Use of the leg-to-leg bioelectrical impedance method in assessing body-composition change in obese women[1–3]

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ABSTRACT

Background: There is little information on whether bioelectrical impedance analysis (BIA) accurately predicts changes in body composition associated with energy restriction, exercise, or both.

Objective: We had 2 objectives: to determine the validity of the leg-to-leg BIA system in *1*) estimating body composition in obese and nonobese women, with a cross-sectional design, and *2*) assessing changes in body composition in obese women in response to 12 wk of energy restriction, exercise training, or both.

Design: Subjects were 98 moderately obese women (43.2 ± 0.6% body fat, 45.0 ± 1.1 y of age) and 27 nonobese control subjects (24.0 ± 1.5% body fat, 43.5 ± 2.5 y of age). Obese subjects were randomly divided into 1 of 4 groups, with fat-free mass, fat mass, and percentage body fat estimated with BIA and underwater weighing before and after 12 wk of intervention. The 4 groups were diet only (4.19–5.44 MJ/d), exercise only (five, 45-min sessions/wk at 78.5 ± 0.5% of maximum heart rate), both exercise and diet, and control (no diet or exercise).

Results: No significant difference was found between underwater weighing and BIA in estimating the fat-free mass of the obese and nonobese women (all subjects combined, $r = 0.78$, $P < 0.001$, SEE = 3.7 kg) or in estimating decreases in fat mass during 12 wk of energy restriction, exercise, or both in obese subjects ($F_{[3, 85]} = 1.45$, $P = 0.233$).

Conclusions: The leg-to-leg BIA system accurately assessed fat-free mass in obese and nonobese women, and changes in fat mass with diet alone or when combined with exercise. *Am J Clin Nutr* 1999;69:603–607.

KEY WORDS Body composition, exercise, energy restriction, body fat, underwater weighing, bioelectrical impedance, obesity, fat-free mass, percentage body fat, women

INTRODUCTION

Bioelectrical impedance analysis (BIA) has been widely used as a method of assessing body composition. BIA is relatively simple, quick, portable, and noninvasive and is currently used in diverse settings, including private clinician's offices, wellness centers, and hospitals (1). Recent attention has been given to the leg-to-leg BIA system, which has several operational advantages when compared with the conventional arm-to-leg approach (2).

Nuñez et al (2) evaluated a single-frequency 50-kHz leg-to-leg BIA system combined with a digital scale that uses stainless steel pressure-contact foot pad electrodes. This leg-to-leg BIA system is functionally different from other BIA systems, which require the use of arm and leg electrodes and separate measurement of body weight. Data from Nuñez et al (2) indicated that pressure-contact electrodes provided impedance measurements and body-composition estimates that were comparable with those obtained with use of conventional gel electrodes, and offered the advantage of increased speed and ease of measurement. Data indicating the validity of the new leg-to-leg BIA system in estimating the body composition of obese females before and after weight loss have not yet been reported.

There is much debate as to whether BIA accurately predicts changes in body composition associated with energy restriction, exercise, or both (1, 3–5). The conventional tetrapolar gel electrode, arm-to-leg BIA system has been reported to accurately assess body-composition changes over time in some (6–10) but not all studies (11–15). The use of inappropriate equations can lead to systematic prediction errors in estimating body composition in obese populations and may explain in part these conflicting results (3, 14, 15). Several investigators have reported that the arm-to-leg system overestimates the fat-free mass of obese individuals, and thus confounds estimates of change over time (14–16). In most studies evaluating the use of BIA in monitoring changes in the body composition of obese subjects, subject numbers were small, very-low-energy diets were used, and changes in fat-free mass were below the SEE of the BIA method (2–15). In no studies were subjects randomly assigned to moderate energy restriction, exercise, or both as is typical in community weight-management programs. This study had 2 objectives: to determine the validity of the leg-to-leg BIA system in *1*) estimating body composition in obese and nonobese women by using a cross-sectional design and *2*) assessing changes in body composition in obese women in response to 12 wk of moderate energy restriction, exercise training, or both.

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SUBJECTS AND METHODS

Subjects and research design

Obese women (*n* = 98) were recruited from the surrounding community through advertisements according to these selection criteria (17): *1*) they were between the ages of 25 and 75 y; *2*) they were in good health, with no known diseases, including diabetes, cancer, or heart disease; *3*) they had a body mass index (BMI; kg/m^2) between 25 and 65; *4*) they were not currently following a weight-loss diet or exercise program (<3 moderate-to-vigorous aerobic sessions >20 min in duration/wk; *5*) they were not experiencing chronic pain, marked sleep disturbance, serious allergies, or salient emotional or mood problems, and no had recent history of systemic infection, bone fracture, or surgery; and *6*) they were not using cigarettes or abusing alcohol. Before being included in the study, subjects had to agree to be randomly assigned to any 1 of 4 groups (control, exercise, diet, diet + exercise) and to not participate in any other formal exercise or weight-loss program outside of that provided during the study. Informed consent was obtained from each subject and the experimental procedures were approved by the university's institutional review board. Twenty-seven nonobese women who were physically active (>3 exercise sessions/wk, >20 min/session), had a BMI <25, and who met all other subject selection criteria were recruited for baseline comparisons. Measurements of cardiorespiratory fitness and body composition were conducted in all obese subjects before and after a 12-wk exercise, energy restriction, or combined intervention period (4.19–5.44 MJ/d, or 1200–1300 kcal/d).

Body composition and cardiorespiratory fitness measurements

One week before the scheduled study, and the last week of the 12-wk study, the body composition and cardiorespiratory fitness of all obese subjects were assessed. Before testing, subjects were required to adhere to these BIA testing guidelines (3): *1*) to not eat or drink within 4 h of the test, *2*) to maintain normal body hydration, *3*) to not consume caffeine or alcohol within 12 h of the test, *4*) to not exercise within 6 h of the test, 5) to not take diuretics within 7 d of the test, and *6*) to urinate within 30 min of the test. Body mass and height were determined by using a physician's balance-beam scale and stadiometer, respectively. Body composition was assessed by using underwater weighing (18–20) and the leg-to-leg BIA system (2).

During underwater weighing, the subject was asked to expel as much air as possible from her lungs during complete submersion. After several trials, the highest underwater weight for each that could be repeated was recorded, with body density determined by using the equation of Goldman and Buskirk (18, 19). Residual volume was measured by the nitrogen washout technique using the Vmax 229-LV metabolic cart from SensorMedics Corporation (Yorba Linda, CA). Fat-free mass and percentage body fat were calculated from body mass and body density by using the equation of Brozek et al (20).

BIA measurements were taken by using the Tanita Body Fat Analyzer (model TBF 105; Tanita Corporation of America, Inc, Arlington Heights, IL). Subjects were measured while standing erect, in bare feet, on the analyzer's footpads and wearing either a swimsuit or undergarments. The system's 4 electrodes are in the form of stainless steel foot pads mounted on the top surface of a platform scale. Each foot pad is divided in half so that the anterior and posterior portions form 2 separate electrodes. Current is applied via the anterior portion of the foot pad electrodes and the voltage drop across the posterior (heel) electrodes is then measured (2). Leg-to-leg impedance and body mass are simultaneously measured as the subject's bare feet make pressure contact with the electrodes and digital scale. Fat-free mass and body density were calculated by using the prediction equations supplied by the manufacturer (which use weight, age, and an impedance index, $height^2/Z$); percentage body fat was estimated by using the equation of Brozek et al (20).

Cardiorespiratory fitness was evaluated by measuring maximal oxygen uptake ($\dot{V}O_2max$) using the Bruce graded maximal treadmill protocol (21). $\dot{V}O_2max$ and ventilation were measured by using the MedGraphics CPX Express metabolic system (MedGraphics Corporation, St Paul).

Exercise training

Subjects in the 2 exercise groups were required to walk 5 times/wk, for 45 min/session, at 60–80% of maximum heart rate, for 12 wk (60 total exercise sessions). Supervised sessions were held 4 d/wk at an indoor track, with duration, heart rate, and distance walked measured and recorded. Subjects walked one session per week without supervision. Duration and intensity of exercise was gradually increased over a 3-wk period from 25–30 min/session at 60–65% of maximum heart rate during the first week to 45 min at 70–80% of maximum heart rate from weeks 4 through 12. Exercise heart rates were measured with chest heart rate monitors (Polar CIC Inc, Port Washington, NY). Subjects in the 2 nonwalking groups (control and diet only) reported to the exercise facility 4 d/wk for 45-min sessions of stretching and mild range-of-motion calisthenic exercises. The intent was to keep heart rates <100 beats/min while exposing the control and diet-only groups to the same staff attention received by the exercise and diet + exercise groups.

Weight-loss diet

Before the study, all subjects kept a 3-d food record after receiving instructions from the project dietitians. Obese subjects were prescribed a 4.19–5.44-MJ/d (1200–1300 kcal/d) diet for 12 wk. The dietary menu was based on dietary exchanges (2 fruit, 3 vegetable, 2 milk, 6 bread, 2 fat, 5 lean protein, and 0.42 MJ or 100 kcal optional foods) (22). Subjects were instructed by the project dietitians on portion sizes, food exchanges, and how to record dietary intake with use of a daily exchange checklist. Compliance with the diet was measured by random-day, 24-h dietary recalls every week (11 per subject during the study) (22). Nutrient intake from the 3-d food records and 24-h dietary recalls was assessed by using the computerized dietary analysis system FOOD PROCESSOR PLUS, version 6.0 (ESHA Research, Salem, OR) (22). Subjects in the 2 diet groups also attended a weekly 45-min class during which they received additional instruction on weight loss principles, nutrition, and exercise guidelines.

Statistical analysis

Obese and nonobese groups were compared at baseline by using Student's *t* tests. Paired *t* tests and Pearson *r* values were calculated to test simple correlations between BIA and underwater weighing. The difference in fat-free mass between underwater weighing and BIA was plotted against mean fat-free mass to explore systematic differences, as suggested by Altman and Bland (23). Data from the 12-wk intervention were analyzed by using a 4 (group assignment) × 2 (pre- and poststudy measures)

TABLE 1
Characteristics of obese and nonobese subjects[1]

	Obese (n = 98)	Nonobese (n = 29)
Age (y)	44.9 ± 1.1	43.3 ± 2.2
Height (m)	1.65 ± 0.01	1.66 ± 0.01
Body mass (kg)	90.4 ± 1.5	58.8 ± 1.0[2]
Body mass index (kg/m^2)	33.2 ± 0.6	21.4 ± 0.3[2]
$\dot{V}O_2$max (mL · kg^{-1} · min^{-1})	22.7 ± 0.4	39.9 ±1.4[2]
$\dot{V}O_2$max (mL/min)	1997 ± 30.4	2299 ± 65.0[2]
Hip (cm)	118.1 ± 1.3	94.3 ± 1.0[2]
Waist (cm)	93.9 ± 1.2	68.1 ± 0.9[2]
Waist to hip ratio	0.80 ± 0.01	0.72 ± 0.01[2]
Fat-free mass by BIA (kg)	50.5 ± 0.4	44.3 ± 0.9[2]
Fat-free mass by underwater weighing (kg)	50.3 ± 0.6	44.5 ± 0.9[2]
Percentage body fat by BIA (%)	42.9 ± 0.5	24.3 ± 1.3[2]
Percentage body fat by underwater weighing (%)	43.2 ± 0.6	24.0 ± 1.5[2]

[1] $\bar{x}$ ± SE. $\dot{V}O_2$max, maximal oxygen consumption; BIA, bioelectrical impedance analysis.

[2] Significantly different from obese, $P < 0.001$.

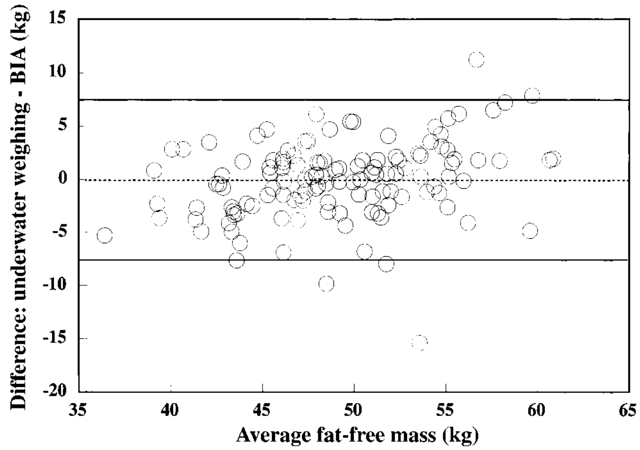

FIGURE 1. Bland-Altman plot of the difference between fat-free mass measured by underwater weighing and bioelectrical impedance analysis (BIA) versus average fat-free mass by the 2 methods (r = 0.30, P = 0.001). The plot shows no systematic difference between the 2 methods (mean difference ± SD: −0.01 ± 3.7 kg). The dotted line represents the mean difference and the 2 solid lines 2 SDs.

repeated-measures analysis of variance. When the group × time interaction P value was ≤0.05, the Duncan's new multiple comparison test was used to compare the changes for the exercise, diet, and diet + exercise groups with the changes in the control group. Statistical significance was set at $P \leq 0.05$ and values are expressed as means ± SEs.

RESULTS

Subjects complying with all aspects of the study design included 98 obese and 27 age-matched nonobese women. Subject characteristics are summarized in **Table 1**. During the 12-wk study, subjects in the calisthenic exercise groups (control and diet only) were required to attend 48 sessions; actual attendance was 84%, with make-up sessions increasing this to 95%. Heart rates during the calisthenic exercise sessions averaged 96 ± 2 beats/min. Subjects in the walking groups (exercise and diet + exercise) were required to attend 48 sessions and exercise once per week on their own time (60 total sessions). Actual attendance at the supervised walking sessions was 83%; unsupervised and make-up sessions resulted in an overall 95% exercise record (just under the goal of 5 walking sessions per week). After the initial 3-wk period of adaptation to the walking program, subjects in the walking groups averaged 45 min/session at a heart rate of 137 ± 2 beats/min (78.5 ± 0.5% of maximum heart rate), and walked an average of 4.33 ± 0.08 km/session. Attendance by the subjects in the energy-restriction groups at the weekly weight-management classes was 83% for the 12-wk study period.

Energy intake during the study as assessed by 11 random, 24-h dietary recalls per subject averaged 5.31 ± 0.16 MJ/d (1270 ± 39 kcal/d) for the diet + exercise and diet groups, with percentage of energy as carbohydrate, fat, and protein measured as 60.3 ± 0.9%, 22.3 ± 0.7%, and 19.1 ± 0.3%, respectively. Before the study, 3-d food records indicated an intake of 8.63 ± 0.32 MJ/d (2065 ± 76 kcal/d) for the subjects randomly assigned to the diet and diet + exercise groups and 7.88 ± 0.35 MJ/d (1884 ± 84 kcal/d) for the subjects randomly assigned to the control and exercise groups.

The cross-sectional assessment of body composition for the obese and nonobese subjects with underwater weighing and BIA before the 12-wk intervention is summarized in Table 1 and **Figure 1**. No significant difference was found between underwater weighing and BIA in estimating the fat-free mass of the obese and nonobese women (Table 1). For all subjects combined, a significant correlation was found between BIA and underwater weighing in estimating fat-free mass (r = 0.78, P < 0.001), with an SEE of 3.7 kg. The correlation between the impedance index (height^2/Z) and fat-free mass from underwater weighing was lower than that reported by Nuñez et al (2) (r = 0.54, P < 0.001, and r = 0.89, P < 0.001, respectively). Figure 1 is the Bland-Altman plot of difference between fat-free mass measured by underwater weighing and BIA versus average fat-free mass by the 2 methods. The plot shows no systematic difference between the 2 methods.

During the 12-wk intervention, body mass loss was significantly greater in the diet (7.8 ± 0.9 kg) and diet + exercise (8.1 ± 0.7 kg) groups, but not in the exercise group (1.0 ± 0.8 kg), than in the control group (0.8 ± 0.8 kg) (**Table 2**). Significant reductions were found for waist, hip, and waist-to-hip ratio measurements for the diet and diet + exercise groups, but not the exercise group, compared with the control group. Loss of fat mass (by underwater weighing) was significantly greater in the diet (6.8 ± 0.6 kg) and diet + exercise (7.2 ± 0.5 kg) groups, but not in the exercise group (1.3 ± 0.3 kg) than in the control group (1.2 ± 0.4 kg). Underwater weighing and BIA were equally effective in assessing the change in percentage body fat and the decrease in fat mass over time in the 4 groups of obese women (**Figure 2**). Fat-free mass changed little in any of the groups.

DISCUSSION

The cross-sectional data from the obese and nonobese subjects showed that the leg-to-leg BIA system accurately assessed fat-free mass relative to underwater weighing, with an acceptable

TABLE 2
Body-composition data for 4 groups of obese women before and after 12 wk of intervention[1]

	Control (n = 22)	Exercise (n = 21)	Diet (n = 26)	Diet + exercise (n = 22)
Body mass (kg)				
Before	90.5 ± 2.4	88.4 ± 2.9	90.6 ± 3.8	89.9 ± 2.5
After[2]	89.7 ± 2.5	87.4 ± 2.8	82.8 ± 3.7[3]	81.8 ± 2.3[3]
Body mass index (kg/m^2)				
Before	32.8 ± 1.0	32.3 ± 1.1	34.2 ± 1.6	32.6 ± 1.0
After[2]	32.5 ± 1.0	32.0 ± 1.1	31.3 ± 1.5[3]	29.7 ± 0.9[3]
Percentage body fat by underwater weighing (%)				
Before	43.2 ± 1.0	43.1 ± 1.3	44.3 ± 1.1	43.4 ± 1.2
After[2]	42.2 ± 1.2	42.1 ± 1.5	39.8 ± 1.4[3]	38.9 ± 1.3[3]
Fat-free mass by underwater weighing (kg)				
Before	51.1 ± 1.2	49.7 ± 1.1	48.6 ± 1.1	50.8 ± 1.4
After[4]	51.5 ± 1.2	50.1 ± 1.2	47.8 ± 1.1	50.0 ± 1.2
Percentage body fat by BIA (%)				
Before	43.4 ± 1.1	42.2 ± 1.2	43.1 ± 1.0	43.2 ± 0.8
After[2]	42.0 ± 1.2	41.0 ± 1.2	39.3 ± 1.1[3]	39.8 ± 1.0[3]
Waist (cm)				
Before	91.6 ± 1.8	94.4 ± 2.8	94.4 ± 3.1	94.4 ± 2.0
After[2]	92.1 ± 1.8	92.3 ± 2.4	89.0 ± 3.1[3]	88.0 ± 1.9[3]
Hip (cm)				
Before	116.9 ± 1.5	117.1 ± 2.1	119.2 ± 3.8	118.3 ± 2.0
After[2]	116.5 ± 1.6	116.1 ± 2.3	114.9 ± 3.1[3]	112.5 ± 2.0[3]
Waist-to-hip ratio				
Before	0.78 ± 0.01	0.81 ± 0.02	0.80 ± 0.02	0.80 ± 0.01
After[2]	0.80 ± 0.01	0.80 ± 0.01	0.77 ± 0.01[3]	0.72 ± 0.01[3]

[1] $\bar{x} \pm$ SE. BIA, bioelectrical impedance analysis.
[2,4] Significant effect of group × time: [2] $P < 0.001$, [4] $P = 0.046$.
[3] Group change significantly different from that of control group, $P < 0.05$ (Duncan's multiple comparison test).

SEE of 3.7 kg, given the diverse nature of the group. The ability of the conventional arm-to-leg BIA system to assess body composition in obese populations has been questioned (1, 3, 14–16, 24–26). Most researchers have reported that equations used in arm-to-leg BIA systems overestimate fat-free mass in obese subjects compared with underwater weighing or other reference methods (3, 14–16, 26–28). Various fat-specific or generalized equations have been developed and recommended for the testing of obese subjects (3, 25, 29). Equations currently used for the leg-to-leg BIA system (Tanita Body Fat Analyzer) have been generalized to allow fat-free mass estimates from women varying widely in body composition and age.

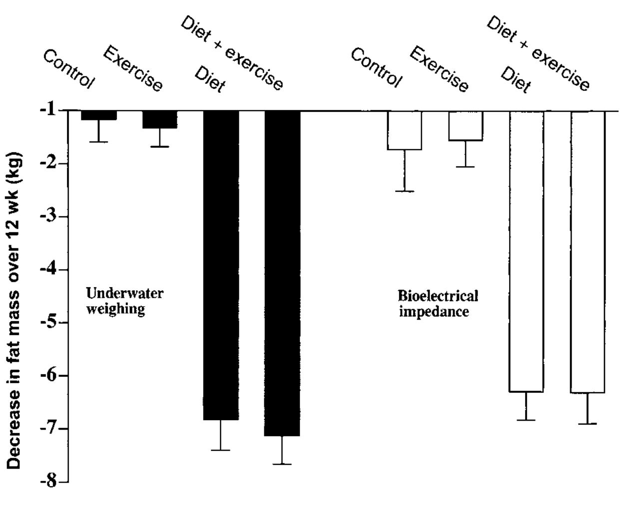

FIGURE 2. Mean decrease in fat mass for each group of obese women after a 12-wk intervention was measured effectively by bioelectrical impedance analysis compared with underwater weighing ($F_{[3,85]}$ = 1.45, P = 0.233).

Decreases in fat mass over a 12-wk period among subjects in the energy-restriction groups were accurately detected by the leg-to-leg BIA system. There are conflicting reports regarding the validity of the conventional arm-to-leg BIA system in predicting changes in body composition. Ross et al (6) reported that the BIA equations of Lukaski (7) and Segal et al (8) accurately estimated fat-free mass changes in mildly obese men. Kushner et al (9) also found that the arm-to-leg BIA system was valid for measuring changes in fat-free mass in obese women. Vazquez and Janosky (13), however, concluded that all 8 BIA equations investigated overestimated losses of fat-free mass in obese women during very-low-energy diets. Other investigators have reported that BIA systematically underestimated loss of fat-free mass during weight loss (11, 12, 30). Kotler et al (4) studied 21 HIV-infected individuals and concluded that the ability of BIA to detect changes in body composition were unreliable unless the change in fat-free mass was ≥5%. In their review, Houtkooper et al (5) reasoned that single-frequency impedance analysis is suitable for measuring change in body composition over time for groups of subjects but not for individuals, and that it is not possible to detect changes in fat-free mass <1–2 kg, which is below the precision of most BIA systems.

In our study, mean group fat-free mass losses ranged from 0.4 to 0.8 kg, an expected result given the moderate degree of energy restriction and aerobic exercise. Nuñez et al (2) showed that the between-day instrument precision for the leg-to-leg BIA system ranges from 1.0% to 3.6%. Thus, we conclude that the leg-to-leg BIA system can accurately detect body-composition changes for community weight-management groups undergoing moderate loss in body mass when changes in fat-free mass are small. Further research is warranted to determine whether the leg-to-leg BIA system is a valid method of assessing loss in fat-free mass during more rapid weight-loss regimens, when fat-free mass often represents 25% of the body mass loss.

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