Evaluation of Hand-to-Hand Bioelectrical Impedance Analysis for Estimating Percent Body Fat in Young Adults

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ABSTRACT

Int J Exerc Sci 2(4): 254-263, 2009. Purposes were to (a) to examine the validity and precision of a hand-to-hand bioelectrical impedance analyzer (HBIA) and (b) to determine the effect of an acute sub-maximal aerobic exercise bout on HBIA percent body fat (%BF) measures. Forty-one young adults (21 women; 20 men) visited the laboratory for body composition assessment on two separate occasions. During the control session, %BF was assessed by HBIA twice, before and immediately after 30 min of rest, and once by air-displacement plethysmography (ADP), using the BOD POD, which was considered the criterion method for comparison. During the exercise session, HBIA %BF measurements were determined prior-to and immediately after 30 minutes of moderate-intensity treadmill exercise. HBIA significantly underestimated %BF in the total sample (mean difference (MD) = 1.4 ± 4.3%) and, when examined by gender, in the women (MD = 2.4 ± 4.1%). The standard errors of estimate (range 4.1-4.3%) also exceeded the recommended range for accuracy (<3.5%). Following exercise, there was minimal, but statistically significant reduction in HBIA-measured %BF pre- to post-exercise for the total sample (19.6 ± 6.0 vs. 19.3 ± 6.0%; $p = 0.011$). HBIA underestimated %BF when compared to ADP and the individual prediction error exceeded current recommendations when assessing young adults. In addition, performing sub-maximal aerobic exercise prior to the assessment decreased the %BF estimate. When one factors the exercise-induced alterations with the currently observed tendency for HBIA to underestimate %BF, it is apparent that exercise may further reduce the accuracy of this method.

KEY WORDS: Body composition, air displacement plethysmography, BOD POD, HBIA

INTRODUCTION

The prevalence of obesity, which doubled among adults between 1980 and 2004, has become a primary health concern in the United States (18). In fact, more than one-third of adults were classified as obese according to body mass index in 2005-2006 (19). These data have generated an increased interest in health management and to the development of programs designed to help individuals lose weight (18). In order to track the effectiveness of such programs, health care professionals are in need of accurate methods of assessing body composition. Laboratory methods such as hydrostatic weighing (HW), air displacement plethysmography

(ADP) and dual-energy x-ray absorptiometry (DEXA) are considered to be the most accurate, but they are costly, time-consuming, require a considerable level of expertise to perform, and are therefore impractical for most community-based health/wellness facilities. A less expensive technology that produces accurate body composition estimates is needed in order to monitor the effectiveness of interventions designed to reduce an individuals' percent body fat (%BF).

Growing in popularity are bioelectrical impedance analysis (BIA) analyzers which are fast, portable and require no technician skill to operate making them an attractive alternative to traditional field methods of assessment such as skinfolds. During the BIA assessment, a small electrical current is passed through the subject's body and resistance to the current flow (i.e. impedance) is measured by the analyzer. Because adipose tissue is a poor electrical conductor due to its small water content, larger impedance values are observed in individuals with higher levels of body fat (13). Currently several different types of BIA analyzers are available including the segmental (SBIA), leg-to-leg (LBIA) and hand-to-hand (HBIA) devices; each named after the electrical pathway used to measure impedance. Although the utilization of these analyzers for the determination of %BF in clinical and health-related facilities appears to be increasing, there are few cross-validation studies supporting their accuracy in the literature. In general, the typical prediction error of the traditional BIA method has been reported to range from 3.0-4.0 %BF (13). However, little data exists on the relatively-new and inexpensive HBIA analyzers.

When using BIA technology, it is recommended that subjects adhere to several pretest guidelines in order to increase the accuracy of the assessment. One such recommendation is "no exercise within 12 hours of the test" (13). This recommendation stems from previous data that demonstrated that the increased blood flow to skeletal muscle and skin, and water loss due to sweating during aerobic exercise can alter the BIA measurements (14). Current evidence demonstrates that aerobic exercise performed prior to LBIA assessment has a significant, but minimal effect on mean impedance (range = 11 to 26 Ω) and %BF (range = 0.4 to 1.8 %BF) in children (1,2,11) and adults (9). Whether exercise prior to HBIA assessment influences %BF estimates in adults is less clear. Demura et al. (7) reported small but statistically significant mean reductions in HBIA-measured %BF (mean difference = 0.9%) following sixty minutes of cycle ergometry in healthy young Japanese men; however, only the muscles of the lower body were activated in that investigation. The effect that treadmill exercise, which incorporates both upper and lower body musculature, has on HBIA measurements in young adults is unknown.

The purposes of this investigation were: (a) to examine the validity and precision of the HBIA analyzer, and (b) to determine the effect of an acute sub-maximal aerobic exercise bout on HBIA %BF measures.

METHOD

Participants

Forty-one healthy adults (20 men; 21 women) between 18 and 32 years of age volunteered to participate in this study. The Institutional Review Board at Lock

Table 1. Subject Characteristics.

	Men (n = 20)		Women (n = 21)	
	mean ± SD	**range**	**mean ± SD**	**range**
Age (yrs)	21 ± 1.6	19 - 26	21.1 ± 2.9	18 - 32
Height (cm)	178.4 ± 5.8	170 - 189	164.6 ± 6.0	157 - 177
Body mass (kg)	87.3 ± 14.7	72.5 – 128.2	62.8 ± 7.8	50.5 – 84.8
BMI (kg/m^2)	27.4 ± 4.2	21.3 - 37.9	23.2 ± 2.4	19.4 – 28.0
Body Fat (%)*	17.2 ± 7.5	3.8 – 34.5	25.4 ± 6.2	15.4 – 37.5

*determined by air-displacement plethysmography

Haven University approved the study protocol and methods. All subjects signed an informed consent form and completed a physical activity medical questionnaire (PAR-Q) prior to participation.

Protocol

Each subject was asked to report to the exercise physiology laboratory for testing on two separate days; an experimental and a control trial, the order of which was determined using a counter-balanced assignment. Prior to testing, all subjects were instructed to adhere to the following traditional BIA guidelines (12): (a) no food or drink within 4 h of the test, (b) no exercise within 12 h of the test, (c) no alcohol consumption within 48 h of the test, (d) empty bladder within 30 min of the test, and (e) no diuretic medications within 7 d of the test. No testing was conducted without written confirmation of these guidelines prior to each trial.

Body composition was assessed using a common HBIA analyzer (Model HBF-306C; Omron Healthcare, Inc., Bannockburn, IL). HBIA measures of %BF were obtained at the beginning and end of each testing session. Prior to the assessment, height was measured using a wall-mounted stadiometer (Tanita Corporation of America, Inc., Arlington Heights, IL) and body mass was measured using a body composition analyzer (Model TBF-300A, Tanita Corporation of America, Inc., Arlington Heights, IL). Gender, age, height and body mass were entered into the HBIA analyzer using the manufacturer's recommended "normal" mode. During each testing session, body mass was determined and that same value was reentered into the HBIA analyzer during the second body composition assessment that day. The subject wearing a t-shirt, shorts and athletic shoes stood erect with the arms extended straight out at a 90° angle from their body and with the hands position properly on the electrodes of the HBIA analyzer. A low-level electrical current (50 kHz and 500 μ A) was passed through the upper body with impedance between the right and left arms recorded by the analyzer. The %BF was then automatically calculated using the analyzer's preprogrammed prediction equations.

During the experimental trial, %BF was assessed using HBIA before and immediately after subjects performed 30 minutes of sub-maximal exercise on a motorized treadmill (TrackMaster TMX425C, Full Vision, Inc., Newton, Kansas). During a 5 minute warm-up, the subject selected a speed and grade which elevated their heart rate between 60-75% of their age-predicted maximum heart rate (220-age). After the speed and intensity was selected, the subject walked or jogged at the constant workload for 20 minutes followed by a 5 minute cool down period. Each subject wore a heart rate monitor (Polar Electro, Inc., Woodbury, NY) to assess intensity during the exercise bout. When necessary, subjects were instructed to adjust the workload intensity in order to maintain heart rate within their targeted range.

In order to explore for normal variability in HBIA-determined body composition measures over time, %BF was assessed by HBIA before and 30-minutes after sitting quietly during the control trial. In addition, at the beginning of the control session, %BF was assessed once using ADP. The ADP %BF estimate was used as the reference value for comparison. The temperature in the laboratory was maintained at 22° C for all assessments.

Air Displacement Plethysmography

The BOD POD body composition system (Life Measurement, Inc., Concord, CA) measures body volume by ADP, as previously described (6,10,16). Before each test, the BOD POD was calibrated according to the manufacturer's instructions using a cylinder of known volume (50.572 L). The subject, wearing a tight-fitting swimsuit and Lycra cap, then entered the chamber. The door was closed and the subjected breathed normally while two measurements of body volume were conducted, each lasting approximately 45 seconds. If these two body volumes differed by more than 150 mL, a third body volume measurement was performed. Thoracic gas volume was predicted using pre-programmed manufacturer equations (17). Upon completion of the test, the computer automatically calculated %BF from the determined body density using the equation by Brozek et al. (5).

Statistical Analyses

Data were analyzed using SPSS 16.0 for Windows (SPSS, Inc., Chicago, IL). All values are expressed as mean ± SD. Paired-samples t-tests were used to compare %BF by HBIA and ADP, and to explore for changes in HBIA-measured %BF pre- to post-exercise. A simple linear regression analysis, using %BF measured by ADP as the dependent variable and %BF measured by HBIA as the independent variable, was performed to determine correlation coefficients (r) and the standard error of estimate (SEE), where SEE = $S_y \sqrt{(1-r^2)}$. The pure error (PE) was calculated as described by Guo and Chumlea (12), where PE = $\sqrt{\Sigma(Y' - Y)^2 \div N}$, when Y' = the predicted value, and Y = the criterion value from ADP. Bland-Altman (4) plots were used to assess individual differences in %BF

Table 2. Comparison of percentage body fat (%BF) between hand-to-hand bioelectrical impedance (HBIA) with air displacement plethysmography (ADP).

	%BF	R	MD (%)	SEE (%)	Subjective SEE Rating‡	PE (%)
All (n = 41)						
ADP	21.4 ± 8.0					
HBIA	20.0 ± 6.0[a]	0.85*	1.4 ± 4.3	4.2	Fairly Good	4.4
Women (n = 21)						
ADP	25.4 ± 6.2					
HBIA	23.0 ± 4.5[a]	0.75*	2.4 ± 4.1	4.3	Fair	4.2
Men (n = 20)						
ADP	17.2 ± 7.5					
HBIA	16.8 ± 5.7	0.82*	0.3 ± 4.3	4.1	Fairly Good	4.7

All values are mean ± SD; * Significant ($p < 0.001$); [a] Significantly different ($p < 0.05$) from ADP; ‡Taken from Lohman (14); MD = mean difference (ADP – HBIA); SEE = standard error or estimate; PE = pure (total) error.

measured by ADP vs. HBIA, and to determine whether body mass difference influenced the magnitude of change for %BF pre- to post-exercise. Due to the apparent body composition differences between men and women, data were examined for the total sample and separately by gender. Statistical significance was established a priori at $p < 0.05$ for all analyses.

RESULTS

The characteristics of the subjects are presented in Table 1. The sample consisted of 41 college-aged young adults (20 men; 21 women). Body mass index (BMI) ranged from 21.3 to 37.9 kg/m² in the men and 19.4 to 28.0 kg/m² in the women. The average duration between the two testing sessions was 3.5 ± 2.3 days.

Validation of HBIA

Table 2 presents the %BF data (means ± SD) and the relation between HBIA and ADP for the entire sample and by gender. When compared to ADP, the HBIA analyzer underestimated mean %BF for the total sample (MD = 1.4 ± 4.3%) despite a strong correlation (r = 0.85) and “fairly good” SEE rating of 4.2%. When examined relative to gender, HBIA significantly underestimated mean %BF in the women (25.4 ± 6.2 *vs*. 23.0 ± 4.5%) despite a significant correlation (r = 0.75) and acceptable SEE rating (4.3%). In the men, there was no significant difference in mean %BF values between ADP and

HBIA, and a relatively strong level of agreement was determined between methods (r = 0.82, p < 0.0001; SEE = 4.1%). Figure 1 illustrates the simple linear regression analysis performed on the total sample with ADP as the dependent variable (y-axis) and HBIA as the independent variable (x-axis).

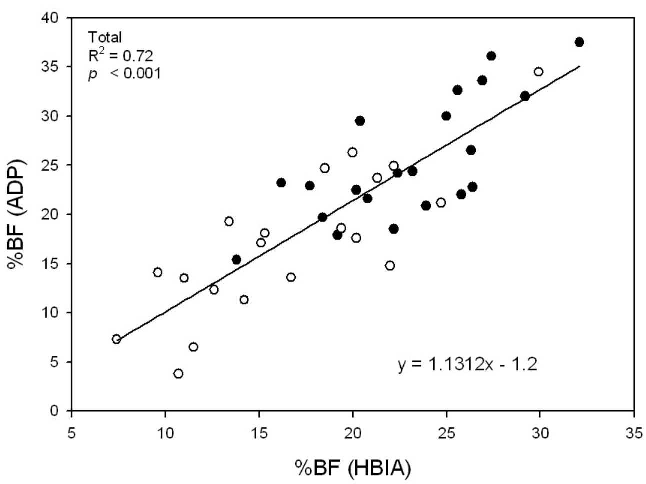

Figure 1. Relation between %BF determined by ADP and HBIA in the women (●) and men (○). The solid line represents the line of best fit as determined by simple linear regression.

A Bland-Altman (4) plot of the difference between the %BF measured by ADP and HBIA versus the %BF from ADP, the criterion method of assessment, was used to explore for a systematic bias (Figure 2). The solid line represents no difference between the %BF determined by HBIA and ADP and the dashed lines represent the minimal acceptable standard for estimating %BF (± 3.5%). As demonstrated in Figure 2, a significant positive correlation was found for the total sample (r = 0.67, p < 0.001) indicating that HBIA tended to overestimate %BF in lean subjects and underestimate %BF in subjects with higher levels of %BF. This relation was also observed when the sample was examined by gender; men (r = 0.66, p = 0.002) and women (r = 0.68, p = 0.001), respectively. In addition, in 40% of the men and 52% of the women the %BF determined by HBIA was outside the minimal acceptable standard for estimating %BF (± 3.5%).

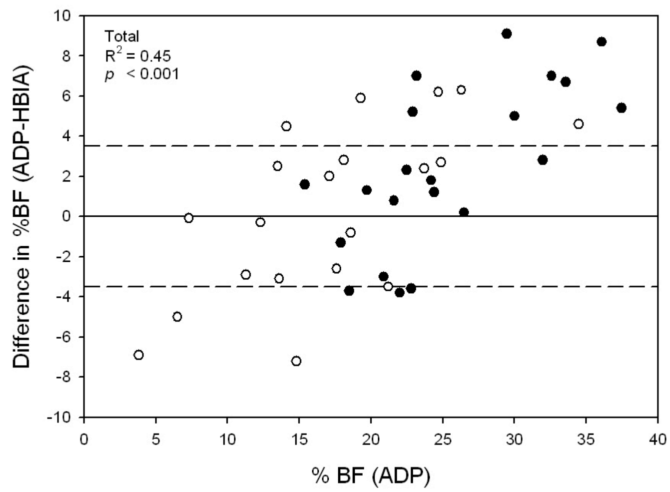

Figure 2. Scatter plot exploring individual differences for %BF estimated by ADP and HBIA in women (●) and men (○). The difference between the 2 methods is plotted against the %BF by ADP, the criterion method. The solid line represents no difference between the %BF determined by HBIA and ADP and the dashed lines represent the minimal acceptable standard for estimating %BF (± 3.5%).

Effect of Exercise on HBIA Measures

For the total sample, there was a significant reduction in HBIA-measured %BF pre- to post-exercise (19.6 ± 6.0 *vs.* 19.3 ± 6.0%; p = 0.011). No significant HBIA %BF differences were observed pre- to post-exercise when the data was examined by gender (men = 16.4 ± 5.7 *vs.* 16.1 ± 5.8%, p = 0.075; women = 22.7 ± 4.6 *vs.* 22.4 ± 4.5%, p = 0.077). A Bland-Altman (4) plot of the difference in HBIA %BF pre-exercise versus post-exercise was plotted against body mass for the entire sample (Figure 3). As demonstrated in Figure 3, the magnitude of change was unaffected by body mass for the entire sample (r = 0.09, p = 0.558). Similarly, no systematic bias was apparent when the data was examined by gender; men (r = 0.11, p = 0.647) and women (r = 0.21, p = 0.356).

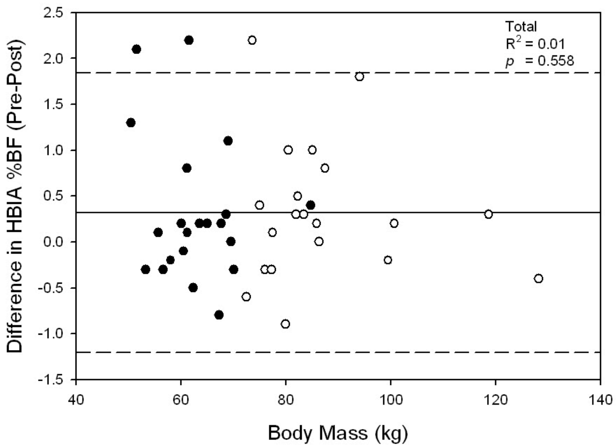

Figure 3. Scatter plot exploring individual differences in HBIA-measured %BF following treadmill exercise. The difference between pre- and post-exercise %BF is plotted against body mass for the women (●) and men (○). Values greater than zero indicate decrease in %BF following exercise. The mean difference is represented by the solid line and the dashed lines represent ± 2 SD from the mean.

DISCUSSION

A primary finding of this investigation was that HBIA significantly underestimated mean %BF (mean difference = 1.4%) when compared to ADP in 41 college-aged adults. When the data were examined by gender, this pattern was observed in the women (mean difference = 2.4%) but not in the men (mean difference = 0.3%). Very few validation studies have been published on HBIA making direct comparisons difficult. Previously, Demura et al. (7) compared %BF measurements determined by HBIA to HW in thirty Japanese young adults (15 men, 15 women). In that study, mean %BF values determined by HBIA (19.8 ± 6.2%) were reported to be not statistically different than those by HW (18.2 ± 6.5%; r = 0.83, p <0.01).

In addition to group mean comparisons, moderately high validity coefficients (r > 0.80) and acceptable (i.e., good to excellent) SEE ratings are recommended when considering good predictive accuracy (13,15). Despite similar mean %BF values and a relatively high correlation coefficient (r = 0.82) between methods in the men, the SEE and PE values were higher (range = 4.1-4.3%) than the recommend guideline (<3.5%). More specifically, in 40% of the men assessed, %BF determined by HBIA exceeded the minimal standard for accuracy of ± 3.5%. The SEE values in the current study do compare favorably to those of Deurenberg and Deurenberg-Yap (8) who reported SEE of 4.5% when %BF determined by HBIA was compared to a four-compartment model equation, which separates body composition into four categories: fat, water, bone mineral, and protein. Collectively, the present data indicate that both the group predictive accuracy and individual prediction error of HBIA is greater than desired for an accurate measurement of %BF in young adults.

Avoiding exercise prior to the assessment is recommended in order to avoid alterations in hydration state that could potentially impact HBIA body composition measures (13). However, if necessary, stringent pretest guidelines significantly reduce the practicality of utilizing the HBIA analyzer for body composition assessment in the field. In the present investigation, 30 minutes of sub-maximal exercise on the treadmill resulted in a minimal, but statistically significant, reduction in HBIA %BF (mean difference = 0.3%) for the total sample. The same %BF magnitude of change was also observed when the sample was examined by gender; however, it was not determined to be statistically significant. Previously, Demura et al. (7) also reported that 60 minutes of cycle exercise caused a significant reduction in HBIA %BF estimates (mean difference = 0.9%). The longer exercise duration (approximately 30 min) implemented by Demura et al. (7) most likely resulted in the larger %BF reduction in that study.

Although data examining HBIA is extremely limited, several studies have examined the effect of exercise on the LBIA and SBIA analyzers. Aerobic exercise performed prior to LBIA and SBIA assessment has been shown to reduce mean %BF values in both adults and children (1-3,9,11). Dixon et al. (9) examined the effect of maximal and sub-maximal treadmill exercise on %BF values determined by LBIA and SBIA in 63 young adults (age = 20.4 ± 1.5 yr). When using the LBIA analyzer, significant %BF reductions were observed after the maximal (women = 1.8%; men = 1.4%) and sub-maximal (women = 1.5%; men = 1.2%) exercise bouts. Similarly, significant %BF reductions were also observed following maximal (women = 1.0%; men = 1.0%) and sub-maximal (women = 1.2%; men = 1.7%) exercise when the SBIA analyzer was used for the assessment. Smaller, non-significant mean %BF reductions (~0.3%) were observed in the men and women when using the HBIA analyzer in this study. The mode (treadmill), intensity (60-75% of age predicted maximal heart rate) and duration (40 min) of the sub-maximal exercise bout implemented by Dixon et al. (9) was similar to that used presently.

Kushner et al. (14) has suggested that some of the mechanisms responsible for the impedance reduction observed following exercise include increased blood flow and warming of skeletal muscle tissue, and increased cutaneous blood flow, skin temperature, and sweating. During treadmill exercise, the greatest fluid disruption would be expected to occur in the active skeletal muscle of the lower extremity. Unlike LBIA and SBIA which both incorporate the lower body into the electrical pathway, HBIA does not. By excluding the active tissue of the lower body in the assessment, aerobic exercise performed on the treadmill had little effect on HBIA %BF measurements in this study. It may be anticipated that upper body exercise, such as arm ergometry, would have the most dramatic effect on HBIA measures; however, this requires further examination to clarify.

A potential limitation of the present investigation was that %BF determined by ADP was used as the criterion for comparison. Despite recognition as a reference method (13), questions regarding the accuracy of ADP still exist. Most of the ADP validation studies have compared %BF estimates from ADP to those determined using HW, DEXA, or both. Fields et al. (10), after reviewing 15 studies performed on adults, reported that the differences among study means ranged from -4.0% to 1.9%BF (ADP – HW) and -3.0% to 1.7%BF (ADP – DEXA) with SEEs ranging from 1.8% to 3.7%BF. The average mean difference in %BF between ADP and HW or DEXA was calculated to be less than 1.0%BF. The authors concluded that on average the methods agreed well, but there were large variations among the study means (10). Similarly, Heyward and

Wagner (13) concluded that although the mean differences may be slightly larger for ADP, the predictive accuracy and validity of the ADP and HW methods appear to be similar.

Additional limitations include that the subject sample consisted of primarily healthy, recreationally-active adults. The accuracy of HBIA-determined %BF estimates and the effect that treadmill exercise has on HBIA body composition measures in other populations (e.g. older adults, sedentary individuals, etc.) cannot be determined from this study. Secondly, the post-exercise assessments were performed immediately following the exercise bout. Although the greatest change in HBIA body composition measurements may be expected to occur immediately post-exercise (14), our findings cannot be generalized to exercise that precedes the assessment by a longer duration than that examined currently. Lastly, our results are specific to moderate-intensity treadmill exercise. The examination of whether similar responses would occur following exercise incorporating alternative exercise modes or intensities are currently unknown and worthy of exploration.

In summary, the development of the HBIA analyzer has provided technicians with a fast, easy-to-use and relatively inexpensive method of estimating %BF. We found that HBIA underestimated %BF when compared to a laboratory method of assessment and the individual prediction error exceeded current recommendations when assessing young adults. In addition, performing sub-maximal aerobic exercise prior to the assessment decreased the %BF estimate in the total sample. Although the %BF reductions were relatively small in magnitude (~0.3%), when one factors these exercise-induced alterations with the currently observed tendency for HBIA to underestimate %BF in adults, it is apparent that exercise may further reduce the %BF estimate and accuracy of this method. As such, when using HBIA to assess %BF, we recommend following the pretest exercise guideline to avoid further reductions in the %BF measurement.

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