

## Clinical Study

# Bioelectrical Impedance and Dual-Energy X-Ray Absorptiometry Assessments of Changes in Body Composition Following Exercise in Patients with Type 2 Diabetes Mellitus

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We aimed to compare the level of agreement between leg-to-leg bioelectrical impedance analysis (LBIA) and dual-energy X-ray absorptiometry (DXA) for assessing changes in body composition following exercise intervention among individuals with Type 2 diabetes mellitus (T2DM). Forty-four adults with T2DM, age  $53.2 \pm 9.1$  years; BMI  $30.8 \pm 5.9$  kg/m<sup>2</sup> participated in a 6-month exercise program with pre and post intervention assessments of body composition. Fat free mass (FFM), % body fat (%FM) and fat mass (FM) were measured by LBIA (TBF-300A) and DXA. LBIA assessments of changes in %FM and FM post intervention showed good relative agreements with DXA variables ( $P < 0.001$ ). However, Bland-Altman plot(s) indicated that there were systematic errors in the assessment of the changes in body composition using LBIA compared to DXA such that, the greater the changes in participant body composition, the greater the disparity in body composition data obtained via LBIA versus DXA data (FFM,  $P = 0.013$ ; %FM,  $P < 0.001$ ; FM,  $P < 0.001$ ). In conclusion, assessment of pre and post intervention body composition implies that LBIA is a good tool for assessment qualitative change in body composition (gain or loss) among people with T2DM but is not sufficiently sensitive to track quantitative changes in an individual's body composition.

## 1. Introduction

Exercise has long been recognized as a cornerstone of diabetes management and for the prevention of incident diabetes [1]. Although reductions in body weight or achievement of an optimal weight is often a therapeutic goal for individuals with type 2 diabetes mellitus (T2DM), The benefits of exercise training may be better reflected

in changes in body composition rather than changes in body weight. Understanding body composition and how it changes is essential to the prescription and evaluation of exercise rehabilitation programs for patients with T2DM.

Dual-energy X-ray absorptiometry (DXA) is an advanced technique for estimating body fat, lean soft tissue mass, bone mineral content, and bone mineral density [2]. DXA assessment of body composition requires minimal

radiation exposure, and is widely available and practical to apply [3] as it merely requires patients to lie supine and clothed on a plinth for scan acquisition. DXA body composition software has established reliability and validity for assessment of fat, lean tissue, and muscle mass, among adults and has been the clinical gold standard for assessment of body composition for some time. However, the utility of DXA is limited due to the cost of the equipment, expertise required to acquire and analyze scans (trained operators), lack of portability, availability of funding, and their ~123 kg weight limit. These criteria combine to limit the availability of DXA in most settings with the exception of some tertiary rehabilitation centers.

Bioelectrical impedance analysis (BIA), particularly, leg-to-leg BIA (LBIA) using a single frequency (50 kHz), footpad electrode system for standing impedance, and body weight measurement has become a popular alternative to DXA for assessing body composition in the general population [4–7]. This LBIA method has several advantages over DXA as the equipment required is relatively inexpensive, portable, requires minimal training to operate, and presents no health risk to participants. To date, one prior validation study has been done using a LBIA system among individuals with T2DM [8]. The previous authors reported that percent of fat mass (%FM) assessed with the LBIA system was comparable to that with DXA in patients with T2DM. However, the validity of LBIA for evaluation of longitudinal change in body composition following an exercise intervention among participants with T2DM has not previously been reported. The present study aimed to compare the level of agreement between LBIA and DXA assessment of FFM, %FM, and FM before and after exercise intervention among participants with T2DM.

## 2. Methods

**2.1. Subjects.** Sixty-two adult men and women with T2DM were recruited from participants of the Diabetes, Exercise, and Healthy Lifestyle Program at the Toronto Rehabilitation Institute (TRI). These individuals had enrolled in a 6-month exercise program. Diagnosis of diabetes was confirmed by a fasting plasma glucose  $\geq 7.0 \text{ mmol} \cdot \text{L}^{-1}$ , use of insulin, or oral hypoglycemic agents. Potential participants were excluded if they had diagnosed cardiovascular disease, a diabetes-related complication including nephropathy, or retinopathy unrepaired hernia, or any other functional impairment that would preclude participation in a high intensity resistance training program. From eligible participants, only those who completed the exercise intervention program, as well as before and after intervention assessments of body composition were included in the data analysis. The study protocol was approved by the Research Ethics Boards of the Toronto Rehabilitation Institute (TRI) and University of Toronto and informed written consent was obtained from each participant.

**2.2. Protocol.** Participants visited TRI on two different occasions for baseline anthropometric measurements. One

visit assessed height, weight, and LBIA. A second assessment allowed for whole body DXA scan acquisition. These visits were completed within 2 weeks of starting the exercise intervention, as well as after completion of the 6-month exercise intervention. Follow-up assessments were performed in the same order as originally acquired.

**2.3. Body Composition.** LBIA and weight were measured using a BIA system (TBF-300A, Tanita Corporation of America, Inc., Arlington Heights, IL, USA), which consists of 4 contact electrodes (2 anterior and 2 posterior) that are mounted on the surface of a platform scale (Nunez CD 1997, MSSE). A constant current of 500 microA at 50 kHz is passed through the anterior electrode on the platform, and the voltage drop is then measured on the posterior electrode. Leg-to-leg impedance of the lower extremities and body weight are measured simultaneously while the subject stands on the scale. This analyzer provides data regarding fat free mass (FFM in kilogram), percent body fat (%FM in %), and fat mass (FM in kilogram). The exact calculation formulae for FFM, %FM, and FM are proprietary.

Whole body DXA scans to assess whole body FFM, %FM, and FM were conducted using Hologic QDR-4500A (Hologic Inc., Waltham, MA, USA). Analysis of the scans was performed using the Hologic whole body software, Version 12.3. For both DXA and LBIA assessments, participants were measured at approximately the same time of day for both before and after tests. They were instructed to refrain from exercise for 24 hours prior to testing, and instructed to take water and medications as necessary on their usual schedule. If patients were not adherent with the premeasurement protocol, the participants were asked to come back a different day to have the measurements.

**2.4. Exercise Intervention.** A progressive resistance training (RT) program was performed as a 10-exercise circuit, repeated two or three times, twice per week. The circuit consisted of a dumbbell row, half-squat, biceps curl, lateral raise, heel raise, hamstring curl, supine fly, triceps extension, abdominal curl up, and the “bird-dog” for core strengthening. In addition, aerobic training (AT) was performed by participants, working up to an hour in duration. Initial AT prescriptions of walking or cycling were given at 60% to 75% of heart rate reserve or peak oxygen consumption based on the initial graded-exercise, cardiopulmonary stress test with gas analysis (Vmax Series Software Version 12-3A, Yorba Linda, CA, USA). All participants were asked to do their AT 5-days a week with one supervised AT and RT session per week.

**2.5. Statistical Analysis.** Statistical analyses were done in overall group except for the differences of body composition between men and women at the baseline. Difference of body composition between men and women were tested by unpaired *t*-test. The difference between similar measures by LBIA and DXA before intervention were tested by paired *t*-tests. Linear regression was used to assess the accuracy of the LBIA compared with DXA before intervention. Agreement

TABLE 1: Subject characteristics at the baseline (Men = 23, Women = 21, Overall = 44).

Variable	Men	Women	Overall
Age (yr)	52.9 ± 9.8	53.5 ± 8.4	53.2 ± 9.1
Height (cm)	172.3 ± 6.1	159.3 ± 7.0*	166.1 ± 9.2
Weight (kg)	92.4 ± 22.3	77.8 ± 16.7*	85.4 ± 20.9
BMI (kg/m <sup>2</sup> )	31.0 ± 6.5	30.6 ± 5.4	30.8 ± 5.9

Values are means ± standard deviation.

\*Significantly different from Men ( $P < 0.05$ ).

between LBIA and DXA was further assessed using a Bland-Altman approach. The effects of the exercise intervention on body weight and body composition variables were tested by paired  $t$ -tests. Linear regression was used to determine the level of relative agreement in changes in body composition between BIA and DXA between LBIA. The Bland-Altman approach was also used to assess the agreement between the two body composition methods for changes in body composition attributed to the intervention(s) [9]. Statistical significance was set at  $P < 0.05$ . All statistical analyses were performed with IBM SPSS 20 for Macintosh (IBM, New York, USA).

### 3. Results

**3.1. Body Composition at Baseline.** In total, 44 participants (men = 23, women = 21) were eligible for study participation (age  $53.2 \pm 9.1$  years, duration of known diabetes:  $56.5 \pm 8.8$  months, HbA1c:  $7.16 \pm 1.11\%$ , oral agent treatment  $n = 31$ , insulin treatment  $n = 13$ ). Table 1 displays the physical and demographic characteristics of the overall participants as well as by gender at baseline. Women were significantly shorter ( $P < 0.001$ ) and had lighter body weight ( $P = 0.019$ ) than men. Additionally, the women had significantly lower FFM and greater %FM than men in both DXA and LBIA ( $P < 0.001$ ) (Table 2). For the overall cohort, there were strong correlations between FFM, %FM, and FM assessed by LBIA and that of DXA (FFM:  $r = 0.942$ ,  $P < 0.001$ ; %FM,  $r = 0.833$ ,  $P < 0.001$ ; FM:  $r = 0.929$ ,  $P < 0.001$ ) (Figure 1). Despite this good relative agreement for estimations, however, %FM and FM by LBIA were significantly different from that of DXA (%FM,  $P = 0.047$ ; FM,  $P = 0.003$ ) (Table 2). Relative to DXA, LBIA overpredicted %FM ( $1.5 \pm 4.9\%$ ) and FM ( $2.3 \pm 4.8$  kg). On average, %FM and FM by LBIA were 105.2% and 107.3% of the value determined by DXA, respectively. There was no significant difference between FFM by LBIA and FFM by DXA ( $P = 0.476$ ). The Bland-Altman plots showed that there were no systematic errors in assessment of FFM ( $P = 0.907$ ), %FM ( $P = 0.100$ ), and FM ( $P = 0.06$ ) using LBIA compared with DXA (Figure 2). The limits of agreement between LBIA and DXA ranged from  $-8.29$  to  $+8.77$  kg for FFM, from  $-11.39$  to  $+9.88\%$  for %FM, and from  $-11.89$  to  $+9.63$  kg for FM.

**3.2. Changes in Body Composition with the Exercise Intervention.** The mean weight loss during the 6 month exercise

intervention was  $-1.99 \pm 4.72$  kg (from  $85.4 \pm 20.9$  to  $83.4 \pm 19.3$  kg,  $P = 0.008$ ), with a decrease in BMI of  $0.69 \pm 1.53$  kg/m<sup>2</sup> (from  $30.8 \pm 5.9$  to  $30.1 \pm 5.7$  kg/m<sup>2</sup>,  $P = 0.005$ ). FM and %FM were significantly decreased after the intervention for both DXA (%FM,  $P < 0.001$ ; FM,  $P < 0.001$ ) and LBIA (%FM,  $P = 0.036$ ; FM,  $P = 0.024$ ) (Table 2). FFM did not show significant change by intervention for both of DXA ( $P = 0.649$ ) and LBIA ( $P = 0.113$ ). There were no statistically significant differences in mean changes in all body composition variables between LBIA and DXA (FFM,  $P = 0.068$ ; %FM,  $P = 0.426$ ; FM,  $P = 0.633$ ). LBIA assessments of changes in %FM, and FM by the intervention showed good relative agreement with those variables assessed by DXA ( $P < 0.001$ ) (Figure 3). There was a trend of positive relationship between changes in FFM by DXA and that of LBIA, however the correlation coefficients were not significant ( $P = 0.053$ ). Bland-Altman plots indicated that there were systematic errors in the assessment of the changes in FFM, %FM, and FM by LBIA compared with DXA. Thus, the more change subjects showed, the greater the disparity in FFM, %FM and FM measures from LBIA and those measures from DXA (FFM,  $P = 0.013$ ; %FM,  $P < 0.001$ ; FM,  $P < 0.001$ ) (Figure 4).

### 4. Discussion

This study demonstrated that body composition as assessed cross-sectionally using LBIA correlated well with DXA assessments in a population of adults with Type 2 mellitus. In absolute terms, however, LBIA significantly overestimated %FM, and FM. After 6 months of exercise intervention, we found that body fat and body fat percentage assessed by DXA decreased. The observed values are in-line with other exercise intervention studies in diabetes [10, 11]. In terms of measuring changes in body composition after the exercise intervention, LBIA assessments of changes in FFM, %FM, and FM showed good absolute agreement with similar DXA assessments. However, Bland-Altman plots showed that there were systematic errors in the assessment of the changes in FFM, %FM, and FM by LBIA. To the best of our knowledge, this is the first study to investigate the validity of bioelectrical impedance analysis (BIA) including LBIA for assessing changes in body composition following exercise intervention among individuals with T2DM.

The LBIA technique demonstrated good relative agreement for assessing FFM, %FM, and FM as shown by high-correlation coefficients, although it overestimated %FM and FM. Additionally the comparison between men and women in body composition evaluated by both DXA and LBIA methods demonstrated that both methods can similarly detect gender difference in body composition (Table 2). These results imply that LBIA may be used for cross-sectional studies or assessments, but LBIA and DXA should not be used interchangeably. Similar overestimation of %FM by LBIA has reported in female subjects with T2DM [8]. The bias in this cross-sectional assessment was similar or smaller than that of previous studies in people with T2DM [8], healthy adults [4] or overweight women [12].

TABLE 2: Subject body composition by method at baseline and change from baseline for overall cohort (men = 23, women = 21, overall = 44).

Method	Variable	Before intervention			Change from baseline for overall cohort
		Men	Women	Overall	
DXA	FFM (kg)	64.4 ± 10.2	47.3 ± 8.8 <sup>#</sup>	56.2 ± 12.8	0.1 ± 1.5
	% FM (%)	27.1 ± 6.3	38.2 ± 4.1 <sup>#</sup>	32.4 ± 7.7	-1.1 ± 1.4 <sup>†</sup>
	FM (kg)	25.3 ± 11.4	29.7 ± 8.0	27.4 ± 10.1	-1.3 ± 2.1 <sup>†</sup>
LBIA	FFM (kg)	64.7 ± 10.5	45.9 ± 6.5 <sup>#</sup>	55.8 ± 12.9	-0.5 ± 2.2
	% FM (%)	28.5 ± 7.6	40.0 ± 5.9 <sup>#</sup>	34.0 ± 8.9 <sup>*</sup>	-0.9 ± 2.7 <sup>†</sup>
	FM (kg)	27.7 ± 13.5 <sup>*</sup>	31.9 ± 11.0 <sup>*</sup>	29.7 ± 12.4 <sup>*</sup>	-1.5 ± 4.2 <sup>†</sup>

Values are means ± standard deviation. DXA: dual X-ray absorptiometry; LBIA: leg-to-leg bioelectrical impedance analysis; FFM: fat free mass; %FM: percentage body fat; FM: fat mass.

<sup>\*</sup>Significantly different from DXA ( $P < 0.05$ ).

<sup>#</sup>Significantly different from Men ( $P < 0.05$ ).

<sup>†</sup>Significant change compared with before intervention ( $P < 0.05$ ).

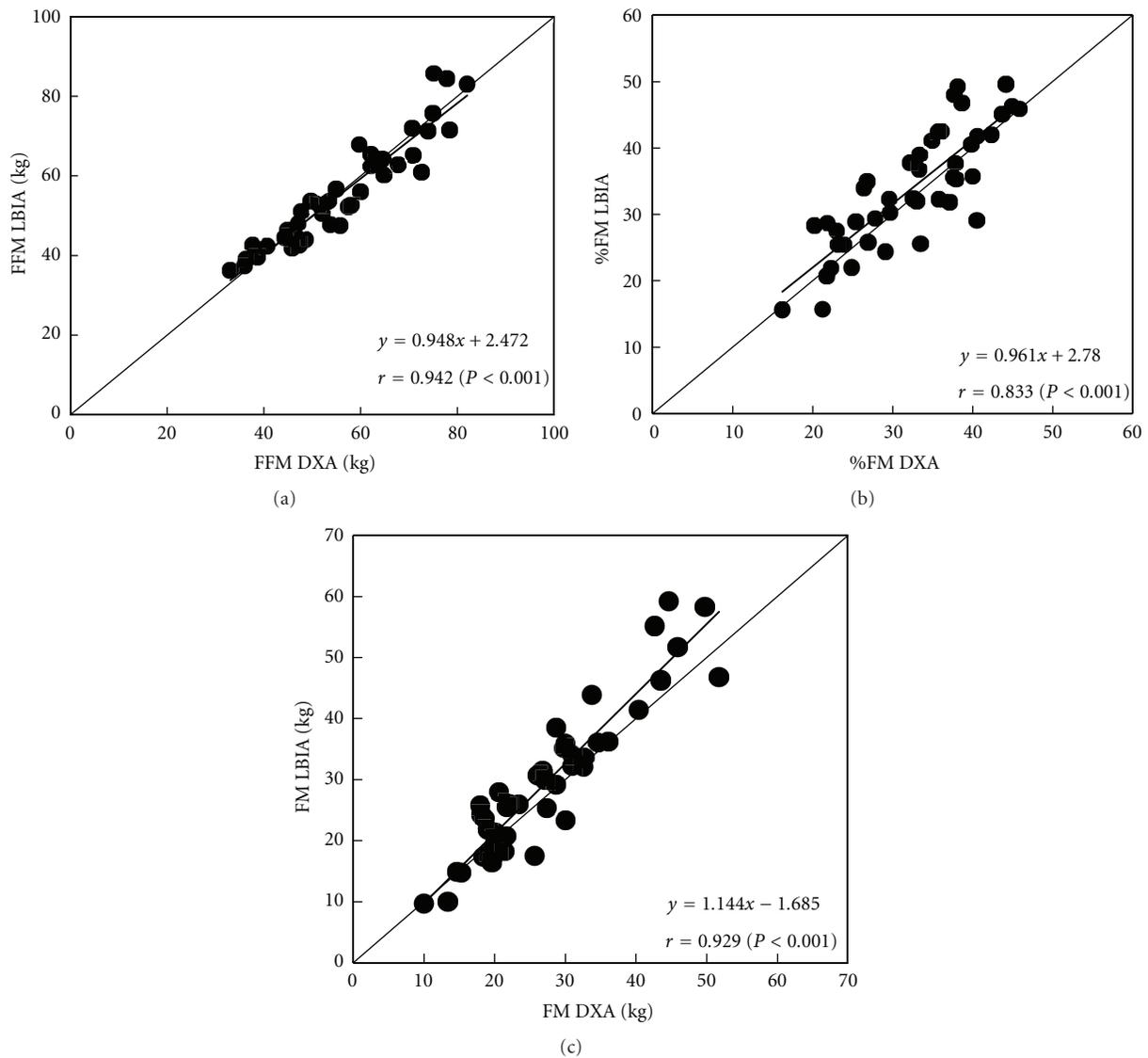


FIGURE 1: Regressions between the FFM (a), %FM (b), and FM (c) assessed by LBIA and that assessed by DXA (before intervention) DXA: dual X-ray absorptiometry; LBIA: leg-to-leg bioelectrical impedance analysis; FFM: fat free mass; %FM: percentage body fat; FM: fat mass. Solid lines regression lines, dotted lines of identity.

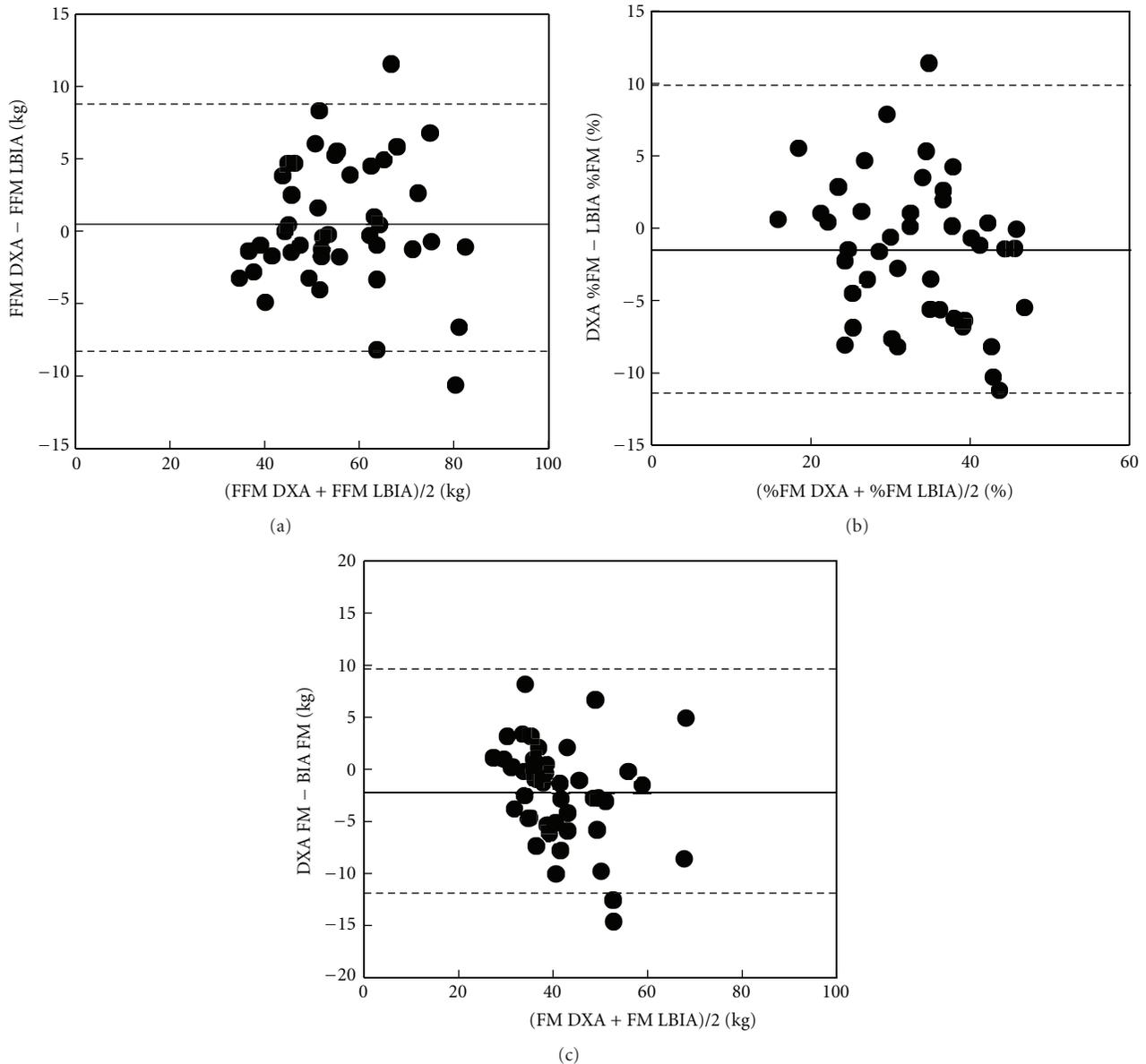


FIGURE 2: Bland-Altman plots comparing the FFM (a), %FM (b), and FM (c) assessed by LBIA and that assessed by DXA (before intervention) DXA: dual X-ray absorptiometry; LBIA: leg-to-leg bioelectrical impedance analysis; FFM: fat free mass; %FM: percentage body fat; FM: fat mass. The middle solid line represents the mean difference between LBIA and DXA; the upper and lower dotted lines represent 95% limits of agreement.

The primary purpose of this study was to investigate the utility of LBIA for assessing changes in body composition during an exercise intervention in individuals with T2DM. There were no statistically significant differences in the mean changes in all body composition variables between LBIA and DXA. Furthermore, there were strong correlations between the changes in %FM and FM measured by LBIA and DXA. These results infer relatively good LBIA accuracy, however, in the Bland-Altman plot, significant correlations were found between the mean of DXA change and LBIA change and the difference between them (Figure 4). This indicates that LBIA tends to overestimate the changes in subjects who lost

or gained more FFM (Figure 4(a)), %FM (Figure 4(b)), and FM (Figure 4(c)). Taken together, these results suggest that LBIA can qualitatively assess the changes in FFM, %FM, and FM (e.g., positive changes are estimated as positive changes), while quantitatively overestimates the changes (e.g., the amount of positive change is overestimated). No prior studies have investigated whether BIA methods, including hand-to-hand BIA and traditional tetrapolar BIA, can accurately detect quantitative changes in an individual's body composition in the T2DM population. However in a study with overweight and obese women, Thomson et al. investigated the relationship between the mean of

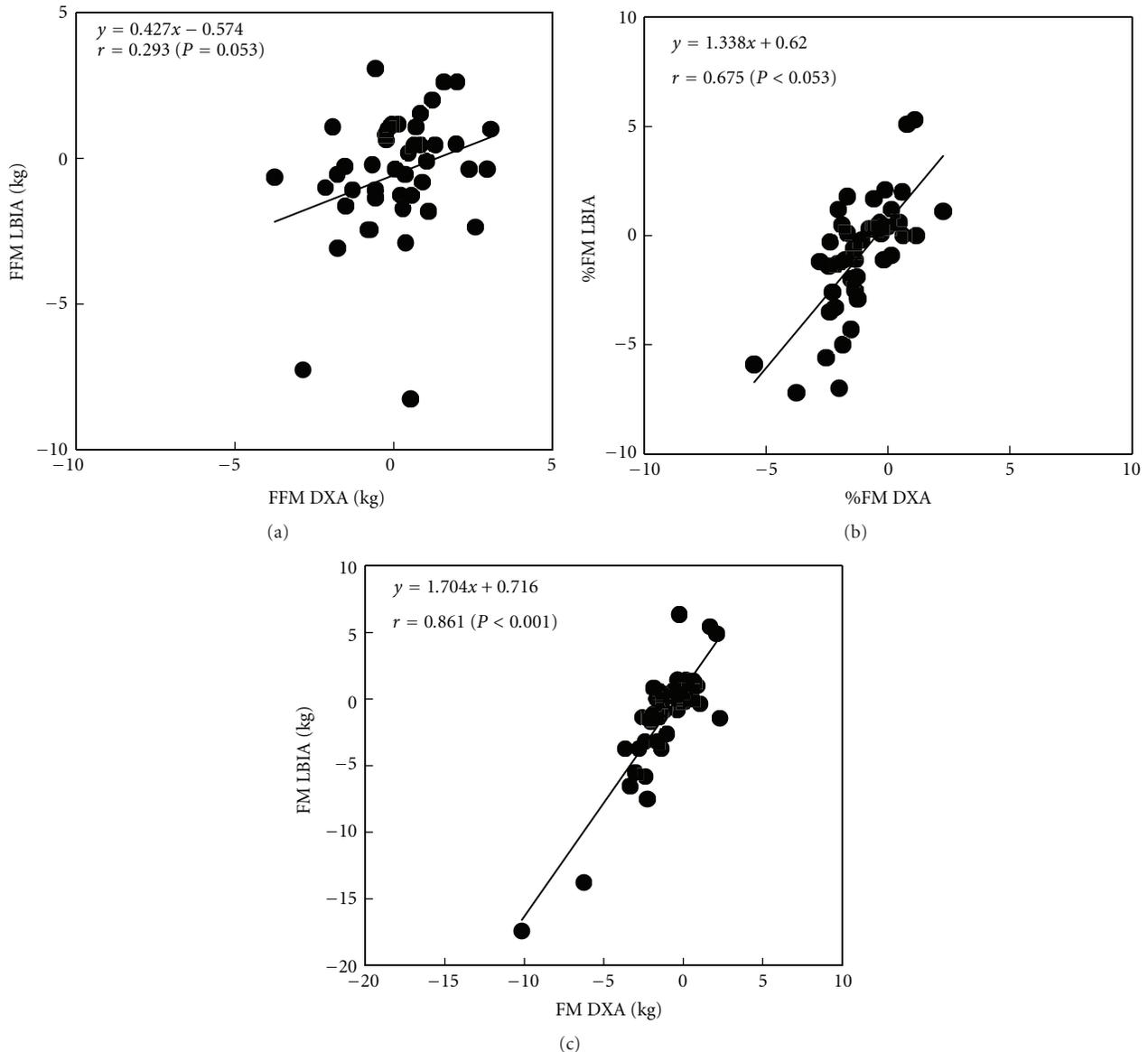


FIGURE 3: Change in FFM (a), %FM (b), and FM (c) measured by LBIA compared with DXA. DXA: dual X-ray absorptiometry; LBIA: leg-to-leg bioelectrical impedance analysis; FFM: fat free mass; %FM: percentage body fat; FM: fat mass.

DXA change and LBIA change after weight loss and the differences between them. They demonstrated that there was no systematic error. This implied that, unlike our results in people with T2DM, the quantitative changes in body composition can accurately be assessed by LBIA in obese women [12].

The mechanisms responsible for the overestimation of %FM and FM in the cross-sectional analysis and the systematic error in the changes in body composition are unclear. However, it is reasonable to hypothesize that the discrepancy is in part due to the population studied, that is, the original BIA equations were likely derived from a generally healthy population. However, our participants were all living with T2DM and had specific medical, anthropometric, and physiological characteristics. We are

unaware of the BIA equations for the specific Tanita scales used in this study to calculate body FFM, %FM, and FM. But typically BIA calculations are based on measurements of impedance, and then applied to a gender-specific equation to calculate either body density (BD) or FFM. In case of BD, BD is in turn used to calculate %FM according to standard densitometric formulae which assumes constant density of fat and FFM [13, 14]. In the case of FFM, FFM is directly used to calculate %FM with body weight. In these calculation procedures, BIA assumes density of each tissue is constant between individuals, and with time during interventions. That assumption is not justified in T2DM. In fact, previous studies in individuals with diabetes mellitus demonstrated that glycaemia and insulin treatments induce changes in water retention and distribution, bone mass,

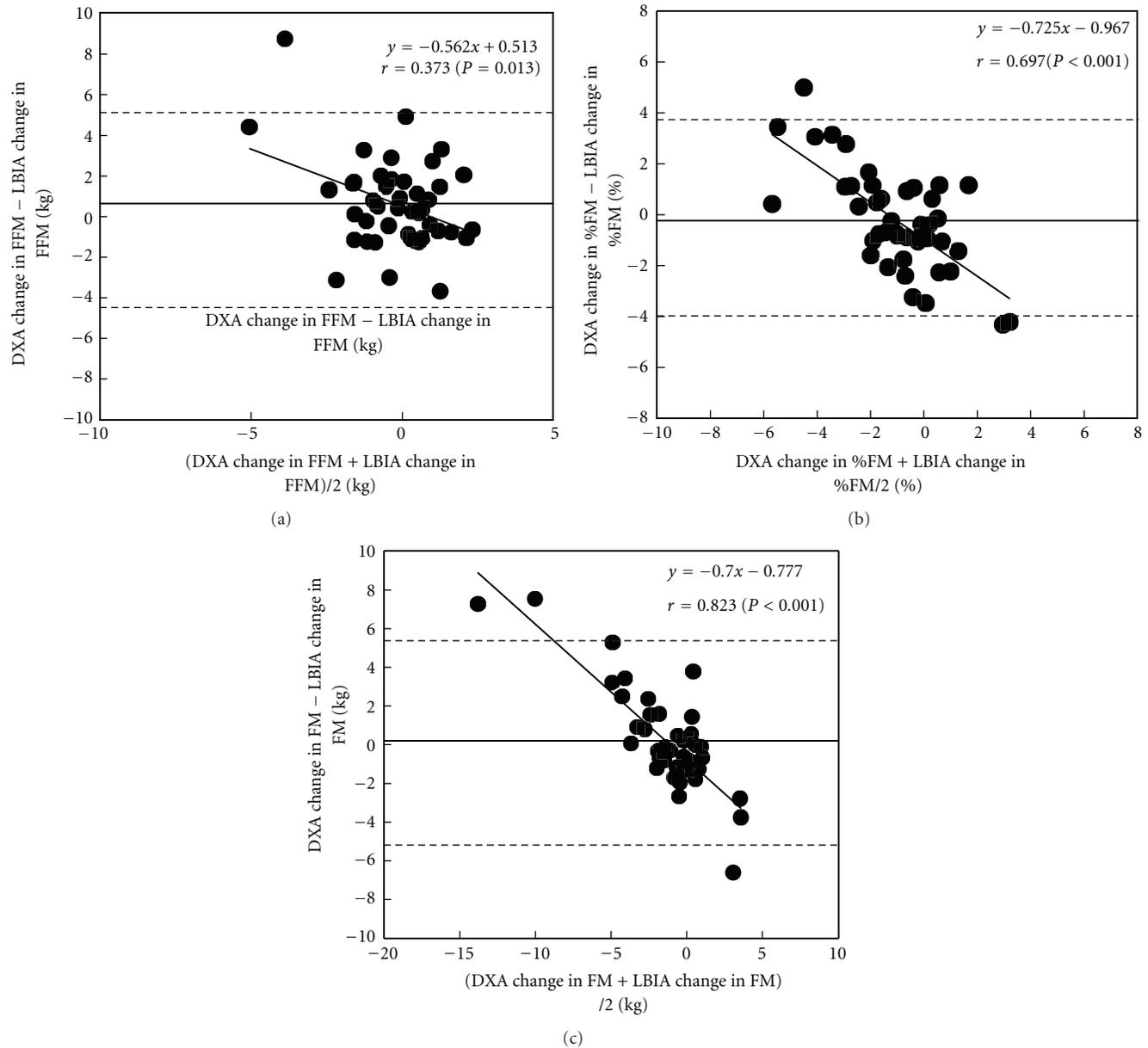


FIGURE 4: Bland-Altman plots comparing LBIA with DXA for changes in the FFM (a), %FM (b), and FM (c) after intervention. DXA: dual X-ray absorptiometry; LBIA: leg-to-leg bioelectrical impedance analysis; FFM: fat free mass; %FM: percentage body fat; FM: fat mass. The middle solid line represents the mean difference between LBIA and DXA; the upper and lower dotted lines represent 95% limits of agreement.

protein, and fat mass through the anabolic effects of insulin [15]. Others have demonstrated that hydration of FFM decreases when weight decreases in individuals with T2DM [16]. All of these aforementioned variables may have resulted in the previously derived predictive equations derived for the general population, becoming less directly applicable to our subjects with T2DM. These factors help explain the resulting lack of absolute agreement and systematic errors in determining changes in %FM and FM following the exercise intervention. Establishment of equations for assessment of body composition in individuals with T2DM using LBIA are desired as LBIA seems well suited for daily or frequent body

composition assessment among individuals with T2DM. LBIA is a relatively inexpensive and portable means of assessment, and needs minimal training to acquire data. Use of skin fold caliper as an alternative may be another option to assess body composition in individuals with T2DM. The method has worked well in other patient populations when assessors are well trained [17].

Our study has some limitations. While DXA has been consistently shown to provide an accurate assessment of body composition [3, 18, 19], and has been used as criterion methods for comparison of other techniques [20, 21], some previous studies demonstrated that using DXA as

a gold standard may lead to some errors [22, 23]. In fact, Minderico et al. demonstrated that DXA significantly overestimated changes in FM and %FM across weight loss compared with a reference four-compartment model [24]. Additionally, Doyon et al. (2011) demonstrated that it was difficult to predict changes in visceral fat using DXA in obese postmenopausal women. Another study limitation is that a gender effect on the applicability of the LBIA was not investigated in this study due to small sample size. Further study is needed to determine the applicability of the LBIA to each gender with a larger sample size.

In conclusion, our analyses show that leg-to-leg BIA could be used for cross-sectional studies or routine assessment of body composition among people with Type 2 diabetes mellitus. However, leg-to-leg BIA and DXA should not be used interchangeably. In longitudinal assessments, although the changes measured using LBIA and DXA showed high correlations, the estimated change by leg-to-leg BIA showed a systematic error, suggesting that the accuracy of LBIA is less than desired, implying that leg-to-leg BIA is appropriate for assessment of qualitative changes in body composition (gain or loss) but is not sufficiently sensitive to accurately quantify changes in body composition over several months among individuals with T2DM. Specific equations for Type 2 diabetes mellitus should be established for accurate body composition assessment in this population.

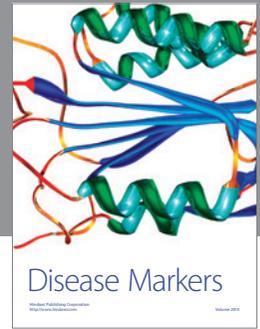
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