Evaluation of multi-frequency bioelectrical impedance analysis for the assessment of body composition in individuals with obesity

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Summary

Objective

The purpose of this study was to compare body composition measurements estimated by multi-frequency bioelectrical impedance analysis (MF-BIA) with air displacement plethysmography (ADP) in individuals with obesity.

Methods

Bariatric patients were recruited from Geisinger's Center for Nutrition and Weight Management Clinic in Danville, Pennsylvania. Sixty-two participants (age = 52.4 ± 9.3 years; body mass index = 38.9 ± 8.0 kg m^{-2}) reported for a same-day testing visit. Body composition was measured using a common MF-BIA analyzer (InBody 720, Biospace Co., Beverly Hills, CA) and ADP.

Results

Strong relationships were observed between MF-BIA and ADP methods ($r = 0.88$–0.96, $P < 0.001$). There were no differences between MF-BIA and ADP measures of per cent body fat, fat mass or fat-free mass for the total sample or when examined by gender.

Conclusions

The InBody 720 MF-BIA analyzer produced body composition measurements that were similar to ADP supporting the use of this technology in the obese population.

Keywords: Bioelectrical impedance analysis (BIA), body composition, obesity.

Introduction

Body composition assessment is an important tool for identifying and assessing the health status of an individual (1). Conducting body composition assessments on obese and extremely obese individuals can be challenging because of altered or varying body hydration, fat-free mass (FFM) composition and limitations based on physical size (2). To track weight loss change, various body composition methods are used in this population (1–3). Methods such as waist circumference measurements, dual-energy X-ray absorptiometry (DXA), air displacement plethysmography (ADP) and bioelectrical impedance analysis (BIA) are all used to measure body composition.

While there are multiple ways to measure body composition, not all methods are practical for the obese population or a bariatric clinical setting. Although DXA has been shown to provide accurate measurements in normal weight adults (4), limitations have been identified in other populations (5–7). For instance, DXA has been shown to significantly underestimate FFM and overestimate fat mass (FM) in the elderly and those with obesity (6,7). In terms of practicality, DXA is not the most applicable method of assessment because of a high cost and need of a trained technician to conduct the test. ADP, a two-component body densitometry method similar to underwater weighing, uses air rather than water displacement to determine body volume. Because ADP has been found to provide similar body composition measurements as underwater weighing (8,9), it has been recognized as a valid method of assessment. ADP is fast and easy to operate and comes with preprogrammed multiple population-specific body composition equations.

Bioelectrical impedance analysis is a rapid, portable and non-invasive method of assessment that is less expensive than traditional laboratory methods (e.g. DXA and ADP). BIA devices do not require a high degree of technical skill to operate, leading to increasing popularity in variety of areas including nutrition, wellness and clinical settings (10–13). The development of the contact electrode system has increased the ease of use compared with the traditional method of applying electrodes at designated anatomical landmarks. During the assessment, BIA analyzers introduce a small electrical current into the body and measure the resistance, or impedance, to current flow (14). FFM is composed of a high electrolyte and water content, which produces high conductivity, making it an excellent conductor of electrical current. Conversely, FM contains low electrolyte and water content, creating a higher impedance resulting in a low conduction of electrical current (14). Preprogrammed equations estimate per cent body fat (%BF) and provide estimations of FM and FFM during the assessment (14). Multi-frequency bioelectrical impedance analysis (MF-BIA) technology utilizes different electrical frequencies (1 to 1,000 kHz), to estimate extracellular water, intracellular water, total body water and FFM (15). MF-BIA technology may be beneficial to weight loss clinics because of the ease of use, relatively short measurement time and maximum scale weighing properties (10).

Although previous investigations have reported significant correlations between MF-BIA and ADP for the assessment of body composition in relatively healthy individuals (11,16), an examination of this technology has not been conducted in the obese population. Therefore, the purpose of this study was to compare body composition measurements estimated by MF-BIA with ADP, the reference method of assessment, in individuals with obesity.

Methods

Participants

Bariatric patients were recruited from Geisinger's Center for Nutrition and Weight Management Clinic in Danville, Pennsylvania. Prior to testing, each participant reviewed and signed an informed consent. The study was approved by the Geisinger Medical Center Institutional Review Board.

Study protocol for body composition

Each participant reported to the Metabolic Laboratory located in the Geisinger's Center for Nutrition and Weight Management Clinic for 1 d of testing. Height (cm) and weight (kg) were measured using a wall-mounted stadiometer (Seca North America, Chino, CA) and digital scale (Tanita Corporation of America, Inc., Arlington Heights, IL).

Pretesting guidelines

All participants adhered to the following manufacturer-recommended pretesting guidelines; (a) no physical exercise within 12 h of the scheduled test, (b) no eating or drinking within 2 h of the test, (c) empty bladder within 30 min of the test, (d) no alcohol consumption within 48 h of the test and (e) no diuretic medications within 7 d of the test.

Multi-frequency bioelectrical impedance analysis

Multi-frequency bioelectrical impedance analysis measurements were conducted using the InBody 720 (Biospace Co., Beverly Hills, CA). Participants wore shorts and a T-shirt and wiped both hands and feet with an antibacterial electrode wipe for conduction as part of MF-BIA pretesting guidelines. In ordinance with the manufacturer's recommendations, participants stood erect on the device with both arms extended and abducted from the trunk. The InBody 720 measured impedance at varying frequencies (1, 5, 50, 250, 500 and 1,000 kHz) across the legs, arms and trunk. All four extremities were in contact with the electrodes, and the participant stood with bare feet on the device until completion of test. Measurements of total body water, %BF, FM, FFM and lean body mass were obtained.

Air displacement plethysmography

Air displacement plethysmography measurements were conducted using the BodPod® (Life Measurement Instruments, Concord, CA). Participants changed into form-fitting compression clothing and a Lycra(R) swim cap (TYR Sport, Inc., Huntington Beach, CA) per pretesting guidelines for assessment. Prior to each test, the BodPod was calibrated following the manufacturer's instructions using a cylinder of a known volume. After entering the chamber, the participant was instructed to breathe normally for two measurements of body volume, which lasted approximately 45 s each. If a difference of 150 mL or greater was produced by the two body volumes, a third measurement was performed. Thoracic gas volume was measured from standard plethysmographic technique in 21 and predicted using preprogrammed equations in 41 participants. McCrory *et al*. found no statistically significant difference between measured and predicted thoracic gas volumes (17).

Following test completion, the computer automatically calculated %BF with the determined body density from the Brozek equation: % Fat = $(4.57/D_b - 4.142) * 100$ (18). The Brozek equation was selected because the Siri equation has been shown to overestimate %BF by 2–4% in obese individuals (14) and produce relatively higher %BF estimates than the Brozek equation in individuals with over 30% of BF (19).

Statistical analyses

All data values are reported as mean ± standard deviation. Data were analysed using SigmaPlot 13 for Windows (Systat Software Inc., San Jose, CA). Paired sample *t*-tests were used to compare mean %BF, FFM and FM between methods. The significance level was set a priori at $P \leq 0.05$. Relationships between both assessment methods were examined for %BF, FFM and FM. Pearson correlations were calculated to determine the agreement between the two body composition devices. Bland–Altman plots were used to assess intra-individual differences for %BF, FFM and FM.

Results

Participant characteristics of the 62 adults (37 women and 25 men) that participated in this investigation are presented in Table 1. All participants were classified as obese with an average body mass index (BMI) of $38.9 \pm 8.0 \text{ kg m}^{-2}$.

Table 2 presents the %BF data (means ± standard deviation) and the relationship between MF-BIA and ADP for all participants and separately as a function of gender. No differences were observed in %BF for the total sample or when examined by gender (Table 2). Strong relationships were also observed between methods ($r = 0.88$–0.96, $P < 0.001$), and standard error of estimate (SEE) values were rated according to Lohman (20) as 'very good' (range = 2.6–2.8%; Table 2). A Bland–Altman plot of the individual agreement in %BF between ADP and MF-BIA is depicted in Figure 1. No systematic bias was observed for the total sample. Seventy-two per cent of men and 84% of women were within the ±3.5% minimally acceptable standard for accuracy (Figure 1).

The relationship for FM between MF-BIA and ADP in all participants and separately as a function of gender is presented in Table 3. No differences were observed in FM for the total sample or when examined relative to gender (Table 3). Strong relationships were observed between MF-BIA and ADP ($r = 0.99$, $P < 0.001$), and SEE ranged from 2.8 to 3.2 kg (Table 3). A Bland–Altman plot for individual agreement in FM between ADP and MF-BIA measurements is depicted in Figure 2. No systematic bias was observed in this sample (Figure 2).

Table 1 Participant characteristics

Participants	Age (years)	Height (cm)	Body mass (kg)	BMI (kg m^{-2})
Total (*n* = 62)	52.4 ± 9.3	164.9 ± 9.2	111.6 ± 24.0	38.9 ± 8.0
Women (*n* = 37)	50.7 ± 10.2	163.3 ± 5.2	109.1 ± 23.0	40.9 ± 8.5
Men (*n* = 28)	55.0 ± 7.0	179.1 ± 5.8	114.3 ± 24.3	35.4 ± 6.1

All values are mean ± standard deviation.
BMI, body mass index.

Table 2 Comparison of per cent body fat between MF-BIA and ADP

Participant and method	Body fat (%)	*r*	MD (%)	SEE (%)	Subjective SEE rating
Total (*n* = 62)					
ADP	43.3 ± 9.1				
MF-BIA	43.4 ± 9.7	0.96*	−0.1 ± 2.8	2.6	Very good
Women (*n* = 37)					
ADP	48.6 ± 5.4				
MF-BIA	49.2 ± 5.0	0.88*	−0.6 ± 2.6	2.6	Very good
Men (*n* = 25)					
ADP	35.9 ± 7.6				
MF-BIA	34.8 ± 8.4	0.93*	0.7 ± 3.0	2.8	Very good

All values are mean ± standard deviation.
ADP, air displacement plethysmography; MD, mean difference; MF-BIA: multi-frequency bioelectrical impedance analysis; SEE, standard error of estimate.
*Significant at $P < 0.001$.
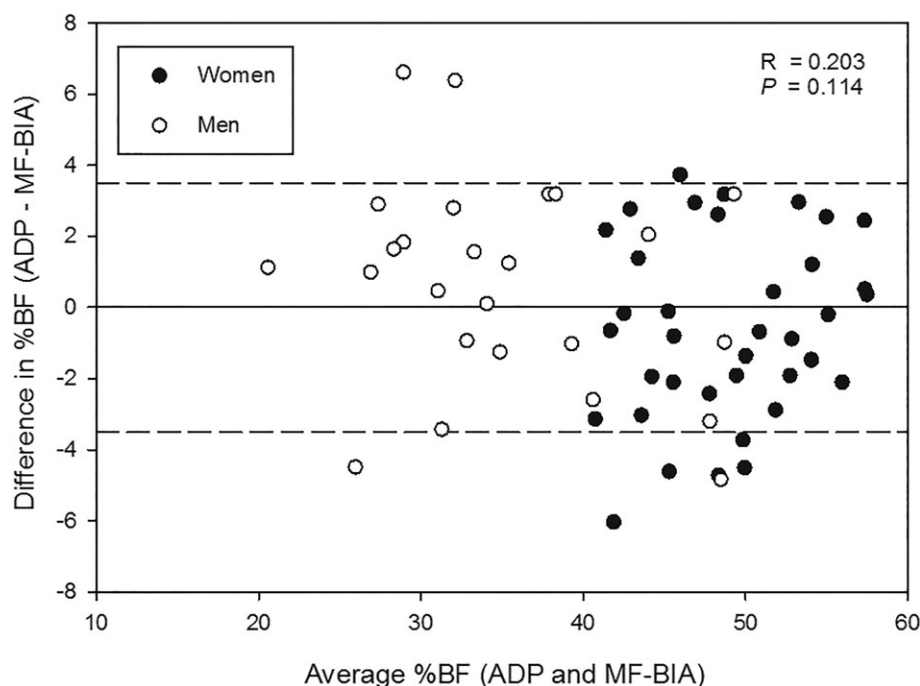
Figure 1 Bland–Altman plot exploring for individual differences in percent body fat (%BF) estimated by air displacement plethysmography (ADP) and multi-frequency bioelectrical impedance analysis (MF-BIA). The difference between the two methods is plotted against the average %BF by the two methods in the women (•) and men (◦). The solid line represents no difference between methods, and the dashed lines represent the minimal acceptable standard for prediction errors set at ±3.5%.

Table 3 Comparison of FM between MF-BIA and ADP

Participant and method	FM (kg)	*r*	MD (kg)	SEE (kg)
Total (*n* = 62)				
ADP	49.2 ± 18.1			
MF-BIA	49.5 ± 18.9	0.99*	−0.3 ± 3.2	3.0
Women (*n* = 37)				
ADP	53.9 ± 16.8			
MF-BIA	54.7 ± 16.6	0.99*	−0.8 ± 2.8	2.8
Men (*n* = 25)				
ADP	42.3 ± 18.1			
MF-BIA	41.9 ± 19.7	0.99*	0.4 ± 3.7	3.2

All values are mean ± standard deviation.
ADP, air displacement plethysmography; FM, fat mass; MD, mean difference; MF-BIA: multi-frequency bioelectrical impedance analysis; SEE, standard error of estimate.
*Significant at $P < 0.001$.

Table 4 presents FFM between both devices. No differences were observed in FFM for the total sample or when examined relative to gender when MF-BIA was compared with ADP (Table 4). Strong relationships were observed between MF-BIA and ADP (r = 0.93–0.97, $P < 0.001$), and SEE values were rated according to Lohman (20) as 'good' (range = 2.9–3.5 kg) (Table 4). A Bland–Altman plot for individual agreement in FFM between ADP and MF-BIA measurements can be seen in Figure 3. No systematic bias was observed in this sample.

Discussion

The primary purpose of this study was to compare MF-BIA (InBody 720) with ADP (BodPod) in obese patients. No significant differences were found for %BF, FM and FFM between the two body composition devices in this population.

Previous research exploring the validity of MF-BIA has reported a consistent underestimation when comparing this technology with ADP and DXA. Hurst and
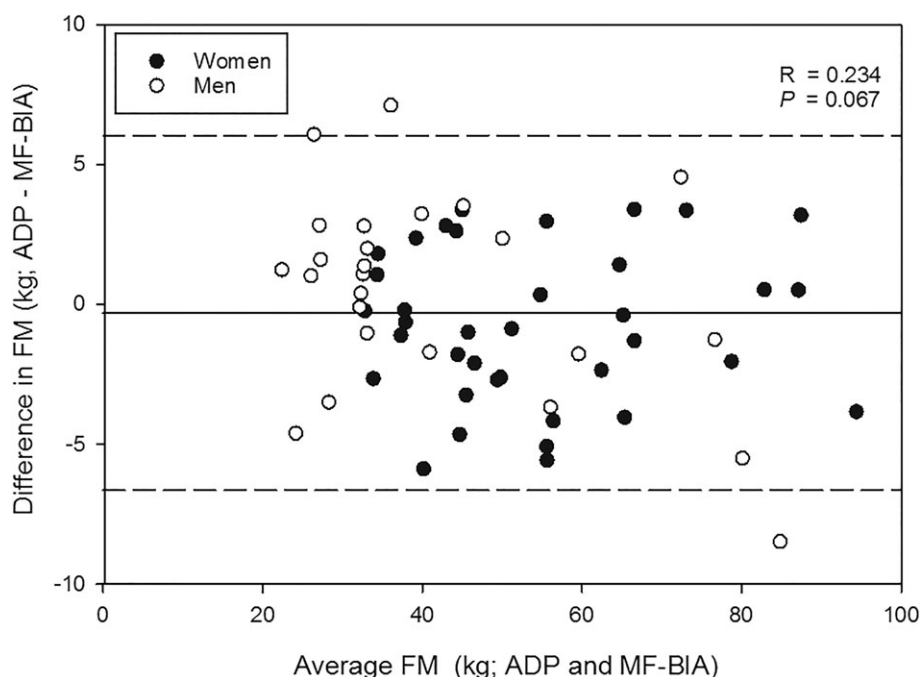
Figure 2 Bland–Altman plot exploring for individual differences in fat mass (FM) estimated by air displacement plethysmography (ADP) and multi-frequency bioelectrical impedance analysis (MF-BIA). The difference between the two methods is plotted against the average FM by the two methods in the women (•) and men (◦). The solid line represents the mean difference between methods for the total sample, and the dashed lines represent ±2 standard deviations from the mean.

Table 4 Comparison of FFM between MF-BIA and ADP

| Participant and method	FFM (kg)	r	MD (%)	SEE (%)	Subjective SEE rating
Total (*n* = 62)					
ADP	62.3 ± 12.4				
MF-BIA	62.3 ± 12.2	0.97*	0.02 ± 3.2	3.2	N/A
Women (*n* = 37)					
ADP	55.1 ± 7.6				
MF-BIA	54.6 ± 7.2	0.93*	0.5 ± 2.8	2.9	Good
Men (*n* = 25)					
ADP	72.9 ± 10.2				
MF-BIA	73.7 ± 8.6	0.94*	−0.7 ± 3.6	3.5	Good

All values are mean ± standard deviation.
ADP, air displacement plethysmography; FFM, fat-free mass; MD, mean difference; MF-BIA: multi-frequency bioelectrical impedance analysis; N/A, not applicable; SEE, standard error of estimate.
*Significant at $P < 0.001$.

colleagues found that MF-BIA significantly underestimated %BF (≈2%) when compared with ADP in participants with an average BMI of 25.5 kg m^{-2} (16). Faria and colleagues found that MF-BIA (InBody 720) underestimated %BF (≈1.6%) when compared with DXA in an obese population (BMI of 40.2 kg m^{-2}) (1). In another comparison study of MF-BIA with DXA in overweight participants, Sun and colleagues compared devices for 591 participants with an average BMI of 26.3 kg m^{-2}, which produced a ≈1.8% underestimation in %BF (21). To our knowledge, a comparison of MF-BIA and ADP body composition values has not been conducted in a homogeneous obese population (BMI > 30.0 kg m^{-2}). In the current investigation, we found no difference in %BF when MF-BIA was compared with ADP. In addition, there were significant correlations and low SEE values. In this obese population, the InBody 720 produced %BF estimations similar to ADP.
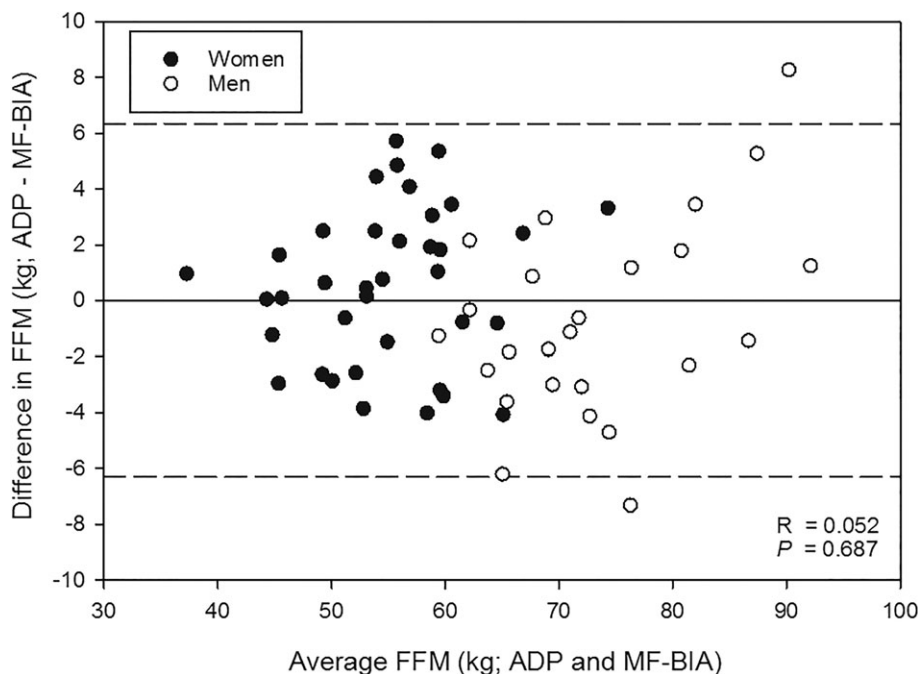
Figure 3 Bland–Altman plot exploring for individual differences in fat-free mass (FFM) estimated by air displacement plethysmography (ADP) and multi-frequency bioelectrical impedance analysis (MF-BIA). The difference between the two methods is plotted against the average FFM by the two methods in the women (•) and men (◦). The solid line represents the mean difference between methods for the total sample, and the dashed lines represent ±2 standard deviations from the mean.

Previously, Pateyjohns and colleagues reported that MF-BIA (ImpediMed SFB7 version 6; ImpediMed, Ltd., Eight Mile Plains, Queensland, Australia) underestimated FM (≈6.6 kg) and overestimated FFM (≈8.0 kg) when compared with DXA in 43 overweight and obese men (22). Similarly, Benton and colleagues found that MF-BIA (Bodystat Quadscan 400, Body Stat Ltd., Isle of Man, British Isles) underestimated FM (≈1.6 kg) and overestimated FFM (≈1.8 kg) when compared with ADP in women with a BMI of 25.7 ± 0.8 kg m^{-2} (11). The current investigation found no differences between MF-BIA and ADP FM or FFM body composition values. Studies by Benton *et al.* and Hurst *et al.* examining MF-BIA have classified their participants according to BMI standards. However, in contrast to the current study, previous participants had an average BMI of approximately 25.5–25.7 kg m^{-2} considered to be average or underweight (11,16). Patients in the present investigation were only included if they met the obese criteria of a BMI of ≥30.0 kg m^{-2}.

Direction comparisons of our findings with previous research are difficult because of the different types of MF-BIA devices used and varying participant characteristics. Each MF-BIA analyzer uses different preprogrammed prediction equations to produce body composition estimates. None of the previous studies mentioned used the same MF-BIA analyzer (InBody 720) or a strict obese population for their sample.

Laboratory methods of body composition assessment such as DXA or ADP are not always practical in obese populations or bariatric clinical settings. DXA, which is considered to be a reliable and valid device, has been used as a criterion measure in some studies with adults with average body composition values. However, in order to accommodate larger individuals with the standard DXA exam table, testing must be performed in segments or mirrored, which may cause discomfort for patients. ADP assessment using the BodPod can also be uncomfortable for larger individuals because pretesting guidelines require tight, spandex clothing for accurate results as well as sitting in the confined chamber of the pod. Both the DXA and the BodPod require a skilled technician and are costly and space inefficient. Therefore, in terms of practicality for factors such as time and cost, as well as comfortability of the patients, these two devices are often considered impractical in clinical settings.

In clinics, efficiency is key to obtaining providers to see as many patients within a reasonable amount of time. Ultimately, patient-centred care and time management skills help to improve the number of patients seen in a clinic. Our findings indicate that MF-BIA produces similar body composition values as ADP. Therefore, utilizing a device such as the InBody 720 will increase the number of patients to be tested, decrease the time to assess each patient, eliminate time spent changing into recommended

testing attire and improve patient satisfaction (1). In conclusion, the InBody 720 MF-BIA analyzer can provide a time-efficient alternative to ADP in clinical settings where the assessment of body composition in obese patients is a component of treatment.

Conflict of Interest Statement

No conflict of interest was declared.

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