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Fat and fat-free mass measurement agreement by dual-energy X-ray absorptiometry versus bioelectrical impedance analysis: Effects of posture and waist circumference

Katie M. Ellison[1] | Sarah E. Ehrlicher[1] | Aseel El Zein[2] | R. Drew Sayer[2]

[1]Department of Nutrition Sciences, The University of Alabama at Birmingham, Birmingham, Alabama, USA

[2]Department of Family and Community Medicine, The University of Alabama at Birmingham, Birmingham, Alabama, USA

Correspondence
R. Drew Sayer, Department of Family and Community Medicine, CHO 20 307B, 930 20th Street S., Birmingham, AL 35205, USA.
Email: sayerd@uab.edu

Abstract

Background: Bioelectrical impedance analysis (BIA) operates under the assumption that the conductor has a uniform cylindrical shape. However, this assumption may be violated if measures are taken in the seated position, especially in people with a high waist circumference (WC).

Aims: The aims of this research were to determine whether posture (supine, standing, and seated) and WC affect agreement between BIA and dual-energy X-ray absorptiometry (DXA) measures of fat mass (FM) and fat-free mass (FFM).

Materials & Methods: Baseline data were collected from 28 adults (mean = 61.4 ± 6.9 years, 64.3% female) with obesity (BMI 38.6 ± 5.0 kg/m^2). Body composition was measured using BIA in the supine, standing, and seated positions and by DXA while supine. Intraclass correlation coefficient (ICC) analyses with two-way mixed effects and absolute agreement were performed to determine agreement.

Results: Point estimates were excellent for FM and FFM while supine, excellent for FM and good for FFM while standing, and moderate for FM and good for FFM while seated. BIA measures in the supine position resulted in the narrowest 95% confidence intervals compared with other positions. Better agreement was observed across all positions in participants with a WC below the median (118.3 cm).

Discussion: Despite the potential pragmatic value of measuring with BIA in a seated position, the results of this analysis demonstrate the poorest agreement between DXA and BIA methods, especially in individuals with high WC.

Conclusion: Findings from this study demonstrate that BIA, particularly when measured in a supine position, can serve as a viable alternative to DXA for measuring body composition in people with obesity.

KEYWORDS
bioelectrical impedance analysis, body composition, dual-energy X-ray absorptiometry, weight loss

Abbreviations: BIA, bioelectrical impedance analysis; BMI, body mass index; DXA, dual-energy X-ray absorptiometry; ECF, extracellular fluid; FFM, fat free mass; FM, fat mass; ICC, intraclass correlation coefficients; ICF, intracellular fluid; LOA, limits of agreement; TBW, total body water; UAB, University of Alabama at Birmingham; WC, waist circumference.

1 | INTRODUCTION

While body mass index (BMI) is a widely utilized tool in primary care for evaluating weight status and obesity, it falls short in providing insights into the body composition, including factors such as fat mass [FM] and fat free mass (FFM). Routinely measuring body composition in primary care would provide greater contextual information about cardiometabolic disease risk[1,2] as well as risk of functional decline resulting from conditions such as sarcopenic obesity.[3] Longitudinal changes in body composition can also be used for assessing intervention effectiveness (e.g., proportion of FM and FFM lost during weight loss) or aging and disease-related processes affecting patient health and wellbeing. While both the American Association of Clinical Endocrinology and Canadian Clinical Practice Guidelines for Obesity recommend that body composition assessments be conducted during primary care visits,[1,2] several barriers currently impede the widespread adoption of body composition assessments in clinical practice.

There are numerous methodologies for assessing body composition, and dual-energy X-ray absorptiometry (DXA) is an empirically supported method that often serves as a reference standard in obesity and body composition literature.[4] DXA measures the attenuation of an X-ray beam through the body to estimate tissue thickness and quantify FM and FFM (bone, soft tissues, muscle) while the patient is lying supine. However, whole-body DXA machines pose several critical limitations that impede their feasible adoption by primary care clinics, including (1) the high cost (~$60,000 for the device and ~$100–$200 per individual scan), (2) space requirements (~96 × 36 inches), (3) time (~10 min per scan), and (4) provider burden (requiring in-depth training for operators).[4,5]

Alternatively, bioelectrical impedance analysis (BIA) is often recommended for primary care settings due to its relative affordability, compact size, faster measurement time, and user-friendly operation compared to DXA.[6] BIA estimates body composition by applying an alternating electrical current at various frequencies through the body from a set of electrodes. Impedance to the current created by the body's biological structures is measured and applied to population-specific regression equations to estimate FM and FFM (including total-body water [TBW]).[6]When currents are distributed at frequencies above 200 kHz, the total amount of intracellular fluid (ICF) and extracellular fluid (ECF) can be quantified, thereby estimating TBW more completely and predicting whole body FM and FFM with a higher degree of accuracy.[7] BIA has been compared to DXA in numerous studies to support the use of BIA in clinical practice.[4,8–14] Overall, agreement between BIA and DXA is good to excellent with intraclass correlation coefficients (ICC) ranging from 0.77 to 0.93.[10,15,16] However, BIA-DXA agreement is adversely affected in people with higher BMIs where BIA underestimates FM and overestimates FFM compared to DXA in this population.[8–12] Although technologies and predictive equations have advanced in recent years to improve the accuracy of body composition measurements in people with obesity, these observed differences between BIA and DXA are likely due to deviations from the basic assumptions upon which BIA properties are based.

One such assumption of BIA is that the conductor (i.e., person being assessed) is cylindrical and uniform in shape, including having space between the conductor's limbs and trunk region so that the current can pass through the body without interference from opposing currents moving through other areas of the body. Creating the necessary space between the limbs and trunk region may not be possible for many people with obesity, especially those with android-type obesity (i.e., high waist circumference [WC]). Additionally, a principle of BIA is that the current flows through the body at different rates depending on the tissue it is passing through. Specifically, tissues with greater water content have higher conductivity and less impedance. Another basic assumption of BIA is that FFM is 73% water (including ECF and ICF). However, people with obesity have a greater relative expansion of ECF than ICF and the ratio of ECF/ICF is highly variable in people with a higher BMI, while ECF/ICF is more consistent at lower BMI values.[17] The inconsistent expansion in ECF and ICF as adipose tissue mass increases will increase the estimated percentage of TBW, which may cause BIA to overestimate FFM and subsequently underestimate FM (FM = total body weight—FFM).[18] Additionally, people with obesity typically have visceral and ectopic fat depots (i.e., FM infiltrated in muscle and organ tissues), especially in the trunk region, which would decrease hydration and further contribute to overestimation of FFM. This limitation can be at least partially addressed by using a specialized BIA device capable of detecting visceral adipose tissue.[19,20]

Similar to DXA, many multifrequency BIA devices used in clinical care require the patient to lie in a supine position. However, people with obesity may face physical limitations that make it challenging to climb on and off a clinic bed, and those with severe obesity may require a bariatric-sized clinic bed to position themselves comfortably. Some multifrequency BIA devices allow the patient to stand during assessments but require the patient to create space between the legs and between the underarms and trunk regions. Achieving and maintaining this posture during the assessment may be challenging for people with obesity and those with limited mobility. Having the patient remain seated while taking the measurement would be operationally advantageous because patients are usually seated while waiting to be seen by the doctor, allowing sufficient time for their body fluid to equilibrate, which is essential to obtaining accurate body composition measures using BIA.[21] However, deviations from BIA's assumptions of a cylindrical shape and uniformity are greatest when in the seated position, especially when the regional distribution of body fat is high around the waist so that the trunk region may come into contact with the arms and legs. The InBody S10 BIA device uses electrodes attached to long cables, permitting the user to have some flexibility in their posture. The S10 user manual provides instructions for taking measures in supine, standing, and seated positions.[22] Despite the physiological differences between each posture, it does not specify which is optimal or recommended, implying to users that any of the three positions are acceptable. To determine the optimal administration of BIA, this research aims to (1) determine the agreement of BIA and DXA FM and FFM measures in people with obesity across the supine, standing, and seated postures and (2) assess the impact of a high WC on body composition estimates and the agreement between devices. The overarching hypothesis was that agreement would be best in the supine position and that a high WC (defined as above the median value in the current sample) would negatively affect agreement, especially in the seated position.

2 | MATERIALS AND METHODS

2.1 | Subjects

This analysis comprises a convenience sample of 28 individuals who were participants in a behavioral weight loss study (NCT04014296) at the University of Alabama at Birmingham (UAB). Inclusion criteria for the weight loss study were ≥50 years old, postmenopausal if female (≥1 year since last menstrual period), BMI ≥30 kg/m^2, not using or stable use (≥3 months on same dosage) of medications affecting body weight, did not have a pacemaker or other battery-operated implant, and were not taking insulin if they had diabetes. Prior to study visits, participants were required to fast for a minimum of eight hours and were instructed to keep hydrated and avoid moderate-to-vigorous physical activity for 24-h prior to their visit. Alcohol consumption and smoking was discouraged throughout the trial although not explicitly restricted for 24-h prior to body composition measurements. Body composition was assessed at baseline prior to initiating the behavioral weight loss program and again at the end of the 16-week intervention. The parent trial and this analysis were approved by the UAB Biomedical Institutional Review Board, and all participants provided written informed consent to participate.

2.2 | Dual-energy X-ray absorptiometry (DXA)

A whole-body DXA scan was completed using the GE Lunar Prodigy Primo (encore software version 15.10.046, GE Healthcare). A quality assurance assessment was conducted on the mornings that participants were planned to arrive. Participants were positioned in a supine position under the scanning arm according to the manufacturer's instructions. Participants were instructed to remove jewelry and wear clothing without zippers, wires, or metal accessories.

2.3 | Bioelectrical impedance analysis (BIA)

Multifrequency bioelectrical impedance analysis (InBody USA, S10) was performed to assess FM and FFM. BIA electrodes were placed according to the manufacturer's instructions. Touch-type electrodes were placed in the same location for all participants, including between the ankle bone and heel, thumbs, and middle fingers. When standing. Participants were instructed to create space between their limbs and trunk region by opening their arms and legs to the best of their ability. When the supine, trained study staff adjusted participants to create space between the arms and legs. Measurements were always completed in the same order (seated, standing, supine) and after having been in each posture for 10 min prior to measurement.

2.4 | Anthropometric measurements

Participants' body weights were measured at baseline and the week 16 follow-up visit using a digital platform scale (DETECTO BRW1000, DETECTO, Webb City, MO) with an accuracy ±0.1 kg, while they were dressed in lightweight clothing and without shoes. Height was measured using a stadiometer, and BMI (kg/m^2) was calculated using the obtained measures of weight and height. Waist circumference was measured by trained research staff in duplicate at the border of the iliac crest as recommended by the National Institutes of Health.[23] The average of the two waist circumference measures was used for analyses.

2.5 | Statistical analysis

All study data were collected and managed using REDCap electronic data capture tools hosted at UAB.[24,25] REDCap is a secure, web-based software platform designed to support data capture for studies, providing (1) an intuitive interface for validated data capture; (2) audit trails for tracking data manipulation and export procedures; (3) automated export procedures for seamless data downloads to common statistical packages; and (4) procedures for data integration and interoperability with external sources. Statistical analyses were performed using IBM SPSS Statistics software (version 29 for Windows).

Differences in FM and FFM measured by DXA and BIA at baseline and week 16, and changes in FM and FFM were compared using paired *t*-tests.[26–28] Body composition by DXA was compared separately to each BIA position. Differences with a *p*-value <0.05 were considered significant. Interrater reliability (i.e., DXA compared to BIA in the 3 positions) was assessed using intraclass correlation coefficients (ICC) with two-way mixed effects and absolute agreement. ICC values of less than 0.5 were considered to have poor reliability, between 0.5 and 0.75 moderate reliability, between 0.76 and 0.9 good reliability, and values above 0.90 excellent reliability.[16] These ICC analyses were repeated to determine agreement between the devices in those above and below the median WC. Bland-Altman plots depicting the mean differences plotted against the averages of FM and FFM measures from DXA and the S10 are shown in Figure S1. Lin's concordance correlation coefficient (Lin's CCC) was also performed. Coefficients <0.40 were considered to have weak concordance, between 0.40 and 0.69 moderate concordance, 0.70–0.89 strong concordance, and >0.90 very strong concordance.[29] Linear correlations (Pearson's r) were also performed to test the linear relationship between FM and FFM variables predicted by BIA across postures with DXA.

3 | RESULTS

Characteristics of study participants are presented in Table 1. A total of 28 participants, aged over 50 years old (61.4 ± 6.9 years [mean ± standard deviation]; 64.3% female) with obesity (BMI 38.6 ± 5.0 kg/m^2) were included in baseline comparisons of FM and FFM. Week 16 completers (n = 25) are included in analyses of changes in body composition. Compared to DXA (50.2 ± 13.4 kg), BIA underestimated FM at baseline in seated (41.8 ± 13.1 kg, $p < 0.001$), standing (45.7 ± 13.7 kg, $p < 0.001$), and supine (47.5 ± 13.8 kg, $p < 0.001$) positions. BIA also overestimated FFM compared to DXA (59.2 ± 11.4 kg) in the seated (66.9 ± 16.5 kg, $p < 0.001$), standing (63.8 ± 13.7 kg, $p < 0.001$) and supine (62.0 ± 13.7 kg, $p < 0.001$) positions. For both FM and FFM, observed differences between DXA and BIA were quantitively greatest in the seated position and lowest in the supine position. Changes in body composition from baseline to week 16 were assessed in 25 participants who completed the weight loss intervention (Table 2). While the average changes in FM and FFM were not statistically different between DXA and BIA, body composition changes were quantitatively most similar to DXA when measured by BIA in a supine or standing position.

Interrater reliability analyses of FM and FFM are presented in Table 3. At baseline and week 16, excellent agreement (ICC >0.90) between BIA and DXA was observed for FM in the supine and standing postures, and agreement was moderate (ICC: 0.50–0.75) to good (ICC: 0.76–0.90) in the seated position. While ICC point estimates were similar for supine and standing positions, the 95% confidence interval was substantially wider in the standing position. For FFM at both time points, BIA agreement with DXA was excellent in the supine position and good when standing or seated. A similar pattern of 95% confidence intervals was observed for FFM with supine having the narrowest interval followed by standing and then seated. The agreement for FM changes after the weight loss intervention was excellent in the supine and standing postures and poor in the seated position. Additionally, agreement for FFM changes was moderate in supine and standing postures and poor in the seated position. A high WC (i.e., above the median) negatively affected agreement between DXA and BIA in the seated position for both FM and FFM and a minor, although statistically significant, effect in the supine and standing positions (Table 4).

TABLE 1 Baseline participant characteristics (n = 28).

Characteristic	Mean ± SD or n (%)
Age	61.4 ± 6.9
Race	
Non-Hispanic white	13 (46.4)
Non-Hispanic black	14 (50.0)
Other	1 (3.6)
Sex	
Male	10 (35.7)
Female	18 (64.3)
Height, cm	168.9 ± 10.6
Weight, kg	109.6 ± 20.1
BMI, kg/m^2	38.6 ± 5.0
WC, cm	120.2 ± 13.4

Note: Characteristics are shown for participants at baseline.
Abbreviations: BMI, body mass index; WC, waist circumference.

TABLE 2 Comparison of DXA- and BIA-measured changes in fat mass (kg) and fat free mass (kg) following a 16-week weight loss intervention.

	DXA (reference) Mean ± SD	Supine Mean ± SD, p-value	Standing Mean ± SD, p-value	Seated Mean ± SD, p-value
Baseline FM	50.2 ± 13.5	47.5 ± 13.8	45.7 ± 13.7	41.8 ± 13.1
		$p = 0.001$	$p < 0.001$	$p < 0.001$
Baseline FFM	59.2 ± 11.4	62.0 ± 13.7	63.8 ± 13.7	66.9 ± 16.5
		$p < 0.001$	$p < 0.001$	$p < 0.001$
Week 16 FM	42.0 ± 13.4	39.4 ± 14.5	37.4 ± 14.1	35.9 ± 13.5
		$p = 0.003$	$p < 0.001$	$p < 0.001$
Week 16 FFM	57.1 ± 10.9	59.8 ± 13.2	61.8 ± 13.5	63.3 ± 13.1
		$p = 0.001$	$p < 0.001$	$p < 0.001$
Δ FM	−8.0 ± 4.7	−8.2 ± 4.4	−8.3 ± 4.7	−5.8 ± 9.1
		$p = 0.71$	$p = 0.43$	$p = 0.17$
Δ FFM	−1.8 ± 2.6	−1.9 ± 2.6	−1.7 ± 2.2	−3.3 ± 6.1
		$p = 0.87$	$p = 0.83$	$p = 0.21$

Note: p-value for comparison of BIA in each position compared to DXA using paired samples t-tests
Baseline: n = 28; 16-Week Weight Loss Intervention: n = 25, Δ; n = 25.

Bland-Altman plots (provided in Supporting Information Figure S1a–l) revealed that bias and limits of agreement (LOA) between BIA and DXA vary by posture with the greatest difference between the upper and lower limit seen when seated (FM: 8.4 ± 9.3, −9.8–26.6; FFM: −7.7 ± 7.2, −21.8–6.4, $p < 0.001$), and improved when standing (FM: 4.5 ± 4.1, −3.5–12.5; FFM: −4.6 ± 4.1, −12.6–3.4, $p < 0.001$), and best when supine (FM: 2.7 ± 3.9, −4.9–10.3; FFM: −2.8 ± 3.9, −10.4–4.8, $p < 0.001$) (Table 5). Week 16 bias and LOA for standing (FM: 4.6 ± 4.0, 3.4–12.5; FFM −4.7 ± 4.2, −12.9–3.5; $p < 0.001$) and supine (FM: 2.6 ± 4.0, −5.1–10.4, $p < 0.003$; FFM: −2.8 ± 3.8, −10.3–4.7, $p < 0.001$) were similar to the baseline. Bias and LOA for the seated position narrowed at week 16 but was still the largest among positions (FM: 6.1 ± 3.9, −1.5–13.7; FFM: −6.3 ± 4.3, −14.7–2.1, $p < 0.001$).

Lin's CCC (ρc) at baseline was considered strong (>0.70) for all measures except for FM in the seated position (ρc = 0.63). Additionally, Lin's CCC for FM and FFM measures at week 16 remained the same with similar confidence intervals (CI) for supine and standing postures and improved with narrower CIs for BIA-seated patients (Table 6). Pearson correlations followed a similar pattern to previous analyses with stronger correlations in the supine (FM: $r = 0.96$, $p < 0.001$; FFM: $r = 0.97$, $p < 0.001$) and standing positions (FM: $r = 0.95$, $p < 0.001$; FFM: $r = 0.96$, $p < 0.001$) compared to the seated position (FM: $r = 0.76$, $p < 0.001$, FFM: $r = 0.93$, $p < 0.001$).

TABLE 3 Interrater reliability analyses of FM and FFM.

	BIA posture		
	Supine ICC (95% CI)	Standing ICC (95% CI)	Seated ICC (95% CI)
Baseline FM	0.94 (0.80–0.98)	0.91 (0.40–0.97)	0.63 (0.10–0.85)
Baseline FFM	0.93 (0.75–0.97)	0.89 (0.31–0.97)	0.77 (0.12–0.92)
Week 16 FM	0.95 (0.81–0.98)	0.91 (0.36–0.97)	0.87 (0.02–0.97)
Week 16 FFM	0.93 (0.74–0.98)	0.88 (0.29–0.96)	0.83 (0.01–0.95)
Δ FM	0.91 (0.80–0.96)	0.91 (0.80–0.96)	0.41 (0.05–0.69)
Δ FFM	0.60 (0.28–0.80)	0.59 (0.25–0.80)	0.26 (−1.3–0.58)

Note: Baseline: $n = 28$; 16-Week Weight Loss Intervention: $n = 25$, Δ; $n = 25$.

Abbreviations: BIA, bioelectrical impedance analysis; FFM, fat-free mass; FM, fat mass; Week 16, end of behavioral weight loss intervention.

TABLE 4 Baseline ICC analyses above and below median WC ($n = 28$).

	Above median WC ICC (95% CI)	Below median WC ICC (95% CI)
Supine FM	0.92 (0.72–0.98)	0.96 (0.78–0.99)
Supine FFM	0.87 (0.78–0.96)	0.97 (0.90–0.99)
Standing FM	0.89 (0.49–0.98)	0.90 (0.01–0.98)
Standing FFM	0.83 (0.16–0.95)	0.92 (0.20–0.98)
Seated FM	0.45 (−0.5–0.78)	0.84 (−0.04–0.97)
Seated FFM	0.65 (0.00–0.89)	0.86 (−0.02–0.97)

Abbreviations: FFM, fat-free mass; FM, fat mass; ICC, interclass correlation coefficient; WC, waist circumference.

4 | DISCUSSION

Findings from this study were consistent with our hypothesis that body composition analysis using the BIA in the supine position would have the best agreement with DXA, whereas the seated position

TABLE 6 Lin's concordance correlation coefficient of FM and FFM between DXA and BIA.

	BIA posture		
	Supine pc (95% CI)	Standing pc (95% CI)	Seated pc (95% CI)
Baseline FM	0.94 (0.88–0.97)	0.90 (0.82–0.95)	0.63 (0.39–0.78)
Baseline FFM	0.93 (0.87–0.96)	0.89 (0.80–0.94)	0.76 (0.62–0.85)
Week 16 FM	0.94 (0.88–0.97)	0.91 (0.82–0.95)	0.87 (0.76–0.93)
Week 16 FFM	0.93 (0.86–0.96)	0.88 (0.78–0.93)	0.82 (0.69–0.90)

TABLE 5 Mean differences, standard deviations, and 95% limits of agreement (kg).

	BIA posture					
	Supine		Standing		Seated	
	Mean difference ± SD	LOA (95% CI)	Mean difference ± SD	LOA (95% CI)	Mean difference ± SD	LOA (95% CI)
Baseline FM	2.7 ± 3.9	−4.9–10.3	4.5 ± 4.1	−3.5–12.5	8.4 ± 9.3	−9.8–26.6
Baseline FFM	−2.8 ± 3.9	−10.4–4.8	−4.6 ± 4.1	−12.6–3.4	−7.7 ± 7.2	−21.8–6.4
Week 16 FM	2.6 ± 3.9	−5.1–10.4	4.6 ± 4.0	3.4–12.5	6.1 ± 3.9	−1.5–13.7
Week 16 FFM	−2.8 ± 3.8	−10.3–4.7	−4.7 ± 4.2	−12.9–3.5	−6.3 ± 4.3	−14.7–2.1
Δ FM	0.2 ± 2.0	−3.8–4.1	0.3 ± 2.0	−3.7–4.3	−2.2 ± 7.8	−17.4–13.0
Δ FFM	0.1 ± 2.3	−4.5–4.6	−0.1 ± 2.2	−4.4–4.2	1.5 ± 5.7	−9.7–12.6

Note: Baseline: $n = 28$; 16-Week Weight Loss Intervention: $n = 25$, Δ; $n = 25$.

Abbreviations: FFM, fat-free mass; FM, fat mass; SD, standard deviation.

would have the poorest agreement. Measuring body composition by BIA in the supine position resulted in mean FM and FFM measures that closely resembled DXA and showed the highest agreement with the narrowest confidence intervals. Interestingly, point estimates for agreement with DXA for the supine and standing positions were similar, but the 95% confidence intervals were narrower with the supine position. These findings indicate that the supine position produces body composition estimates that are similarly accurate but more precise than standing (i.e., similar ICC with narrower confidence intervals) and more accurate and precise than measures in the seated position. Also, as hypothesized, a higher WC negatively impacted BIA-DXA agreement, particularly in the seated position where the assumptions underlying BIA are most affected.

Estimates of body composition obtained from the InBody S10 BIA device were previously compared to DXA in at least 5 studies, including generally healthy adult volunteers[10,30–32] and patients undergoing hemodialysis.[33] Although these studies included adults with obesity, to our knowledge, no previous studies comparing the S10 to DXA have been conducted exclusively in this population. It is important to accurately determine body composition in people with obesity to fully understand potential obesity-related chronic disease risks, and monitoring changes in body composition with weight loss therapy is an important consideration for treatment effectiveness.[1,2] In the current study, the S10 device underestimated mean FM and overestimated mean FFM compared with DXA in all positions, but the supine position produced the quantitatively most similar estimates to DXA. Lower estimates of FM from the S10 device compared to DXA is a consistent finding with previous research.[30,32,33]While some previous studies[10,30] also reported higher estimates of FFM from the S10 device, a study in hemodialysis patients found that the S10 device underestimated FFM compared to DXA[33] and another found no significant difference in FFM between the S10 and DXA.[32] Importantly, mean changes in FM and FFM over the course of the 16-week behavioral weight loss program in the current study were nearly identical between DXA and S10 in the supine and standing positions. Collectively, these findings support using a supine position when using the S10 to measure both absolute body composition as well as to monitor body composition changes over time in adults with obesity.

Previous research across multiple BIA and DXA devices has generally found moderate-to-strong correlation coefficients and moderate to excellent agreement of body composition estimates between methods.[8,10,30,32–35] Results from the current study are perhaps most comparable to a study by D'Hondt et al. that was conducted in younger (21.9 $\pm$ 1.5 years) healthy adults with mean BMI in the normal weight range and compared body composition estimates from the S10 device (supine position) to DXA.[30] Patterns of mean whole-body FM and FFM, correlations, and agreement between devices were similar to those in the current study despite the large age and BMI differences between studies. Observed LOAs in BIA/DXA comparative studies are generally wide[8,33,34,36,37] including in the current study where the baseline LOAs in the supine position were −4.9 to 10.3 kg for FM and −10.4 to 4.8 kg for FFM. These LOAs indicate that 95% of the differences in FM and FFM as measured by the S10 and DXA would be expected to fall within these respective ranges. At the individual level, this range of potential discrepancies between devices may be interpreted as too wide to justify the clinical use of BIA for measuring body composition.

There are several important considerations for determining the suitability of an alternate device or assessment for clinical use as compared to a more established or accepted method. Ideally, a threshold for a clinically acceptable difference between devices would be established a priori. The current study did not set a clinically acceptable difference between body composition assessment methods, but a previous review of the use of BIA for body composition assessment referred to LOAs of 5%–10% as large and indicating a high degree of potential clinical error.[38] Most LOAs observed in the current study exceeded this threshold of 10%. However, it is essential to remember that all measurement devices—even those accepted as "gold standards"—are only able to estimate true values and are subject to their own inconsistencies and errors in doing so.[39] In the case of the current study, DXA was treated as the reference method for body composition, but this should not be interpreted as though estimates of FM and FFM by DXA are without error compared to true body composition values. In fact, comparisons of DXA to MRI-based body composition assessments (the 'gold standard' or reference method) found that DXA overestimated FM compared with MRI in non-HIV-positive participants (female: 21.3 vs. 15.4 kg; male: 31.6 vs. 25.3 kg) and reported LOAs similar to the current study (approximately −4 to 10 kg for FM). Therefore, clinicians and researchers must rely on their own judgment to determine the suitability of using the S10 BIA device for assessing body composition in people with obesity due to the absence of an established threshold for a between-device clinically acceptable difference and the inherent uncertainty of any estimate of body composition compared to the true values. Our interpretation of the current results is that the S10 device is suitable for clinical assessments of body composition in people with obesity when the test is performed in the supine position with at least 10 min of time in that position prior to testing.

Several factors may influence the accuracy of BIA-measured estimates of body composition and their agreement with other methods such as DXA. The current study investigated several factors including postural differences (supine vs. standing vs. seated), high WC, and weight loss. For BIA, acutely changing postures causes fluid shifts within the body that may impact body composition estimates.[21,40,41] For example, Kim et al. used BIA to compare resistance and reactance measured in supine, standing, and seated postures.[41] They reported significant differences in resistance values across all postures, with supine having the greatest resistance and sitting having the least. Similar to the present study, they also found that FFM was lowest, and FM was highest in the supine position. The present study also observed poorer agreement in those with a WC above the median, especially in the seated position. The assumption of a uniform cylindrical shape for BIA-based estimates of body composition[42] is most violated in a seated position and further violated in people with a high WC due to greater contact of the abdomen with the thighs. This contact reduces the total distance traveled by the electrical current, which is expected to underestimate FM. This is consistent with results from the current study demonstrating the greatest mean differences and agreement with DXA when conducting the BIA test in the seated position. These findings are substantiated by another study that also investigated the effects of a high WC on BIA estimates. Long et al. compared three types of BIA devices (hand-to-hand, hand-to-foot, foot-to-foot electrodes) to a Bod Pod and found that BIA estimates of BF were lower compared to BodPod only among participants in the highest tertile for WC (104.6 ± 8.7 cm).[43]

Weight loss and the resulting reduction in WC would be expected to reduce the abdomen to thigh contact and improve the accuracy of body composition estimates in the seated position. BIA agreement with DXA improved with weight loss in the current study, but agreement was still poorest in the seated position. Specifically, baseline BIA in the seated position underestimated FM by 8.4 kg compared with DXA (50.2 vs. 41.8 kg). At week 16, the difference in estimated FM between devices was 6.1 kg (42.0 vs. 35.9 kg), which largely accounts for the observed 2.2 kg difference in FM changes between DXA and BIA-seated (−8.0 kg vs. −5.8 kg). BIA-seated also overestimated FFM changes compared with DXA (−1.8 kg vs. −3.3 kg). Underestimation of FM loss and overestimation of FFM loss would substantially alter clinical assessments of intervention effectiveness, especially among patients with or at risk of sarcopenic obesity. Comparatively, estimates of changes in FM and FFM from the supine and standing positions were within 0.3 kg of estimates from DXA, which supports the clinical utility of the S10 device for monitoring body composition changes over time in these positions.

A primary limitation of the current research is the small sample comprising a convenience sample of participants engaged in a behavioral weight loss trial. This may have limited statistical power and reduced the generalizability of the study's findings. In particular, it is likely that the study was underpowered for comparing changes in body composition between the measurement approaches. Larger prospective studies with more representative samples are needed to confirm and validate the current findings. However, the current sample is likely representative of adults with obesity who are seeking behavioral weight loss treatment, which is consistent with obesity treatment guidelines for assessing body composition in this population.[1,2] Another strength of the current study is that BIA and DXA were compared using multiple methods that consistently demonstrated the superiority of using a supine position for measuring body composition with BIA.

5 | CONCLUSION

Findings from this study demonstrate that BIA, particularly when measured in a supine position, can serve as a viable alternative to DXA for measuring body composition in people with obesity. While BIA in the supine position slightly underestimated FM and overestimated FFM compared to DXA, the overall agreement between these methods was excellent as measured by high ICC point estimates (above 0.90), concordance was strong-to-very strong, and the mean changes in body composition during weight loss were virtually identical. Given the significant clinical interest in monitoring longitudinal changes in body composition during obesity treatment, the results of this study support the clinical implementation of using BIA for routine body composition assessments in individuals with obesity during weight loss interventions.

AUTHOR CONTRIBUTIONS

Conceptualization, Katie M. Ellison and R. Drew Sayer; methodology, Katie M. Ellison and Aseel El Zein; formal analysis, Katie M. Ellison and Aseel El Zein; investigation, Katie M. Ellison and Sarah E. Ehrlicher; resources, R. Drew Sayer; data curation, Katie M. Ellison; writing—original draft preparation, Katie M. Ellison; writing—review and editing, R. Drew Sayer, Aseel El Zein, and Sarah E. Ehrlicher; visualization, Katie M. Ellison; supervision, Sarah E. Ehrlicher; project administration, Katie M. Ellison, Sarah E. Ehrlicher, and R. Drew Sayer; funding acquisition, R. Drew Sayer. All authors were involved in writing the paper and had final approval of the submitted and published versions.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

Katie M. Ellison https://orcid.org/0000-0003-2141-2592
R. Drew Sayer https://orcid.org/0000-0002-9488-7030

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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