

Agreement Between Six Bioelectrical Impedance Analysis Devices and Dual-Energy X-Ray Absorptiometry

Original Research

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Abstract

Introduction: Bioelectrical impedance analysis (BIA) is a low-cost, accessible method to assess percent body fat (%BF). Rising recognition of the role of body composition in overall health and disease prevention has led to an increased usage of at-home BIA devices. The purpose of this study was to assess the level of agreement between six BIA devices and dual-energy x-ray absorptiometry (DXA).

Methods: Male (n=42) and female (n=35) participants completed body composition testing on six different BIA devices and a DXA scan. Agreement was assessed using intraclass correlation coefficients (ICC) with 95% confidence intervals, Spearman's correlations, and Bland-Altman analyses to determine limits of agreement (LoA) for %BF.

Results: Four BIA devices demonstrated moderate reliability (ICC: 0.66-0.73) and two devices demonstrated poor reliability (ICC: 0.25 and 0.43). The most favorable agreement profile from a BIA device was a mean bias of -2.21% and relatively narrow LoA (-9.88% - 5.46%). The least favorable agreement profile from a BIA device was a mean bias of 2.88% and LoA of -10.25% -16.01%.

Conclusions: The present study indicated that multi-frequency BIA devices outperformed single-frequency BIA devices, and that the Omron had the highest LoA with DXA.

Key Words: Body composition assessment, body fat percentage

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Introduction

Since 1980, overweight and obesity rates in the United States have continued to rise, with the Centers for Disease Control and Prevention estimates indicating that 73.6% of Americans are overweight or obese ¹. Obesity, defined as a body mass index (BMI) $\geq 30\text{kg/m}^2$ or percent body fat (%BF) of $\geq 30\%$ in women and $\geq 25\%$ in men ², is strongly associated with numerous comorbidities, including cardiometabolic diseases, certain cancers, and increased risk of all-cause mortality ³. Therefore, identifying obesity and monitoring %BF is essential to mitigate health risks. Numerous validated body composition methods can be used to determine %BF, such as underwater weighing, skinfolds, air-displacement plethysmography, and dual energy X-ray absorptiometry (DXA) ⁴.

DXA is commonly used in research and has been indicated as a reliable and valid measure to assess body composition ^{5,6}. DXA utilizes two low-dose X-ray beams sent through the body, creating a three-compartment model including bone mineral content, lean mass (LM), and %BF ⁵. Prior research has used DXA to quantify regional and whole-body

adiposity and longitudinal body composition changes, and its precision and reproducibility make it a preferred method for monitoring body composition changes in interventions and epidemiological studies ^{7,8}. However, DXA is often inaccessible and costly to the consumer and relies on specialized staff and facilities, and thus may not be a good, reliable method for the average consumer to assess body composition ⁴. Consequently, more convenient and accessible methods, such as bioelectrical impedance analysis (BIA), may be an affordable, non-invasive, and user-friendly method for the average consumer to assess body composition at home ⁹. Traditional BIA devices use a single frequency electrical current and utilize a two-compartment model, separating total body mass into BF and fat-free mass ¹⁰. Recent developments in BIA research have improved raw impedance algorithms by deriving data from large and diverse populations to improve the accuracy of BIA assessments ¹¹. The accuracy of BIA devices can be affected by both user-related factors and device-specific factors. User-related factors that may contribute to variability or reduced accuracy include recent fluid or nutrient intake, recent physical activity, alcohol or caffeine intake, and the time of day of assessment ^{12,13}. Device-specific factors may consist of the type of BIA device used (e.g., segmental vs. single-point), electrode placement, limb positioning during evaluation, and the reference values embedded within each device's algorithm, which is often proprietary information ¹¹.

Several studies have examined how %BF assessed via BIA compares with other body composition methods, including air displacement plethysmography, hydrostatic weighing, skinfolds, and DXA; however, the findings have been equivocal ^{14–16}. Previously targeted toward the research sector, BIA devices have recently gained popularity among consumers through the widespread availability of at-home BIA devices. In 2022, BIA devices emerged as a leading product category, accounting for over 21.5% of total market revenue ¹⁷. While consumer BIA devices are a cost-effective and accessible solution, the accuracy of consumer and research-grade BIA devices compared to standard body composition methods, such as DXA, is unknown. Although prior studies have examined the accuracy of BIA devices, none have simultaneously assessed multiple at-home BIA devices, which are widely available to consumers. Therefore, the present study aimed to evaluate the reliability of six BIA devices by assessing the level of agreement with DXA.

Methods

Participants

College-aged men and women between the ages of 18 and 25 were recruited via flyers and word of mouth to participate in this study. Participants were included if they fell within the age range and excluded if they had four DXA scans within the last 12 months. Methods were approved by the Institutional Review Board of the University of Idaho (#22-209). This study was conducted in accordance with the Declaration of Helsinki.

Study Protocol

The study consisted of a single one-hour visit to the Human Performance Laboratory at the University of Idaho. Participant visits occurred in the morning (0500–1100), following an 8-hour fast. Participants were instructed to drink water ad libitum to ensure euhydration prior to testing. Upon arrival at the laboratory, participants gave informed consent. Before body composition assessments, participant hydration status was assessed using a urine sample and a dip-style refractometer (ATAGO[®], Tokyo, Japan). Participants were considered euhydrated if urine specific gravity (USG) was between 1.002 and 1.025. If USG was >1.025, the participant was instructed to consume 12 fluid ounces of water prior to a second hydration assessment. If USG was <1.002, the participant was rescheduled for a later date due to hyperhydration. Across all participants, one participant was rescheduled due to hyperhydration. Participants completed a demographics questionnaire via Qualtrics (Qualtrics XM, 2023). Height and weight were measured using a stadiometer (InBody BSM170, Seoul, Republic of Korea) and digital clinical scale (DETECTO, Apex-SH, Webb City, MO).

Body composition was assessed using six different BIA devices and DXA. Measurements were conducted in triplicate for each BIA device. BIA device characteristics are included in **Table 1**. No user-performed calibration procedures were required for any BIA devices. Each participant followed the same standard order of devices: Renpho (Shezhen, China), Tanita (BF-679W, Tokyo, Japan), Triumph (Richmond, British Columbia, Canada), OMRON (Yangzhou, Jiangsu, China), and InBody H₂O (Gangnam-gu, Seoul, Republic of Korea). This standard order was selected to minimize variability in testing procedures, reduce logistical complexity, and ensure that participants experienced identical testing conditions. While use of a fixed order introduces the possibility of an order effect, the risk was considered minimal because all assessments occurred within a single visit, time between devices was short, and measurements were non-invasive with negligible physiological carryover. Moreover, the only postural change occurred at the end of testing,

when participants transitioned from standing to supine for the DXA scan and InBody S10, further limiting the potential for systematic biases related to order. Following the InBody H₂O, participants were asked to complete one anteroposterior whole-body DXA scan (Hologic Inc. Horizon W QDR Series) administered by a trained research assistant. After completing the DXA scan, participants were asked to remain supine for the InBody S10 (Gangam-gu, Seoul, Republic of Korea). Averages over the three trials were used in the analysis, and all testing was performed on the same day.

Table 1. Bioelectrical impedance analysis device characteristics.

Device	Model	Electrode Type	Frequency Type	Posture During Measurement	Weight Capacity (kg)
Renpho	ES-CS20M	Single point	Single-Frequency	Standing	180
Tanita	BF-679W	Single point	Single-Frequency	Standing	135
Triumph	EMSC91	Single point	Single-Frequency	Standing	180
Omron	BF511CM-500	Segmental	Multi-Frequency	Standing	150
InBody H ₂ O	H ₂ ON	Segmental	Multi-Frequency	Standing	150
InBody S10	S10	Segmental	Multi-Frequency	Supine	250

Dual energy X-ray Absorptiometry

Daily quality assurance was performed using a standard aluminum spine phantom (Hologic Phantom) provided by the manufacturer. All phantom measurements remained within the manufacturer's specified precision limits, with a coefficient of variation (CV) of less than 0.5%. The test–retest CV for the DXA was 1.1% for LM and 0.69% for BF. DXA results were analyzed with APEX software, version 4.5.2.1.

Statistical Analysis

All statistical analyses were conducted using R version 4.5.0, an open-source programming language, and statistical significance was determined with a p-value <0.05. Two participants' data were excluded from analysis due to missingness. Prior to analysis, the data were assessed for normality. Intraclass Correlation Coefficients (ICCs) and 95% confidence intervals (CIs) were calculated to determine the degree of absolute agreement between DXA and each of the six BIA devices. Analyses were based on the average of three repeated trials per device, and ICCs were computed using a two-way mixed effects model for absolute agreement, average measures [ICC(3,k)]. Spearman's correlations (ρ) were calculated for the rank-based association between BIA devices and DXA. Bland-Altman analyses were conducted to assess the 95% limits of agreement (LoA) between DXA and each of the six BIA devices for %BF. Assumptions for Bland-Altman analysis, including constant variance of differences across the measurement range, were visually inspected and verified prior to interpretations.

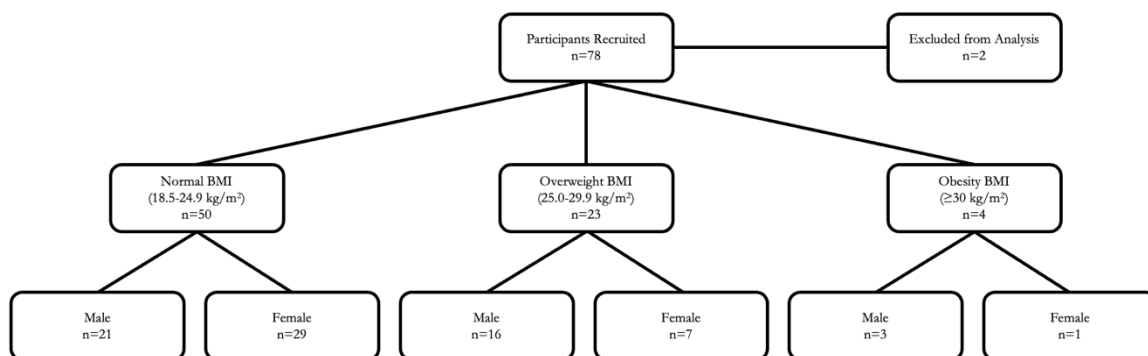


Figure 1: Participant exclusion and body mass index stratification.

Note: BMI = Body Mass Index

Results

Data from 77 participants were analyzed, and participant characteristics are displayed in **Table 2**. The majority of participants were Caucasian (90.9%) and 60.5% were categorized as having a normal BMI (**Figure 1**).

Table 2. Participant characteristics.

	All n=77	Male n=42	Female n=35
Age	21.0 ± 1.9	21.2 ± 1.9	20.9 ± 1.8
Height (cm)	172.0 ± 9.8	175.5 ± 9.0	167.8 ± 9.2
Weight (kg)	74.5 ± 12.9	81.2 ± 10.7	66.3 ± 10.7
BMI (kg/m ²)	24.7 ± 3.1	25.4 ± 3.4	23.6 ± 2.5
%BF	24.1 ± 7.7	19.3 ± 5.6	30.0 ± 5.6
Note: BMI = Body Mass Index, %BF = Percent Body Fat, derived from dual-energy x-ray absorptiometry			

To assess the agreement between BIA- and DXA-derived %BF, Spearman's rank correlation coefficients (ρ) were used. All BIA devices demonstrated significant positive correlations with DXA ($p < 0.001$), indicating a strong rank-based association. Among them, InBody S10, InBody H₂O, and Tanita exhibited the strongest correlations (**Table 3**). Triumph, the lowest-performing device, still maintained a statistically significant correlation with DXA, suggesting a consistent trend despite weaker overall performance (**Table 3**).

Table 3. BIA devices vs. DXA %BF correlation and agreement.

	Device	Means ± SD	Spearman's	ICC	ICC CI
All n=77	DXA	24.1 ± 7.8			
	Renpho	21.7 ± 5.7	0.72***	0.66***	0.46-0.78
	Tanita	20.9 ± 6.5	0.88***	0.81***	0.31-0.92
	Triumph	21.2 ± 4.7	0.51***	0.41***	0.19-0.58
	Omron	26.3 ± 8.3	0.88***	0.85***	0.68-0.92
	InBody H ₂ O	21.4 ± 8.7	0.86***	0.82*	0.59-0.91
	InBody S10	19.8 ± 8.4	0.91***	0.79***	0.06-0.93
Male n=42	DXA	19.3 ± 5.6			
	Renpho	18.8 ± 5.1	0.35*	0.51***	0.25-0.70
	Tanita	16.6 ± 4.2	0.63***	0.62**	0.22-0.81
	Triumph	20.4 ± 5.2	0.38*	0.46***	0.18-0.67
	Omron	20.6 ± 5.4	0.71***	0.73***	0.54-0.85
	InBody H ₂ O	16.9 ± 7.3	0.81***	0.70***	0.44-0.84
	InBody S10	14.8 ± 6.7	0.79***	0.65*	-0.02-0.87
Female n=35	DXA	29.9 ± 5.6			
	Renpho	25.3 ± 4.2	0.54***	0.43*	-0.05-0.73
	Tanita	26.2 ± 4.7	0.82***	0.68*	-0.04-0.89
	Triumph	22.3 ± 3.8	0.50**	0.25	-0.10-0.59
	Omron	33.2 ± 5.2	0.72***	0.66*	0.10-0.86
	InBody H ₂ O	26.8 ± 7.0	0.84***	0.73**	0.31-0.88
	InBody S10	25.6 ± 6.1	0.87***	0.69*	-0.05-0.90

Note: DXA = Dual energy x-ray absorptiometry; ICC = Interclass correlation; CI = Confidence interval
 * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

To evaluate the agreement between BIA devices and DXA, ICCs were calculated using a two-way random-effects model for absolute agreement (**Table 3**). Omron demonstrated the highest agreement, followed by InBody H₂O Tanita, and InBody S10. Notably, the CI for InBody S10 was wide (CI: 0.06-0.93), suggesting a high degree of uncertainty despite a strong correlation. Triumph had the lowest agreement with DXA (ICC = 0.41, 95% CI: 0.19-0.58), which reinforces the limitations observed in the correlation results. Renpho showed moderate agreement, supporting its utility with caution. Taken together, the findings indicate that while most BIA devices demonstrate a strong correlation with DXA, only Omron, InBody H₂O, and Tanita show both strong correlation and acceptable agreement, making them more reliable for estimating %BF in comparison to DXA.

Bland-Altman plots were used to assess individual-level agreement between each BIA device and DXA for estimating %BF (Figure 2). Omron (Figure 2D) had a mean bias of -2.21%, with narrow limits of agreement (-9.88% to 5.46%), indicating minimal systematic over- or underestimation and acceptable precision. Moreover, Tanita (Figure 2B) and Renpho (Figure 2A) demonstrated moderate positive biases of 3.18% and 2.38%, respectively. Tanita exhibited tighter agreement (LoA: -3.46% to 9.81%), while Renpho showed greater variability (LoA: -7.95%-12.74%). InBody H₂O (Figure 2E) and InBody S10 (Figure 2F) overestimated %BF compared to DXA, with a mean bias of 2.72% and 4.36%, and LoA ranges of 5.73% to 11.17% and -2.25% to 11.07%, respectively. Alternatively, Triumph (Figure 2C) displayed the widest LoA (-10.25% to 16.01%) and a mean bias of 2.88%, reflecting the greatest individual-level variability and weakest with DXA.

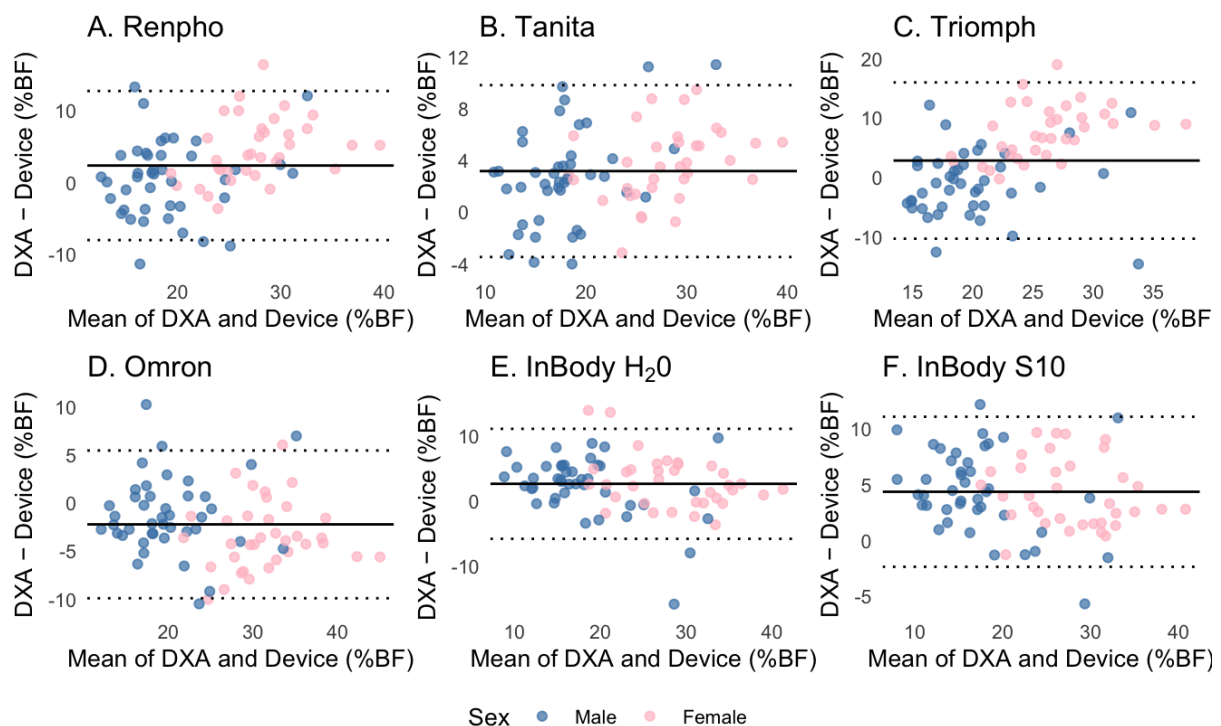


Figure 2: Bland-Altman Plots Level of Agreement (LoA). DXA: Dual x-ray absorptiometry.

Discussion

This present study evaluated the agreement between DXA and several commercially available BIA devices in estimating %BF. Although most devices showed statistically significant correlations with DXA, Bland-Altman analysis revealed meaningful differences in agreement and precision, which have important implications for researchers, consumers, and practitioners in terms of at-home and research body composition assessments.

Among the devices tested, Omron demonstrated the most favorable agreement profile, with the smallest mean bias (-2.21%) and relatively narrow LoA (-9.88% - 5.46%). This suggests that Omron provided relatively stable estimates across participants, making it a practical option for at-home longitudinal body composition tracking. This finding aligns with previous research indicating that specific BIA devices can provide reliable estimates of fat mass when compared to DXA. InBody H20 and InBody S10 also demonstrated moderate biases (2.72% and 4.36%, respectively), with LoA ranges indicating reasonable agreement, supporting their potential utility for clinical body composition monitoring. These findings support prior research^{15,16,19} suggesting that multi-frequency or segmental BIA systems, such as those used in both InBody devices and Omron, may offer improved accuracy over single-point BIA devices. Since multi-frequency and segmental BIA devices assess impedance across multiple frequencies and body segments, it is likely that the greater number of measurements improved device accuracy.

Conversely, both Triumph and Renpho showed larger variability, with Triumph exhibiting the widest LoA (-10.25% - 16.01%) and the highest bias (2.88%). The magnitude and inconsistency of the disagreement raise concerns about the validity of these devices for individual-level body composition assessment. Renpho, which has gained popularity in the consumer market due to its affordability and app-based interface, demonstrated particularly wide LoA (20.71%), calling into question its validity and utility despite ease of access.

Several factors may contribute to the observed discrepancies between BIA devices and DXA. BIA measurements are influenced by hydration status, recent food intake, physical activity, and other physiological variables. For instance, dehydration can increase the body's electrical resistance, leading to an overestimation of %BF. Although hydration status was measured, participants who were hypo- or hyper-hydrated were asked to consume water or reschedule. Respectively, there could have been varying levels of hydration, which could have been confirmed if we collected hydration markers, such as urine osmolality or specific gravity^{20,21}. Given the consistent conditions between measurements, these findings suggest that device proprietary algorithms may have contributed to the variability within %BF measurements. Each of the BIA devices required input of height and sex, and the scales independently measured weight.

When the sample was analyzed as a whole, all ICC CIs were above zero, indicating a consistent degree of reliability across all participants. However, when examined by sex, we observed wide ICC CIs, likely reflecting small subgroup sample sizes, or greater within- compared to between-participant variability. Additionally, the proprietary algorithms used by the BIA devices, along with the body composition reference data used to develop them, may contribute to these wide CIs. Given these limitations, sex-based subgroup analysis should be interpreted with caution. Future studies should ensure sufficient power for subgroup comparisons, such as age, sex, %BF, and ethnicity, to examine the reliability across a more diverse sample.

The present study offers several strengths, including the evaluation of six different BIA devices, providing a comprehensive comparison of commercially available devices, including those marketed for at-home tracking. Standardization of hydration status, recent food intake (>8 hours), and testing occurring within the same time of day enhances study validity for body composition testing¹³. However, there are limitations to consider. The sample size lacked ethnic diversity, and most participants were within a normal BMI range, limiting the generalizability of results to those with different ethnic backgrounds or BMI categories. The cross-sectional design prevents assessment of device reliability over time (i.e., test-retest reliability) or sensitivity to changes in body composition. An additional consideration is that most of the BIA devices did not allow for user calibration, as their algorithms and reference equations are proprietary. Measurements, therefore, reflect standard end-user conditions, which enhances ecological validity but may also contribute to the observed variability compared with DXA. In contrast, research and clinic-grade devices such as the InBody models include a manufacturer-driven quality control process, which may explain in part their narrower LoAs. The lack of accessible calibration in consumer-grade devices underscores an essential limitation for both researchers and consumers, as accuracy cannot be independently verified or adjusted. The present study did not evaluate test-retest reliability, and therefore, the results may not generalize to long-term device accuracy and performance. Finally, the moderate sample size limits the ability to conduct detailed subgroup analyses, and findings may not extend to populations with different ages and health statuses.

Practical Implications

From a practical perspective, these findings highlight that not all commercially available BIA devices are equally appropriate for tracking body composition. Segmental or multi-frequency devices such as Omron, InBody H20, and InBody S10 demonstrated a narrower LoA, thus a more consistent bias compared with DXA. This suggests they may be more suitable for consumers seeking to monitor general trends in %BF over time, or for practitioners interested in tracking longitudinal changes in body composition within a clinical or fitness setting. In contrast, single-frequency consumer-grade devices such as Triumph and Renpho exhibited wide variability and significant biases, limiting their suitability for individual-level assessment or clinical application where accuracy is critical. The use of these devices may be more appropriate for broad tracking or casual self-monitoring.

For females, the included BIA devices may be better for tracking trends or comparing differences, but less accurate for absolute %BF values. For males, BIA devices appear to provide more accurate absolute values, making them more reliable for estimating

Conclusions

While BIA devices offer a practical and affordable solution for monitoring body composition trends over time, the variability in accuracy compared to DXA suggests BIA devices should be used with caution. Many BIA devices are available to consumers and researchers to purchase, and our findings indicate that at-home, consumer-marketed devices may be insufficient in terms of %BF estimation compared to DXA. Among the devices tested, Omron, InBody H20, and InBody S10 demonstrated the most favorable agreement within DXA, indicating a greater promise for consumer and research-grade multi-frequency BIA devices compared with single-frequency BIA devices.

Conflicts of Interest

The authors declare no conflicts of interest.

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