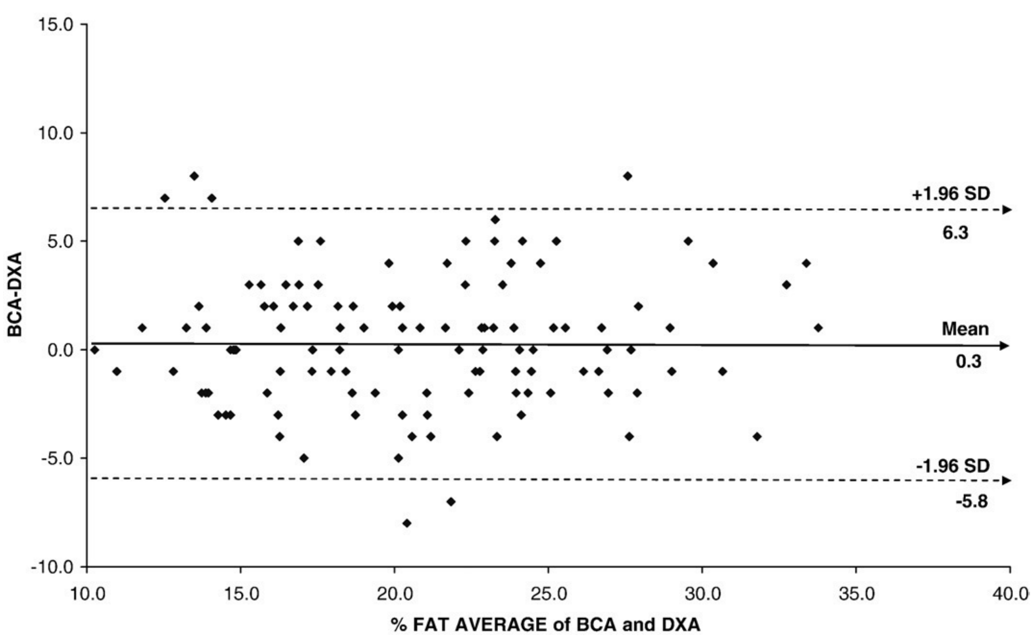

Fig. 2. Bland-Altman plot showing difference between %BF measured by the bioelectrical composition analyzer (BCA) and DXA versus mean percent fat of BCA and DXA for men 18 to 80 years old. The solid line represents mean %BF difference between methods, with the dotted lines representing the limits of agreement (±2SD). No significant difference was observed for mean difference (0.3, P = .37) between methods, and no bias was found between the mean and difference (r = 0.06, P = .55).

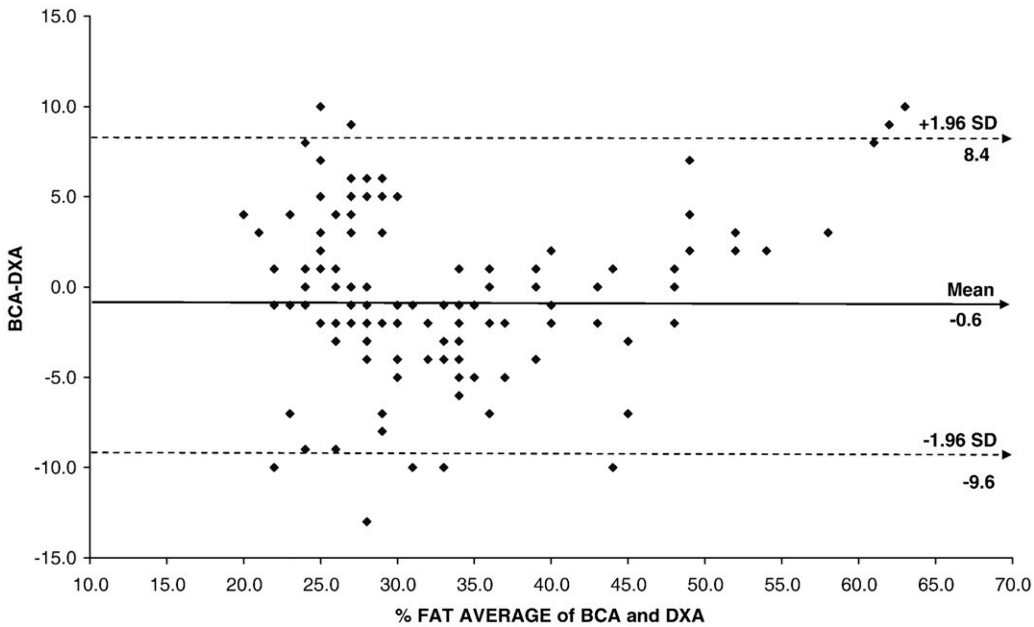

Fig. 3. Bland-Altman plot showing difference between %BF measured by the bioelectrical composition analyzer (BCA) and DXA vs mean percent fat of BCA and DXA for women 18 to 80 years old. The solid line represents mean %BF difference between methods, with the dotted lines representing the limits of agreement (±2SD). No significant difference was observed for mean difference (−0.6, P = .20) between methods, and no bias was found between the mean and difference (r = 0.12, P = .17).

(r = 0.12, P = .17) indicating good precision between methods. This finding was not supported by Lukaski et al [25] in adults 21 to 60 years old, where upper and lower regional BIA devices were compared to DXA. The BIA devices systematically demonstrated a bias to underestimate body fat as total body or regional body fatness increased. Thus, the new equations underpinning the present Stay-healthy device appear to have improved the prediction of body fat compared to reports for other BIA devices.

When assessing device validity for children, the mean %BF values between BIA and HW were not significant; however, others have reported significantly different %BF values between BIA and reference measures [8,13,24]. In our study, BIA was moderately correlated to HW for children resulting in a significant r value of 0.79. This is in agreement with one study [4,26], but not others [27] that have reported higher individual values for boys and girls (r > 0.90).

Bland and Altman plots revealed a similar trend to the adults with children having a negligible, nonsignificant mean difference bias of −0.4 with the limits of agreement ranging from 10.2% to −11.0%BF. Similar limits of agreement have also been reported between BIA and reference measures for children [4,8,24]. Bias as determined by linear regression analysis (r = 0.02) was not significant for children. However, previous investigators have reported that BIA has a tendency to overestimate FM or underestimate FM in children when compared with DXA [8,28]. Differences in findings for adults and children from previous investigations and the present study may be due to different reference measures (eg, HW vs DXA), participant characteristics, and proprietary BIA equations. In addition, limitations associated with this study may in part explain the variance in %BF values between BIA and reference methods. Although DXA and HW are widely considered the “gold standards” to which other methods are compared, it should be noted that all measures of body composition are estimates. Investigators have reported DXA to underestimate total body mass compared to anthropometric measures [24,29] and demonstrate some variability between repeated measures [24]. However, anthropometric measures are subject to user technique and experience that can cause variable results. A review of DXA by Pietrobelli and Tato [17] stated that attenuation ratios are assumed to be stable for FFM and FM tissue; however, tissue constancy may vary with children and aging, and thus, over time or between children, there may be some systematic change in body composition measured by DXA. Furthermore, DXA attenuation ratios may be influenced by an individual’s thickness, that is, anterior-posterior. However, for an individual DXA, measurements of body composition are usually consistent and reliable [30]. Despite these potential limitations, DXA has been validated by carcass analyses and provides accurate and reliable data [31]. The technique of HW was used in conjunction with Lohman’s age-adjusted %BF equations to minimize overestimation of %BF that may occur from using adult body composition prediction equations [32]. To determine body density, a gastrointestinal gas volume of 115 mL was assumed to be constant for all children, and residual volume was estimated from equations [18]. Prediction of residual volume to determine body density and ultimately %BF may be a source of error up to 3.7% for an individual. However, when group means are of interest as in this study, the error may not be significant [33].

In adults, the repeatability of measures by BIA as assessed by ICC and the CV were greater than 0.99 and 3.3% for men and greater than 0.99 and 1.8% for women. These data suggest strong repeatability of measures for adults, which are similar to findings by other studies [3,6]. When determining the repeatability of measure by BIA for children, the intraclass correlation was 1.00. This result is in agreement with Gutin et al [24], who reported an ICC greater than 0.99 for 9- to 11-year-old children using a single-frequency BIA device. In addition, the CV was small (1.7%) for children also indicating good repeatability of measure.

Studies investigating the validity of BIA are often limited to one or more of the following factors: small number of participants, specific population, or a narrow range of %BF from a healthy population limiting the application of certain BIA devices. This study aimed to overcome these limitations and expand the applicability of BIA as a method for determining %BF. The population was otherwise healthy, diverse, and with a body mass index ranging from normal to obese for adults and across the percentile ranking for children. In addition, the aforementioned factors combined with a wide age range for both sexes allowed for determining device bias and precision of measure for the proprietor's prediction equation using Bland and Altman analyses.

Our findings show that mean %BF measurements by BIA compared to reference methods for adults and children were not significantly different, suggesting the Stayhealthy BIA device is a reliable alternative to using DXA or HW. When using Bland and Altman analyses, the mean difference bias was not significantly different between methods with limits of agreement similar to findings in previous studies. A simple regression analysis for Bland and Altman plots also demonstrated no significant bias by BIA to over- or underestimate %BF for a range of body compositions in adults and children. Bland and Altman analyses revealed good agreement between reference methods and BIA for the present study. Further studies are required to determine the validity of this device when used to assess body composition in individuals where %BF may be extremely low or high, such as very lean elite marathon runners or morbidly obese persons.

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References

[1] Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999-2004. JAMA 2006;295:1549-55.

[2] Campanozzi A, Dabbas M, Ruiz JC, Ricour C, Goulet O. Evaluation of lean body mass in obese children. Eur J Pediatr 2008;167:533-40.

[3] Bolanowski M, Nilsson BE. Assessment of human body composition using dual-energy x-ray absorptiometry and bioelectrical impedance analysis. Med Sci Monit 2001;7:1029-33.

[4] Fors H, Gelander L, Bjarnason R, Albertsson-Wikland K, Bosaeus I. Body composition, as assessed by bioelectrical impedance spectroscopy and dual-energy x-ray absorptiometry, in a healthy paediatric population. Acta Paediatr 2002;91:755-60.

[5] Claros G, Hull HR, Fields DA. Comparison of air displacement plethysmography to hydrostatic weighing for estimating total body density in children. BMC Pediatr 2005;5:37.

[6] Oppliger RA, Nielsen DH, Vance CG. Wrestlers' minimal weight: anthropometry, bioimpedance, and hydrostatic weighing compared. Med Sci Sports Exerc 1991;23:247-53.

[7] Brennan DD, Whelan PF, Robinson K, Ghita O, O'Brien JM, Sadleir R, et al. Rapid automated measurement of body fat distribution from whole-body MRI. AJR Am J Roentgenol 2005;185:418-23.

[8] Hosking J, Metcalf BS, Jeffery AN, Voss LD, Wilkin TJ. Validation of foot-to-foot bioelectrical impedance analysis with dual-energy x-ray absorptiometry in the assessment of body composition in young children: the EarlyBird cohort. Br J Nutr 2006;96:1163-8.

[9] Hoffer EC, Meador CK, Simpson DC. Correlation of whole-body impedance with total body water volume. J Appl Physiol 1969;27: 531-4.

[10] Wu YT, Nielsen DH, Cassady SL, Cook JS, Janz KF, Hansen JR. Cross-validation of bioelectrical impedance analysis of body composition in children and adolescents. Phys Ther 1993;73:320-8.

[11] van den Ham EC, Kooman JP, Christiaans MH, Nieman FH, Van Kreel BK, Heidendal GA, et al. Body composition in renal transplant patients: bioimpedance analysis compared to isotope dilution, dual energy x-ray absorptiometry, and anthropometry. J Am Soc Nephrol 1999;10:1067-79.

[12] Sun G, French CR, Martin GR, Younghusband B, Green RC, Xie YG, et al. 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;81:74-8.

[13] Williams CA, Bale P. Bias and limits of agreement between hydrodensitometry, bioelectrical impedance and skinfold calipers measures of percentage body fat. Eur J Appl Physiol 1998;77: 271-7.

[14] Desport JC, Preux PM, Bouteloup-Demange C, Clavelou P, Beaufrere B, Bonnet C, et al. Validation of bioelectrical impedance analysis in patients with amyotrophic lateral sclerosis. Am J Clin Nutr 2003;77: 1179-85.

[15] Brozek J, Grande F, Anderson JT, Keys A. Densitometric analysis of body composition: revision of some quantitative assumptions. Ann N Y Acad Sci 1963;110:113-40.

[16] Harsha DW, Bray GA. Body composition and childhood obesity. Endocrinol Metab Clin North Am 1996;25:871-85.

[17] Pietrobelli A, Tato L. Body composition measurements: from the past to the future. Acta Paediatr Suppl 2005;94:8-13.

[18] Cook CD, Hamann JF. Relation of lung volumes to height in healthy persons between the ages of 5 and 38 years. J Pediatr 1961;59:710-4.

[19] Lohman TG. Applicability of body composition techniques and constants for children and youths. Exerc Sport Sci Rev 1986;14: 325-57.

[20] Diessel E, Fuerst T, Njeh CF, Tylavsky F, Cauley J, Dockrell M, et al. Evaluation of a new body composition phantom for quality control and cross-calibration of DXA devices. J Appl Physiol 2000; 89:599-605.

[21] Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307-10.
[22] Houtkooper LB, Lohman TG, Going SB, Hall MC. Validity of bioelectric impedance for body composition assessment in children. J Appl Physiol 1989;66:814-21.
[23] Gudivaka R, Schoeller DA, Kushner RF, Bolt MJ. Single- and multifrequency models for bioelectrical impedance analysis of body water compartments. J Appl Physiol 1999;87:1087-96.
[24] Gutin B, Litaker M, Islam S, Manos T, Smith C, Treiber F. Body-composition measurement in 9-11-y-old children by dual-energy X-ray absorptiometry, skinfold-thickness measurements, and bioimpedance analysis. Am J Clin Nutr 1996;63:287-92.
[25] Lukaski HC, Siders WA. Validity and accuracy of regional bioelectrical impedance devices to determine whole-body fatness. Nutrition 2003;19:851-7.
[26] Eisenkolbl J, Kartasurya M, Widhalm K. Underestimation of percentage fat mass measured by bioelectrical impedance analysis compared to dual energy x-ray absorptiometry method in obese children. Eur J Clin Nutr 2001;55:423-9.
[27] Okasora K, Takaya R, Tokuda M, Fukunaga Y, Oguni T, Tanaka H, et al. Comparison of bioelectrical impedance analysis and dual energy x-ray absorptiometry for assessment of body composition in children. Pediatr Int 1999;41:121-5.
[28] Lazzer S, Boirie Y, Meyer M, Vermorel M. Evaluation of two foot-to-foot bioelectrical impedance analysers to assess body composition in overweight and obese adolescents. Br J Nutr 2003;90: 987-92.
[29] Ogle GD, Allen JR, Humphries IR, Lu PW, Briody JN, Morley K, et al. Body-composition assessment by dual-energy x-ray absorptiometry in subjects aged 4-26 y. Am J Clin Nutr 1995;61:746-53.
[30] Prior BM, Cureton KJ, Modlesky CM, Evans EM, Sloniger MA, Saunders M, et al. In vivo validation of whole body composition estimates from dual-energy x-ray absorptiometry. J Appl Physiol 1997; 83:623-30.
[31] Svendsen OL, Haarbo J, Hassager C, Christiansen C. Accuracy of measurements of body composition by dual-energy x-ray absorptiometry in vivo. Am J Clin Nutr 1993;57:605-8.
[32] Boileau RA, Lohman TG, Slaughter MH. Exercise and body composition in children and youth. Scand J Sport Sci 1985;7:17-27.
[33] Morrow Jr JR, Jackson AS, Bradley PW, Hartung GH. Accuracy of measured and predicted residual lung volume on body density measurement. Med Sci Sports Exerc 1986;18:647-52.