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ORIGINAL CONTRIBUTIONS

Agreement Between Body Composition Assessed by Bioelectrical Impedance Analysis and Doubly Labeled Water in Obese Women Submitted to Bariatric Surgery

Body Composition, BIA, and DLW

Gabriel Cunha Beato [1] · Michele Novais Ravelli [2] · Alex Harley Crisp [3] · Maria Rita Marques de Oliveira [4]

Abstract

Introduction Bariatric surgery has a significant influence on body composition (BC), which should be monitored. However, there is a need to recommend low-cost practical methods, with good estimation of BC for class III obese and/or bariatric patients.

Objective The aim of this study was to determine accuracy and agreement between BC assessed by direct segmental multifrequency bioelectrical impedance analysis (DSM-BIA) and doubly labeled water (DLW) as reference method.

Material and Methods Twenty class III obese women (age 29.3 ± 5.1 years; body mass index 44.8 ± 2.4 kg/m^2) underwent Roux-en-Y gastric bypass surgery. BC (fat mass [FM], fat-free mass [FFM], and total body water [TBW]) was assessed by InBody 230 and DLW in the following periods: before and 6 and 12 months after surgery. Accuracy between the methods was evaluated by the bias and root mean square error. Pearson's correlation, concordance correlation coefficient (CCC), and Bland-Altman method were used to evaluate agreement between the methods.

Results Correlations were significant ($p < 0.001$) and CCC was good/excellent between both methods for the evaluation of FM ($r = 0.84$–0.92, CCC = 0.84–0.95), FFM ($r = 0.73$–0.90, CCC = 0.68–0.80), and TBW ($r = 0.76$–0.91, CCC = 0.72–0.81) before and after bariatric surgery. In addition, no significant bias was observed between DSM-BIA and DLW for FM (mean error [ME] = -1.40 to 0.06 kg), FFM (ME = 0.91–1.86 kg), and TBW (ME = 0.71–1.24 kg) measurements.

Conclusion The DSM-BIA was able to estimate the BC of class III obese women submitted to bariatric surgery with values consistent with those of the DLW method.

Keywords Body composition · Bariatric surgery · Bioimpedance analysis · Total body water · Fat mass · Fat-free mass · DSM-BIA

✉ Gabriel Cunha Beato
gabrielcbeato@gmail.com

1   School of Pharmaceutical Sciences, São Paulo State University (UNESP), Araraquara-Jaú Road, km 01, s/n, Araraquara, SP 14800-903, Brazil

2   Institute of Biosciences, São Paulo State University (UNESP), Antônio Celso Wagner Zanin, 250, Botucatu, SP 18618-689, Brazil

3   Methodist University of Piracicaba, Sugar Road, Km 156, Taquaral, Piracicaba, SP 13400-911, Brazil

4   Department of Education, Institute of Biosciences, São Paulo State University (UNESP), Antônio Celso Wagner Zanin, 250, Botucatu, SP 18618-689, Brazil

Introduction

The monitoring of body composition is very important for individuals undergoing bariatric surgery because the ideal body mass loss must be associated with a decrease in the body fat mass and maintenance of the body fat-free mass short- and long-term after surgery [1, 2]. The follow-up of body composition changes may support the medical care to better monitor the nutritional status of the patient, which can be affected in certain cases of malnutrition after the surgery [3].

At present, bariatric surgery is considered the most effective method for the control of class III obesity (body mass index [BMI] > 40 kg/m^2) associated or not to comorbidities. In addition to the direct effect of energy intake restriction, the surgery plays an important role in the control of hormonal concentrations that contribute to prolonged long-term body

mass loss, remission of several obesity-related comorbidities, and reduction in mortality [4, 5].

The doubly labeled water (DLW) method has been proposed as a gold standard to assess free-living total energy expenditure and can be used to monitor the body composition. It can estimate fat-free mass (FFM), fat mass (FM), and total body water volume (TBW) of an individual from dilution equations of the isotopic material in the body [6]. However, this method is costly, requires specialized professionals to manipulate, and is difficult to perform in clinical practice [6, 7].

One of the major challenges in clinical practice has been the difficulty to measure fat mass and fat-free mass outside the laboratory with low-cost methods and which requires minimal technical skills. In this sense, bioelectrical impedance analysis (BIA) is considered a practical, non-invasive, and relatively inexpensive method to quickly assess the body composition. The methods consist of the passage of imperceptible low-amplitude electric currents that measure resistance and reactance values to estimate TBW, FFM, and FM [2, 8, 9].

Despite the wide use of the BIA equipment in research and clinical practice, when used in class III obese and bariatric patients, caution should be taken in the interpretation of its results. The body geometry and a relative increase of extracellular water and TBW are factors that can compromise BIA accuracy of body composition estimates in obese subjects. [8, 10, 11]. Nowadays, BIA technology has evolved, and a technology called direct segmental multifrequency bioelectrical impedance analysis (DSM-BIA) uses multiple frequencies at five segments of the body (whole body, both feet, and hands) to estimate body composition with higher accuracy compared to single-frequency BIA [12].

Several studies in the literature have used different BIA for the assessment of body composition in obese [13–17] and bariatric surgery patients [13, 18–21]. However, there is no scientific or medical consensus on the use of a particular type of BIA to evaluate the bariatric population. Therefore, the choice between the body composition assessment methods available should consider their accuracy and their inherent biases and limitations [22].

To the best of our knowledge, no study has verified the accuracy of the DSM-BIA method to evaluate class III obese subjects and follow-up changes in FFM and FM in response to bariatric surgery. Simple and accurate devices to monitor body composition before and after bariatric surgery are important for clinical practice. Therefore, this study aimed to determine the level of accuracy and agreement between body composition measurements by DSM-BIA in comparison to DLW (reference method) in the follow-up of class III obese women submitted to the Roux-en-Y gastric bypass (RYGB) surgery.

Materials and Methods

Study Design

This is a longitudinal study designed to verify the agreement and accuracy between the estimation of body composition by the DSM-BIA equipment InBody 230 (BioSpace, Seoul, Korea) and the doubly labeled water as the reference method in women submitted to bariatric surgery. For this purpose, body composition analyses were performed by both methods in three moments: preoperative (M1), and 6 months (M2) and 12 months (M3) after the RYGB surgery. At each moment of data collection, the subjects visited the laboratory three times. At the first meeting, the subjects received verbal instructions on the procedures and preparation for the DSM-BIA and DLW test. At the second meeting, the DSM-BIA assessment was performed, baseline urine sample was collected, and a dose of DLW ($^2H_2^{18}O$) was given. At the third meeting (14 days after the second meeting), the volunteers returned with the refrigerated urine samples, which were collected daily.

Subjects

Twenty class III obese women (age 29.3 ± 5.1 years, body mass index 44.8 ± 2.4 kg/m^2) who were on the waiting list for bariatric surgery volunteered to participate in the study.

The inclusion criteria for participation in the study were premenopausal female; age between 20 and 45 years; body mass index > 40 kg/m^2 and < 60 kg/m^2; waiting for the bariatric surgery; without any disease that changes the energetic metabolism such as diabetes mellitus, hypothyroidism, HIV infection, cancer, heart, and liver or kidney diseases, or edema-causing conditions such as venous insufficiency, pregnancy, thrombosis, sepsis, inflammation, and lymphedema; not consuming drugs that cause metabolic and absorptive changes such as diuretics, amphetamines, thyroid hormones, topiramate, orlistat, and corticosteroids.

The subjects who did not meet inclusion criteria, who did not complete all stages of the study, and whose samples were not sufficient or were not in optimal conditions for analysis were excluded from the study. All subjects were recruited from the same bariatric center and underwent RYGB surgery performed by the same medical staff. Power calculations showed that 17 subjects needed to attain a statistical power of at least 0.90, with an expected moderate correlation coefficient of 0.70 (based on body fat mass as primary outcome), and two-sided alpha level of 0.05.

Bioimpedance Analysis

Body composition was determined by a vertical direct segmental multifrequency BIA analyzer (InBody 230;

BioSpace, Seoul, South Korea). The equipment uses the multifrequential system (10 measures of impedance in the frequency of 20 and 100 kHz) of tetrapolar electrodes with an eight-point tactile electrode. The information of FM, FFM, and TBW were obtained by the Lookin'Body Software version LBM.1.2.0.16.

On the day of BIA measurements, the volunteers were instructed to not shower, to fast for 3 h (including water), to empty the bowel and bladder previously (at least 30 min before), to refrain from strenuous exercise 24 h prior to the test, and to not wear any metallic accessories (e.g., watches, rings, earrings) during the test. During the evaluation, the women stood on the equipment with light clothing for the determination of body weight, in kilograms; they placed their hands and feet on the instrument's tactile electrodes for the measurement of impedance, according to the manufacturer's instructions.

Doubly Labeled Water

The DLW method was used as a reference method for the determination of the body composition. This method's protocol consisted of the ingestion of a standard oral dose composed of 2 g per kilogram of the total body water (about 50% of the total body mass) of oxygen-18 (^{18}O) enriched to 10.8 atoms% and 0.12 g per kilogram of total body water of deuterium (^{2}H) enriched to 99.8 atoms%. The volunteers were instructed to fast for 12 h and were allowed to drink only water. The ingestion of the DLW (^{2}H$_2$^{18}O) was performed with a straw to avoid losses. Then, 50 ml of drinking water was added in the standard oral dose recipient to ensure the ingestion of all isotopic components.

Urine samples were collected prior to intake of the DLW and daily for 14 days. The women were instructed to collect the sample at the same time every day, to identify the collection containers, and to not use the first urine of the day. These samples were kept under refrigeration until the moment of delivery in the clinic, where they were pipetted in cryotubes with capacity of 4.5 ml, sealed with parafilm and kept under refrigeration until analysis.

The basal samples were analyzed in triplicate at the 1st, 2nd, 3rd, 13th, and 14th day after the standard oral dose in an isotope ratio mass spectrometer (IRMS), Hydra 20–20 and Hydra 20–22, Europe Scientific-Cheshire/UK®, to obtain the isotopic turnover of the enriched components in body water.

The determination of the body composition occurred from formulas to obtain the water dilution spaces of the stable isotopes in relation to the basal values [23]. The determination of the FFM considered the hydration constant of this tissue composed of 73.2% of water. The FM was obtained by subtracting this value from the body mass [23]. All body composition data were expressed in kilograms and treated as independent variables.

It was not possible to compare DLW and data obtained with the BIA from two subjects in M3 due to incorrect sample collection.

Statistic Analysis

Values are given as mean ± SD. Differences between the means obtained in the three moments of the research were analyzed by ANOVA for repeated measures while the differences between the methods were evaluated by the t test for independent samples. The Pearson correlation coefficient (r) was used to explore the relationship between the variables obtained with the body composition assessment methods at each time point. To evaluate the agreement between the variables obtained with the methods, the concordance and correlation coefficient (CCC) was calculated [24], with the classification proposed by Altman [25]: poor (≤ 0.20), weak (0.21–0.40), moderate (0.41–0.60), good (0.61–0.80), and excellent (0.81–1.00).

The graphical approach of Bland-Altman [25] was also used to explore the agreement of the variables between the methods of evaluation of body composition in the three moments through the mean difference between each variable against the mean values.

The accuracy between the methods was evaluated by the calculation of mean error (ME), mean square error (MSE), and root mean square error (RMSE) [26]. p values < 0.05 were considered significant.

Results

The results reported in Table 1 show that for both methods of assessment of the body composition there was a significant decrease of the body components analyzed between M1 and M2. For M3, only FM presented reduced values ($p < 0.05$) when compared to M1, for both methods. There was no significant difference between methods in the change in TBW, FFM, and FT after surgery (Δ values of M2 and M3).

Table 2 shows the values of accuracy and agreement between BIA and DLW method. The Pearson's correlation coefficient test indicates a significant ($p < 0.001$) concordance (r value between 0.73 and 0.92) between both methods in M1, M2, and M3. An excellent agreement was evident for TBW (CCC = 0.81) and FM (CCC = 0.84 and 0.95) values at M1 and M2. For the other variables at other moments, a good agreement (CCC between 0.68 and 0.80) was observed. The accuracy analysis revealed that ME, MSE, and RMSE were better for TBW than FFM, but still with acceptable bias levels.

These findings were also confirmed by the analysis of the Bland-Altman graphs which show that most individuals were concentrated between the upper and lower 95% limits of agreement (Fig. 1).

Table 1 Body composition variables obtained by bioelectrical impedance analysis and doubly labeled water before and 6 and 12 months after bariatric surgery

Variables		M1 (n = 20)	M2 (n = 20)	M3 (n = 18)	Δ M2 Δ value	Δ M3 Δ value
DLW	TBW (kg)	39.34 ± 3.43 [a,A]	35.48 ± 3.42 [b,A]	35.13 ± 3.33 [b,A]	− 3.86 ± 1.45 [A]	− 4.42 ± 3.10 [A]
	FFM (kg)	53.89 ± 4.70 [a,A]	48.60 ± 4.68 [b,A]	48.13 ± 4.57 [b,A]	− 5.29 ± 1.98 [A]	− 6.06 ± 4.24 [A]
	FM (kg)	58.48 ± 5,67 [a,A]	33.17 ± 7.17 [b,A]	26.07 ± 6.35 [c,A]	− 25.31 ± 4.57 [A]	− 32.31 ± 5.51 [A]
BIA	TBW (kg)	38.63 ± 2.64 [a,A]	34.24 ± 2.68 [b,A]	34.06 ± 3.07 [b,A]	− 4.39 ± 1.02 [A]	− 4.64 ± 1.45 [A]
	FFM (kg)	52.98 ± 3.42 [a,A]	46.74 ± 3.69 [b,A]	46.52 ± 4.19 [b,A]	− 6.24 ± 2.32 [A]	− 6.14 ± 1.96 [A]
	FM (kg)	58.42 ± 5.48 [a,A]	33.43 ± 6.99 [b,A]	27.47 ± 7.04 [c,A]	− 24.99 ± 5.65 [A]	− 31.42 ± 6.36 [A]

Different lowercase and uppercase letters indicate, respectively, statistical differences between the means of the periods and the methods; $p < 0.05$. Data expressed as mean ± SD

M1, preoperative moment; *M2*, moment 6 months; *M3*, moment 12 months; *Δ M2*, difference between M2 and M1; *Δ M2*, difference between M3 and M2; *DLW*, doubly labeled water; *BIA*, bioelectrical impedance; *TBW*, total body water; *FFM*, fat-free mass; *FM*, fat mass

Discussion

The present study determines the accuracy and agreement between DSM-BIA and DLW to estimate body composition in the follow-up of class III obese patients after bariatric surgery. Our findings indicate that DSM-BIA proved to be a good tool for providing body composition data with a good level of agreement in relation to the results obtained with the DLW method. Moreover, the device tested (InBody 230) was viable for tracking changes in TBW, FFM, and FM after bariatric surgery in the population studied.

The significant loss of body weight after the bariatric surgery is a well-established fact in the literature [13, 18, 19, 21, 27]. However, unhealthy fat-free mass loss may occur if there

is no adequate dietary intake (malnutrition). The hydration state of these individuals can also lead to adverse health conditions due to the excess or the reduction of body water levels [1, 3, 28]. The need to monitor this body composition after the surgical intervention to prevent health problems and to improve the long-term postoperative results is evident.

The DSM-BIA method assumes that the human body consists of five interconnecting cylinders and measures the direct impedance of the subject's trunk, arms, and legs at different frequencies (in the case of InBody 230, at 20 and 100 kHz). Compared to single-frequency BIA, DSM-BIA presents better determination of the distribution of TBW and favors a better estimation of the FFM [29]. However, it should be highlighted that the model InBody 230 is not the latest and possibly not

Table 2 Agreement and accuracy level between body composition variables by bioelectrical impedance analysis and doubly labeled water before and 6 and 12 months after bariatric surgery

Variables	Correlation (95% CI)	CCC (95% CI)	ME (kg)	MSE (kg)	RMSE (kg)
M1					
TBW (kg)	0.86 (0.68–0.95)*	0.81 (0.63–0.91)	0.71	3.41	1.85
FFM (kg)	0.73 (0.43–0.89)*	0.68 (0.40–0.84)	0.91	10.60	3.25
FM (kg)	0.84 (0.63–0.93)*	0.84 (0.64–0.93)	0.06	9.51	3.08
M2					
TBW (kg)	0.91 (0.78–0.96)*	0.81 (0.64–0.91)	1.24	3.66	1.91
FFM (kg)	0.90 (0.77–0.96)*	0.80 (0.61–0.90)	1.86	7.51	2.74
FM (kg)	0.95 (0.89–0.98)*	0.95 (0.89–0.98)	− 0.26	4.36	2.09
M3					
TBW (kg)	0.76 (0.46–0.91)*	0.72 (0.42–0.88)	1.08	5.76	2.40
FFM (kg)	0.77 (0.48–0.91)*	0.72 (0.42–0.88)	1.61	10.96	3.31
FM (kg)	0.92 (0.80–0.97)*	0.90 (0.76–0.96)	− 1.40	8.77	2.96

CCC, coefficient of concordance and correlation; *95% CI*, 95% confidence intervals; *ME*, mean error; *MSE*, mean square error; *RMSE*, root mean square error; *M1*, preoperative moment; *M2*, moment 6 months; *M3*, moment 12 months; *DLW*, doubly labeled water; *BIA*, bioelectrical impedance; *TBW*, total body water; *FFM*, fat-free mass; *FM*, fat mass

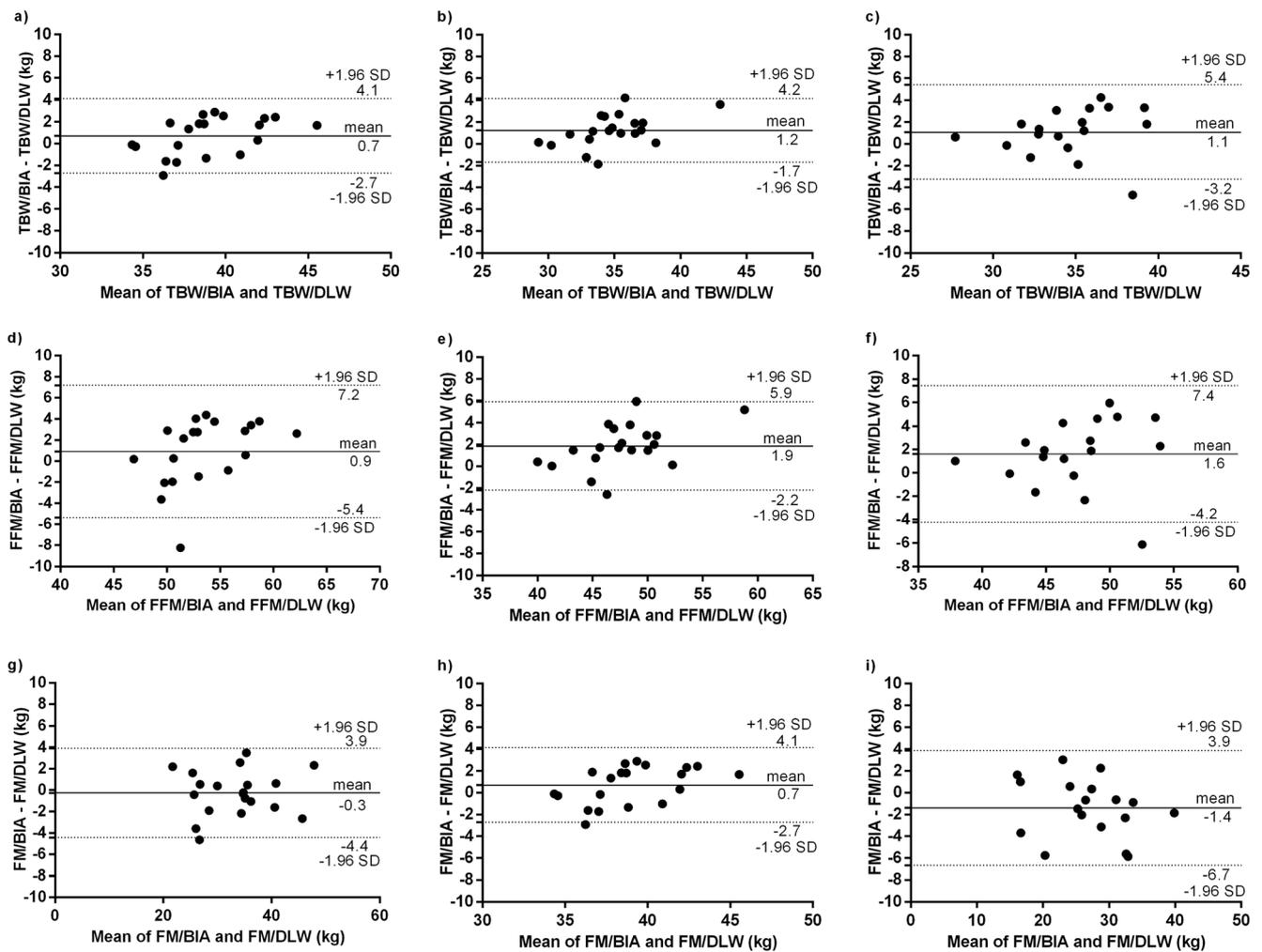*Statistically significant correlation, $p < 0.05$

Fig. 1 Bland-Altman plots of the difference between bioelectrical impedance analysis and doubly labeled water measurements of total body water (TBW), fat mass (FM), and fat-free mass (FFM) at baseline (M1: **a**, **d**, **g**), and during the follow-up at 6 (M2: **b**, **e**, **h**) and 12 months (M3: **c**, **f**, **i**)

the most accurate DSM-BIA device from InBody available nowadays. Nevertheless, the device tested under the conditions of this study proved to be a viable alternative to estimate the body composition.

It is difficult to compare the results presented here with other studies due to the differences in the BIA equipment and technology that have been validated in the literature. A previous study [30] showed that the InBody 230 model provided a strong correlation with dual-energy X-ray absorptiometry (DXA) to estimate total FFM and FM in apparently healthy men and women (mean BMI 24.5 ± 3.8 kg/m^2). Regarding severely obese subjects, Faria et al. [31] reported that the InBody 720 model (measuring impedance at six different frequencies: 1 kHz, 5 kHz, 50 kHz, 250 kHz, 500 kHz, 1000 kHz) had a high intraclass correlation coefficient with DXA for estimating FFM and FM in patients waiting for bariatric surgery (BMI $\geq$ 35 kg/m^2 with comorbidities or BMI $\geq$ 40 kg/m^2).

When compared to other methods of assessment of body composition, the BIA results are still conflicting. In obese

adolescents, segmental tetrapolar multifrequency BIA was accurate for determining body composition, but this accuracy was not observed in morbid obese adolescents [32]. Faria and colleagues found a greater effectiveness of the InBody 230 for assessing the body fat of eutrophic and overweight adolescents compared to direct horizontal tetrapolar single-frequency BIA [33].

Regarding changes in body composition after a massive body mass loss, two other studies [18, 19] have shown good agreement between single-frequency BIA compared to reference methods when determining changes in FFM and FM at 6 and 12 months after bariatric surgery. However, no study analyzed the agreement of DSM-BIA with a reference method to assess body composition changes after bariatric surgery. Thus, our study contributes with new findings to the current literature, showing that the InBody 230 model (DSM-BIA) has good agreement with DLW for assessing total body composition changes at 6 and 12 months after RYGB surgery.

It is known that higher amounts of body fat mass can negatively affect the accuracy of the measurements obtained with BIA [34]. Moreover, the body water distribution may interfere with the results as obesity is associated with higher body water levels. The elevated extracellular water levels compared to intracellular water levels may affect the evaluation of the body composition of obese patients [12].

The type of equipment seems to influence the results too. The problems seem to be concentrated in the algorithms used to calculate the body segments in the different types of BIA equipment used in research [35]. When applied to the same subjects, different types of BIA provided non-concordant results in the assessment of body composition [35–37]. This may explain divergences between results obtained with BIA.

However, the data presented here must be analyzed with caution. Although the results of the CCC analysis were positive, the confidence intervals of these measures show that the classifications can be changed according to the actual value. Analyses of the Bland-Altman graphs reveal that in some cases there is a tendency for DSM-BIA to overestimate body components. Thus, long-term follow-up is indicated for a better understanding of DSM-BIA in relation to the reference standard.

Some limitations of this study need to be addressed. First, the sample of female bariatric patients precludes generalizing the results to male subjects. Another important aspect to highlight was that hydration status was not analyzed in the study (e.g., urine-specific gravity). However, the subjects followed a strict testing protocol for all evaluation sessions as described in the methods section.

DXA is recognized as a standard method to measure bone mineral density and is also often used as a reference method to measure body composition (fat mass and fat-free mass) [7, 9]. However, there are some problems regarding instrument size and weight capacity to evaluate severely obese subjects [38] which limited the execution of this analysis in the study.

DLW is a gold standard method for the assessment of the total energy expenditure. Although this method is not considered a gold standard method for the assessment of body composition, it can estimate the body composition by determining the water dilution in the whole body [6]. Das et al. [39] and Levitt et al. [40] which used air displacement plethysmography and DXA, respectively, to compare % FM in relation to that obtained from stable isotope (labeled water), showed that changes in the FFM hydration after bariatric surgery were not different from the reference value (73%), concluding that these changes do not represent abnormal changes in fluid balance.

In the present study, the DLW was used as a reference method for assessing body composition due to the proposal of evaluation of the total energy expenditure of class III obese women after bariatric surgery in another study of the research group [41].

The positive preliminary results of this paper suggest that the direct segmental multifrequency tetrapolar BIA can be used to monitor the changes in the body composition of obese subjects submitted to bariatric surgery. Studies with a larger sample size are necessary to test the sensitivity and specificity of the DSM-BIA in relation to DLW or to the dilution of deuterium oxide. The validation of this technique in the population submitted to bariatric surgery is advised to assess the FM, FFM, and the distribution of water in the body compartments (intracellular and extracellular).

Conclusion

The DSM-BIA, under the conditions of this study, was able to estimate the body composition of class III obese women submitted to bariatric surgery with values consistent with those of the DLW method, suggesting its use in clinical practice with a good level of confidence.

Compliance with Ethical Standards

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