

Bioelectrical Impedance vs. Four-compartment Model to Assess Body Fat Change in Overweight Adults

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Abstract

CHOUINARD, LAURA E., DALE A. SCHOELLER, ABIGAIL C. WATRAS, R. RANDALL CLARK, RACHEL N. CLOSE, AND ANDREA C. BUCHHOLZ. Bioelectrical impedance vs. four compartment model to assess body fat change in overweight adults. *Obesity*. 2007; 15:85–92.

Objective: The Tanita TBF-305 body fat analyzer is marketed for home and clinical use and is based on the principles of leg-to-leg bioelectrical impedance analysis (BIA). Few studies have investigated the ability of leg-to-leg BIA to detect change in percentage fat mass (%FM) over time. Our objective was to determine the ability of leg-to-leg BIA vs. the four-compartment (4C) model to detect small changes in %FM in overweight adults.

Research Methods and Procedures: Thirty-eight overweight adults (BMI, 25.0 to 29.9 kg/m²; age, 18 to 44 years; 31 women) participated in a 6-month, randomized, double-blind, placebo-controlled study of a nutritional supplement. Body composition was measured at 0 and 6 months using the Tanita TBF-305 body fat analyzer [using equations derived by the manufacturer (%FM_{T-Man}) and by Jebb et al. (%FM_{T-Jebb})] and the 4C model (%FM_{4C}).

Results: Subjects in the experimental group lost 0.9%FM_{4C} ($p = 0.03$), a loss that did not reach significance using leg-to-leg BIA (0.6%FM_{T-Man}, $p = 0.151$; 0.6%FM_{T-Jebb},

$p = 0.144$). We observed large standard deviations (SDs) in the mean difference in %FM between the 4C model and the Tanita_{Manufacturer} (2.5%) and Tanita_{Jebb} (2.2%). Ten subjects fell outside ± 1 SD of the mean differences at 0 and 6 months; those individuals were younger and shorter than those within ± 1 SD.

Discussion: Leg-to-leg BIA performed reasonably well in predicting decreases in %FM in this group of overweight adults but resulted in wide SDs vs. %FM_{4C} in individuals. Cross-sectional determinations of %FM of overweight individuals using leg-to-leg BIA should be interpreted with caution.

Key words: body composition, Tanita, DXA, densitometry, conjugated linoleic acid

Introduction

Bioelectrical impedance analysis (BIA)¹ has emerged as a popular method of assessing fat mass because it is quick, portable, and relatively inexpensive. The traditional supine (arm-to-leg) BIA method has been shown to be accurate in assessing percentage fat mass (%FM) of groups but not of individuals (1–3). During measurement using the newer leg-to-leg BIA, a weak current is passed up one leg, across the pelvis, and down the other leg. Small metal foot plates measure the voltage drop that occurs as the current passes through the subject's body. BIA theory proposes that this voltage drop is caused by the relative composition of the subject's body; fat provides greater resistance to the current than fat-free mass (lean soft tissue, water, etc.), allowing quantification of each body compartment (4). Leg-to-leg BIA is an attractive alternative to the traditional supine method because subjects stand during measurement and are

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¹ Nonstandard abbreviations: BIA, bioelectrical impedance analysis; %FM, percent fat mass; SD, standard deviation; UWW, underwater weighing; 4C, four compartment; CLA, conjugated linoleic acid; TBW, total body water; TBM, total body mineral.

not required to fix electrodes to their body; the method also does not require the assistance of a technician. It is, therefore, more user-friendly and is currently marketed for home and clinical use. Similar to arm-to-leg BIA, cross-sectional studies have shown leg-to-leg BIA to be a valid tool for measuring %FM of groups but not of individuals (5). The little research done to date that has assessed the ability of leg-to-leg BIA to detect changes in %FM has been promising. Utter et al. (6) and Powell et al. (7) found leg-to-leg BIA vs. underwater weighing (UWW) to accurately predict changes in %FM ranging from 1% to 13% FM. Frisard et al. (8) determined that leg-to-leg BIA was sensitive enough to detect a 2.1% FM loss, as measured by DXA. However, the reference methods used in these studies are associated with limitations in measuring body composition. Whether leg-to-leg BIA can detect changes in %FM relative to the reference standard four-compartment (4C) model of body composition has yet to be determined.

The goal of our study was to determine whether leg-to-leg BIA is sufficiently sensitive, relative to the reference standard 4C model, to detect small changes in %FM over a 6-month period in overweight adults randomized to daily supplementation of either conjugated linoleic acid (CLA) or placebo. We prospectively tested the Tanita manufacturer-derived equations and the more recently validated Tanita equations of Jebb et al. (9).²

Research Methods and Procedures

Subjects

Healthy men and women, 18 to 44 years of age, were recruited through local newspapers and posted flyers to participate in a 6-month study of the effect of daily CLA supplements vs. placebo on body composition. The study design was double-blinded, randomized, and stratified by sex and age (<30 and ≥30 years). Subjects were randomly assigned to 4 g/d of placebo (safflower oil) or 4 g/d of 78% active CLA isomers of safflower oil (3.2 g/d CLA: 39.2% cis-9, trans-11 and 38.5% trans-10, cis-12). Subjects were instructed to take four soft gel capsules each morning with food. Full methodology and results of this study are described elsewhere (10). Volunteers considered overweight (BMI between 25.0 and 29.9 kg/m²) on initial screening were eligible for participation. Subjects were further evaluated for eligibility based on a medical history and physical exam (completed by a doctor), including an ECG and routine blood analysis. Exclusion criteria included pregnancy and lactation; smoking; history or presence of cardiovascular, endocrine, gastrointestinal, hepatic, or renal diseases; and presence of hyperlipidemia, hypercholesterolemia, or hypertension. Subjects on a weight loss program or plan-

ning to be on a weight loss program were excluded, as were subjects who were taking medications that caused weight gain or loss.

Of the subjects screened, 48 were eligible for participation in the study. Three subjects left the study because of a lack of time for participation, one subject moved out of the area, two subjects became ineligible during the course of the study (one resumed smoking and one started medication), and four subjects completed BIA measurement at only one of two study visits. Thirty-eight subjects were, therefore, used in these analyses.

All testing occurred in the morning within a 4-hour time period, at each of the 0- and 6-month visits. Subjects arrived after a 12-hour fast and were provided with a small breakfast bar (energy, 180 kcal; carbohydrate, 26 grams; protein, 10 grams; fat, 4 grams; Clif Bar, Berkeley, CA) and bottled water (8 oz). The study protocol was approved by the University of Wisconsin-Madison Health Sciences Institutional Review Board, and all subjects provided written informed consent.

4C Model

The 4C model equation of Selinger was used to calculate the criterion body fat mass (11): %FM = $\{[(2.747(\text{BD}/\text{BW})) - [0.714 \times (\text{TBW}/\text{BW})] + [1.146 \times (\text{TBM}/\text{BW})] - 2.0503\} \times 100\%$, where %FM is percentage fat mass; BD is body density (kilograms per liter) determined by UWW; BW is body weight (kilograms); TBW is total body water (kilograms) determined by ¹⁸O isotope dilution; and TBM is total body mineral (kilograms) calculated from DXA.

Body Weight. Body weight was measured within 0.1 kg on a calibrated beam balance platform scale (Continental Scale, Bridgeview, IL) and on a Tanita BIA instrument (model TBF-305; Tanita, Arlington Heights, IL). Subjects wore a dry swimsuit or lightweight shorts and a t-shirt.

Body Density. Body density was determined by UWW using procedures previously described (12). Each subject's underwater weight was measured a minimum of eight times, with the mean of the three heaviest weights used to calculate body density. Residual lung volumes were measured before underwater weighing using the closed-circuit oxygen dilution method described by Wilmore (13). With the subject in a seated position to simulate underwater weighing, a minimum of two trials were conducted using a 13.5-liter respirometer (Collins Medical, Braintree, MA) and a Med Science nitrogen analyzer (Model 505; Med Science, St. Louis, MO). The mean of two trials within 75 mL, plus a 0.1-liter correction for gastrointestinal volume, was used in the body density equation. At 6 months, the mean of the 0- and 6-month residual volumes was used to minimize within-subject variability.

TBW. TBW was measured by ¹⁸O dilution using 10.3 atom% enriched water (Rotem Industries, Beer Sheva, Israel). A baseline urine sample was collected from subjects

² Jebb SA. Correction to equation published in *Br J Nutr* in 2000. Personal communication, 2005.

to determine the predose ^{18}O concentration. Subjects weighing <80 kg received a dose of ~ 19.4 grams, and those weighing >80 kg received a dose of ~ 24.2 grams. Subjects drank the dose from a 50-mL container. They refilled the container with ~ 50 mL of bottled water and drank this volume from the container to ensure that the entire dose was ingested. Urine samples were collected at 1, 2 to 3, and 3 to 4 hours after ^{18}O dose. Subjects were provided with a small breakfast bar and bottled water after the dose but were not permitted to eat or drink 1 hour before the final urine sample. The urine samples were decolorized with carbon black, filtered through a sterile acetate filter, and isotopically equilibrated with CO_2 at 30°C for 24 hours. The ^{18}O abundance of the CO_2 was determined by continuous-flow isotope ratio mass spectrometry (Delta S; Finnigan MAT, Bremen, Germany) using procedures described by Schoeller and Luke (14). TBW was calculated from the dilution of the isotopic water using the difference in enrichment between the pre-dose sample and the final (3 to 4 hours) urine sample. Each sample was analyzed on 2 separate days, and the average enrichment was used (within-subject SD = 0.16/million). The ^{18}O dilution space was assumed to be 0.7% higher than TBW (15).

TBM. Bone ash was determined by whole body DXA using the Norland XR-36 bone densitometer with software version 3.7.4/2.1.0 (Norland, Ft. Atkinson, WI). Calibration was performed before each scan using standards to simulate lean (0.6% NaCl), fat (stearic acid), and bone (hydroxapatite). Coefficients of variation based on 18 scans of six subjects were as follows: soft tissue mass, 0.2%; total body mass, 0.2%; lean body mass, 1.0%; fat mass, 2.5%; percent fat, 2.4%; TBM, 0.9%. Subjects removed all metal objects and wore a dry swimsuit or lightweight shorts and a t-shirt. All subjects were scanned in the supine position by the same investigator. Because 4.18% of osseous material is lost during the ashing process and non-osseous material is estimated to be 23.5% of total bone ash, TBM was calculated by multiplying total body bone ash as determined by DXA by 1.279 (16).

BIA

BIA was performed using a single frequency leg-to-leg Tanita body fat analyzer (Model TBF-305; Tanita). Subjects removed their shoes and socks and wore a dry swimsuit or lightweight shorts and a t-shirt during the measurement. Resistance to the alternating current flow (500 μA , 50 kHz) was measured with the subjects standing on the analyzer's platform and interpreted using the "standard" option of the manufacturer's software while the subjects stood motionless with their arms at their sides. Data output included body weight (kilograms), impedance (ohms), fat mass (kilograms), fat-free mass (kilograms), TBW (kilograms), and $\%FM_{T\text{-Man}}$ ($\%FM$ Tanita as calculated by the manufacturer software). We also tested the Tanita BIA equation proposed

by Jebb et al. (9)²: $\%FM_{T\text{-Jebb}} = -156.1 - 89.1 \ln(\text{height}) + 45.6 \ln(\text{weight}) + 0.120 \text{ age} + 0.0494 Z + [19.6 \ln(\text{height}) \text{ (for women)}]$, where Z is impedance in ohms, height is in meters, weight is in kilograms (measured by Tanita BIA), and age is in years.

Height

Subjects' height was measured within 0.5 cm using a custom wall-mounted stadiometer. Heels, buttocks, and shoulders were pressed against the stadiometer, with subjects' heads in the Frankfurt plane.

Data Analysis

Data were analyzed using the Statistical Package for the Social Sciences (Version 12.0; SPSS, Chicago, IL). A p value of ≤ 0.05 was considered significant. Data are expressed as mean \pm SD. The sample size for the original study was based on 80% power to detect a 1-kg difference in FM between CLA and placebo groups; post hoc analysis of data from this study indicated that we had 73% power to detect a 1-kg difference in $\%FM_{T\text{-Man}}$ in the CLA group. The differences between $\%FM_{T\text{-Man}}$ and $\%FM_{4C}$ for the whole group at 0 and 6 months were compared using paired t tests, and between CLA and placebo groups using a regression model adjusted for the covariates of age, sex, and baseline BMI. Agreement between $\%FM_{T\text{-Man}}$ and $\%FM_{4C}$ for the whole group was explored using simple linear regression and the method of Bland and Altman (17). The relationship between abdominal FM and the difference in measurement of $\%FM$ using leg-to-leg BIA vs. 4C was also determined using simple linear regression. To better understand the differences between $\%FM_{T\text{-Man}}$ and $\%FM_{4C}$, subjects for whom differences were greater than ± 1 SD from the mean difference were identified for further analysis. Using this criterion, there were 10 subjects at 0 months and 10 subjects at 6 months; 6 of these subjects were outside of ± 1 SD at both 0 and 6 months. Age, sex, height, and weight of outliers were compared with subjects within ± 1 SD of the mean difference, using a Wilcoxon signed rank test. The above analyses performed using $\%FM_{T\text{-Man}}$ equations were repeated using the $\%FM_{T\text{-Jebb}}$ equation.

Results

Baseline Characteristics

Group baseline characteristics are presented in Table 1. There were no differences in age, sex, body weight, or BMI between the CLA and placebo groups (data not shown) (10).

Changes in $\%FM_{4C}$ vs. $\%FM_{T\text{-Man}}$ and $\%FM_{T\text{-Jebb}}$

Changes in $\%FM$ between groups at 0 and 6 months, as measured by 4C model and both Tanita equations, are shown in Table 2. Paired t tests showed no significant differences between $\%FM_{4C}$ and $\%FM_{T\text{-Man}}$ or $\%FM_{T\text{-Jebb}}$

Table 1. Participant characteristics at baseline ($n = 38$)*

	Baseline (mean \pm SD)	Range
Sex	M = 7, F = 31	
Age (years)	33.5 \pm 7.0	19.8 to 44.6
Height (cm)	168.8 \pm 7.4	155.0 to 189.0
Weight (kg)	79.1 \pm 9.8	60.8 to 105.9
BMI (kg/m ²)	27.7 \pm 2.0	24.0 to 31.3

* No differences between CLA and placebo (11).

in either group at 0 months. The 4C model detected a significant decrease in %FM between 0 and 6 months in the CLA group ($p = 0.03$), whereas Tanita_{Manufacturer} ($p = 0.151$) and Tanita_{Jebb} ($p = 0.144$) did not. Relative to the 4C model, Tanita_{Manufacturer} overestimated the change in %FM between 0 and 6 months by 0.9 percentage points in the placebo group ($p < 0.05$). The 6-month change values calculated by the Tanita_{Jebb} equation were not different from Tanita_{Manufacturer} for the entire group ($p = 0.189$), the CLA group ($p = 0.629$), or the placebo group ($p = 0.222$). No significant correlation was found between abdominal fat mass as measured by DXA and the difference between %FM as predicted by Tanita_{Manufacturer} and 4C at either 0 ($p = 0.069$) or 6 months ($p < 0.001$).

As shown in Figure 1, correlation coefficients between %FM_{T-Man} and %FM_{4C} at 0 (Figure 1A) and 6 months (Figure 1C) were $r \geq 0.90$ ($p < 0.001$). The trendline did not differ from the line of identity at either 0 ($p = 0.991$) or

6 months ($p = 0.426$). Bland and Altman analyses (Figure 1B and D) showed no biases between methods at 0 ($r = -0.15$, $p = 0.370$) or 6 months ($r = -0.033$, $p = 0.846$). However, the SD of the mean differences was wide at both time-points. Ten (26%) subjects fell outside of ± 1 SD of the mean differences at each of 0 and 6 months (2.17%FM and 2.63%FM, respectively). The wide SD of the mean difference was comparable when the Tanita_{Jebb} was examined against the 4C model at both 0 (2.28% FM) and 6 months (2.46% FM). The subset of subjects for whom Tanita_{Manufacturer} overestimated %FM ($> +1$ SD of the mean difference) were younger (7.8 years, $p < 0.05$) at 0 months, and those for whom Tanita_{Manufacturer} underestimated %FM (> -1 SD of the mean difference) were shorter (by 10.4 and 5.6 cm at 0 and 6 months, respectively; both $p < 0.05$) than subjects within ± 1 SD of the mean difference.

Discussion

To our knowledge, this is the first study to determine the ability of leg-to-leg BIA vs. the reference standard 4C model to detect change in %FM in overweight adults. The most important findings are that, in a group of overweight American adults, leg-to-leg BIA: 1) performed reasonably well in predicting small changes in %FM at the group level; 2) produced unacceptably wide limits of agreement with the reference standard 4C model at the individual level; and 3) systematically overestimated %FM of comparatively younger subjects and underestimated %FM of comparatively shorter subjects.

Nearly two thirds of Americans are overweight or obese (BMI ≥ 25 kg/m²) (18). Given the health risks associated

Table 2. Percent fat mass at 0 and 6 months as measured by the 4C model (%FM_{4C}), the manufacturer-derived Tanita equation (%FM_{T-Man}), and the Tanita equation of Jebb et al. (%FM_{T-Jebb}) for the whole group, CLA group, and placebo group

	%FM _{4C}			%FM _{T-Man}			%FM _{T-Jebb}		
	Whole group (n = 38)	Placebo (n = 17)	CLA (n = 21)	Whole group (n = 38)	Placebo (n = 17)	CLA (n = 21)	Whole group (n = 38)	Placebo (n = 17)	CLA (n = 21)
0 months	34.8 \pm 6.4	36.2 \pm 4.3	33.6 \pm 7.6	35.1 \pm 6.1	36.0 \pm 4.2	34.4 \pm 7.2	34.4 \pm 5.6*	35.1 \pm 3.7*†	33.7 \pm 6.7*
6 months	34.3 \pm 6.0	36.3 \pm 3.9	32.7 \pm 6.9	35.3 \pm 5.9	37.1 \pm 3.5	33.8 \pm 7.0	34.4 \pm 5.2*	35.8 \pm 3.1*	33.3 \pm 6.4*
Δ %FM	-0.4 \pm 2.1	0.1 \pm 2.3	-0.9 \pm 0.8‡§	0.2 \pm 2.5	1.0 \pm 3.1†	-0.6 \pm 1.7	-0.1 \pm 2.2	0.7 \pm 2.5	-0.5 \pm 1.8

Values are means \pm SD.

* Different ($p > 0.05$) from Tanita model using a paired t test.

† Different ($p < 0.05$) from the 4C model using a paired t test.

‡ Significant change from baseline ($p < 0.05$) using a paired t test.

§ Different ($p < 0.05$) from placebo group using a regression model that adjusted for baseline age, sex, and BMI.

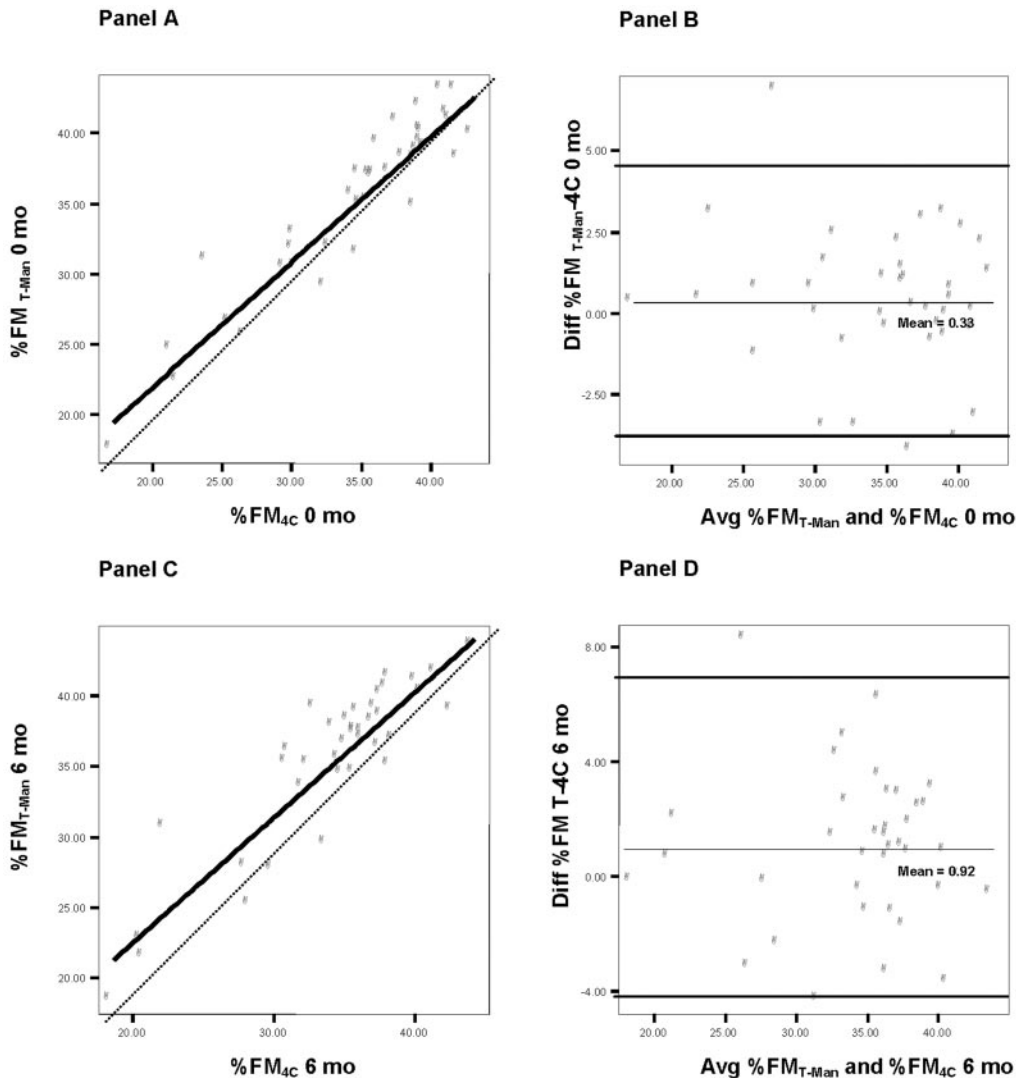


Figure 1: Relationship between percentage fat mass measured by the 4C model (%FM_{4C}) vs. Tanita-305 body fat analyzer (%FM_{T-Man}) in 38 overweight adults. (A and C) r between the two methods at 0 and 6 months (A: $r = 0.94$, $p = 0.00$; C: $r = 0.90$, $p = 0.00$). Bold lines represent trendlines; dotted lines represent the line of identity. The trendline did not differ from the line of identity at either 0 ($p = 0.991$) or 6 months ($p = 0.426$). (B and D) Bland and Altman analyses between the two methods at 0 and 6 months (B: $r = -0.15$, $p = 0.370$; mean difference = $0.33 \pm 2.17\%$ FM; D: $r = -0.033$, $p = 0.846$; mean difference = $0.92 \pm 2.63\%$ FM). Lines represent mean \pm 2 SD.

with increased body fat, the ability to measure fat mass and monitor changes in fat mass, using a simple and rapid tool, becomes important. Leg-to-leg BIA has the potential to be one such tool. Relative to the 4C model, we found leg-to-leg BIA able to detect small changes in %FM with reasonable accuracy. However, while these changes were in the same direction as those measured by the 4C model, they did not reach statistical significance. Leg-to-leg BIA has performed well in assessing change in %FM in a number of large validation studies. Utter et al. (6) found leg-to-leg BIA to accurately predict change in %FM relative to UWW in 98 moderately obese women who lost between 1% and 8.5% of their body fat. UWW was also the reference method used by

Powell et al. (7), who found leg-to-leg BIA to accurately predict the average decrease of 13% FM in 201 overweight and obese women. Most recently, Frisard et al. (8) found leg-to-leg BIA to accurately predict a 2.1% FM loss, as determined by DXA, in 56 overweight men and women. Our results contribute to this growing body of literature supporting the use of leg-to-leg BIA in measuring change in %FM in groups of overweight adults.

We did, however, find unacceptably wide limits of agreement at the individual level between %FM determined by leg-to-leg BIA relative to the 4C model. There were 10 subjects (26%) who fell outside ± 1 SD of the mean difference of %FM as measured by Tanita_{Manufacturer} and the 4C

model at each of 0 and 6 months. At 0 months, subjects $>+1$ SD of the mean difference were, on average, 7.8 years younger than those who were within ± 1 SD of the mean difference, and subjects >-1 SD of the mean difference were, on average, 10.4 cm shorter than those within ± 1 SD of the mean difference. At 6 months, subjects >-1 SD of the mean difference were, on average, 5.6 cm shorter than those within ± 1 SD of the mean difference. Such differences in height and age may help explain why BIA was a poor predictor of %FM in these individuals. For example, for one 30-year-old female subject at 6 months, the $Tanita_{\text{Manufacturer}}$ equation overestimated %FM_{4C} by 8.2%. This subject would have been classified as lean ($<25\%$ FM) using results of the 4C model but would have been classified within the normal reference range (25% to 33% FM) using $Tanita_{\text{Manufacturer}}$ (19). This error is concerning, because recommendations to individuals related to diet and exercise are made by health professionals based on such classifications.

The large SD of the younger female subject described above and of the other younger and shorter subjects whose measurements fell outside ± 1 SD of the mean difference may be explained by the extent to which the body composition of our subjects differed from assumptions made by the BIA instrument. Because Tanita prediction equations are proprietary, it was not possible to obtain information regarding the population in which the equations were validated. However, because height and age are entered into the instrument before measurement, they must be important in the manufacturer-derived equation for %FM, and deviations in these variables may influence the validity of the equation. Furthermore, because leg-to-leg BIA measures only the resistance of the legs, it may be influenced by variations in the distribution of muscle and fat mass about the body (20). We found no relationship between abdominal obesity as measured by DXA and the residual between %FM_{T-Man} and %FM_{4C}. Our overweight subjects may have differed in their proportion or distribution of muscle tissue rather than fat tissue from those individuals on which the manufacturer's equations were validated. Further research on such individuals would increase our understanding of the effects of distribution of muscle mass in overweight individuals on validity of leg-to-leg BIA measurements.

Similar to our study, Jebb et al. (9) found that leg-to-leg BIA using the Tanita manufacturer equations resulted in large errors in predicting %FM in individuals, relative to the 4C model. These authors validated a new Tanita equation in a large heterogeneous population (9)² of overweight, lean, and obese adults, which we tested in this study. We found this new equation to perform similarly to the Tanita manufacturer equation. While the 6-month change in %FM was in the same direction as that measured by the 4C model, the change did not reach statistical significance. The Jebb equation also resulted in wide limits of agreement at the in-

dividual level: the SDs of the mean difference between %FM_{T-Jebb} and %FM_{4C} (2.28% and 2.46% at 0 and 6 months, respectively) were comparable with those of %FM_{T-Man}. This may be because of the fact that the Jebb equation includes many predictors other than impedance, such as height and weight. When we calculate the contribution of change in weight and impedance to the predicted change in %FM in the CLA group, we find that change in weight contributes -0.30% FM and change in impedance contributes -0.36% FM to the final result. There was no change in height, and the change in age, which was minimal, contributed $+0.06\%$ FM to the final result. What is interesting in the CLA group is that the change in body composition is atypical in that FM decreased by 0.9 kg, whereas fat-free mass tended to increase by 0.37 kg (not significant). This is not unexpected for CLA in light of animal studies showing increases in fat-free mass during CLA supplementation (21), but the composition of the weight change is not the typical relationship for decrements in FM (60% to 80%) with decreasing weight (22). Thus, the $Tanita_{\text{Jebb}}$ -predicted change in %FM underestimates true change because it uses weight in the prediction. In other words, the Tanita failed as an independent measure of %FM just when one wanted a weight-independent measure, when the composition of the weight change was atypical. The same would likely apply for body composition changes secondary to treatment with exercise alone because fat loss is equal to or greater than weight loss (23). Indeed, had fat loss been of the usual 0.6 to 0.8 fraction of weight change, the weight change for the observed change in FM would have been ~ 1.3 kg, and if this value is inserted into the Jebb equation, we calculate a change in %FM of 1% FM, a value quite close to the highly accurate 4C model. We do not have access to the Tanita manufacturer prediction equation, but it is clear that it also uses weight in predicting %FM because of the inclusion of the athlete mode option in their %FM calculation. As such, the failure of Tanita using the manufacturer equation is also likely caused by the inclusion of weight as a major predictor of %FM. Thus, we conclude that the equations used in the Tanita leg-to-leg instrument are inappropriate for measuring change in body composition because they are largely anthropometric prediction equations with an impedance modifier.

While an important strength of our study was the use of the 4C model as the criterion method, our sample size and composition were somewhat limited. However, post hoc analysis indicated that the sample size ($n = 21$ in CLA group) provided 73% power to detect a 1-kg difference in FM using the Tanita instrument. Thus, there is a 73% chance that the accuracy of Tanita for detecting change was poorer than that of 4C and only a 27% chance that random error kept the instrument from detecting change. Of the 38 subjects studied, 31 were women, and 36 were white. The

homogeneity of our sample may limit the generalizability of our findings to more diverse populations.

We conclude that, relative to the reference standard 4C model, leg-to-leg BIA performed reasonably well in predicting change in %FM at the group level, although it underestimated the small but significant 6-month decrease in %FM in this group of overweight adults. More concerning are the unacceptably wide limits of agreement for individual determination of %FM and the systematic overestimation of %FM of comparatively younger subjects and underestimation of %FM of comparatively shorter subjects. Taken together, these findings support the general consensus in the literature that leg-to-leg BIA should be used with caution to predict %FM of overweight or overfat individuals (24,25). In 2002, 35.1% of American adults were considered overweight (18). Although subjects in this study may not reflect the exact demographic profile of the population of American adults, our results nonetheless suggest that leg-to-leg BIA would be a poor predictor of individual %FM and may underestimate change in %FM for a potentially large portion of the American population. We recommend that %FM determined by leg-to-leg BIA in overweight adults be interpreted with caution.

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