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# MIND THE GAP: CLINICAL CAUTION IN USING MFBIA FOR BODY FAT ASSESSMENT

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**Abstract** *Impedance-based body composition assessment is commonly used because it is quick, noninvasive, and practical in clinical and field settings. However, its accuracy compared with reference methods can vary across different populations. The current study examined how well multi-frequency bioelectrical impedance analysis (MFBIA; seca mBCA 514) agreed with dual-energy X-ray absorptiometry (DXA) in estimating body fat percentage (BF%) and fat mass in adults. In this agreement study, 45 adults received the same-day body composition measurements using MFBIA and DXA. Agreement between the two methods was evaluated using Bland-Altman analysis, paired statistical tests, effect sizes, and root mean square error (RMSE). Correlation and linear regression analyses were also performed to assess the strength of association and predictive relationship between the methods. The results showed that MFBIA and DXA produced similar estimates for body weight and body mass index (BMI). However, MFBIA consistently underestimated body fat-related measures. Mean BF% was 30.32 ± 8.08% with MFBIA compared with 33.86 ± 7.79% with DXA, resulting in a mean bias of -3.54 percentage points (95% CI: -4.34 to -2.74;* $p < 0.001$*; Cohen's* $d = -1.33$*). Bland-Altman analysis demonstrated limits of agreement ranging from -8.75 to +1.67 percentage points for BF% and from -8.41 to +3.40 kg for fat mass, with no evidence of proportional bias. Although BF% estimates from the two methods were strongly correlated (*$r = 0.945$*;* $R^2 = 0.892$*), the RMSE of 4.41 percentage points indicated considerable variation at the individual level. Overall, MFBIA showed a strong relationship with DXA measurements but systematically underestimated BF% and fat mass. While the two methods were closely associated, the observed bias and relatively wide limits of agreement suggest that MFBIA should not be used interchangeably with DXA when precise individual-level estimates of body fat percentage are required.*

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## Introduction

Obesity has become increasingly prevalent worldwide and is characterized by the excessive buildup of body fat. This condition is strongly linked to a greater risk of several metabolic and cardiovascular diseases, including type 2 diabetes mellitus, non-alcoholic fatty liver disease, and dyslipidemia (Nathan and Moran, 2008). Within this context, body fat percentage (BF%) has gained importance as a more informative clinical measure than the commonly used body mass index (BMI), because it more accurately reflects metabolic health risk (Zeng et al., 2012). Nevertheless, BF% is not a complete measure of disease risk because it does not differentiate between increased adiposity, low skeletal muscle mass, or the coexistence of both conditions, which may each carry different metabolic implications (Bennett and Lim, 2025). Consequently, there is growing interest in precise BF% assessment methods that can be integrated into both clinical and field-based health evaluations. Multiple techniques are currently available for estimating BF%, ranging from relatively simple field methods, such as skinfold-thickness measurements and bioelectrical impedance analysis (BIA), to more sophisticated imaging techniques like dual-energy X-ray absorptiometry (DXA) (Wells and Fewtrell, 2006). DXA is widely used as a clinical reference standard for body composition assessment, although multi-compartment models such as the four-compartment model are considered the true gold standard (Genton et al., 2002). However, its use is limited by cost, the requirement for trained personnel, and limited accessibility in routine clinical or field settings.

BIA is a convenient, low-cost, non-invasive method that estimates body composition by measuring how body tissues resist a low-voltage electrical current (Bosy-Westphal et al., 2008). Advanced devices like the MFBIA use multi-frequency bioelectrical impedance analysis (MFBIA) algorithms to assess fat mass, fat-free mass, total body water, and its compartments. Its portability, speed, safety, and practicality support broad use in clinical and research settings (Kyle et al., 2015). Although BIA is a well-established and widely used method for estimating BF%, particularly in large-scale and field-based studies (e.g., NHANES 1999–2004), some variability in its accuracy compared to DXA has been reported. Prior research has demonstrated that BIA can provide reasonably accurate estimates of body fat percentage in general populations (Kabiri et al., 2015; Talma et al., 2013). However, its accuracy may be influenced by variables such as age, sex, ethnicity, hydration status, and body fat distribution. (Dehghan and Merchant, 2008; Sim et al., 2014). While paediatric studies offer a valuable methodological background, the current study is centered on adults; therefore, adult validation data are given greater weight when interpreting the findings. In individuals with obesity, variations in body shape and fluid distribution may affect measurement accuracy, and comparable limitations have also been reported in overweight or obese paediatric populations (Wells et al., 1999; Goldfield et al., 2006). Sex-related variations in body fat, fat distribution, and hormonal status can affect BIA accuracy and may introduce bias in fat mass estimates. Therefore, subgroup-specific validation is important to ensure reliable body composition assessment across different populations (Bosy-Westphal et al., 2008; Heymsfield and Wadden, 2017).

Prior studies of the MFBIA-based mBCA platform have shown encouraging but variable results. Bosy-Westphal et al. reported that its accuracy depends on the prediction equations applied and the reference method used, such as four-compartment models, DXA, densitometry, or dilution techniques (Bosy-Westphal et al., 2013). Direct comparisons between MFBIA and DXA have shown reasonable agreement at the group level, but meaningful differences may occur in individual patients. Day et al. found that MFBIA slightly underestimated fat mass compared with GE iDXA by an average of 0.32 kg, indicating partial agreement but not full equivalence across BMI categories. (Day et al., 2018). Lahav et al. reported strong agreement between MFBIA and DXA for body fat percentage in adults across a wide age and BMI range. Although the mean difference was small, the wide limits of agreement indicated that individual results should be interpreted cautiously in clinical settings (Lahav et al., 2021). Taken together, existing evidence indicates that MFBIA may be suitable for estimating body composition in groups, but its agreement with DXA can differ across patient populations. This highlights the need for additional validation studies in varied clinical settings. The present study compared body fat percentage measured by MFBIA using the seca mBCA device with DXA in adults. We evaluated agreement, mean differences, measurement bias, and predictive relationships between the two methods. We hypothesized that MFBIA-derived body fat percentage would show systematic bias compared with DXA, limiting its interchangeability for precise individual adiposity assessment. Because BIA performance may differ by sex due to differences in fat distribution, body shape, and hydration, exploratory sex-stratified analyses were also performed. Overall, this study focuses on clinically interpreting agreement and bias between MFBIA and DXA rather than establishing population novelty alone.

## Materials and Methods

### *Study Design and Participants*

This comparative cross-sectional study was performed at Life Core Private Clinic LLC, Abu Dhabi, UAE, between May 2023 and February 2025. It included 45 adults and assessed agreement between the Seca mBCA 514 multi-frequency bioelectrical impedance analysis device and DXA for body fat percentage estimation. The study used fully deidentified retrospective clinical data; therefore, under institutional policy, formal IRB approval was not required, and informed consent was waived. Participants were not prospectively recruited for a specific intervention or disease-focused protocol; rather, the study sample consisted of eligible adults with available same-day MFBIA and DXA assessments during the study period.

### ***Inclusion and Exclusion Criteria***

Adults aged 18 years or older who were able to complete both MFBIA and DXA assessments on the same day were eligible for inclusion. Exclusion criteria included pregnancy, implanted electronic medical devices, or known conditions that could substantially alter body fluid balance, as these may affect impedance-based measurements.

### *Anthropometric and Body Composition Measurements*

### **MFBIA Measurements**

Body composition was assessed using the MFBIA (SECA mBCA 514 system) (seca GmbH, Hamburg, Germany), which employs an eight-electrode, multi-frequency bioelectrical impedance analysis approach. The MFBIA (seca mBCA 514 system) uses a standing eight-electrode configuration with integrated hand and foot electrodes, enabling segmental impedance measurements without the use of adhesive electrodes in a supine position. Participants were measured in the standing position according to the manufacturer's standard clinical protocol. Assessments were performed during a single clinical visit with participants wearing light clothing, without shoes or metal accessories, and positioned on the device with proper hand and foot electrode contact.

Participants were assessed following routine clinical preparation procedures, which included removal of metallic objects and measurement under standardized standing posture conditions. Because this study was a retrospective analysis of routinely collected clinical data, additional pre-measurement standardization procedures commonly recommended in research settings, such as fasting status, recent fluid intake, recent physical activity, and alcohol consumption, were not systematically documented. MFBIA measurements were obtained as single measurements during routine clinical assessment rather than repeated replicate measurements.

**DXA Measurements**

A Hologic Horizon Wi Dual-Energy X-ray Absorptiometry System (Hologic Inc., Marlborough, MA, USA; APEX System Software Version 5.6.0.7) was used to evaluate whole-body body composition. From the DXA scans, the total fat mass, total lean mass, and total bone mineral content were derived. A trained operator performed all scans following the standard procedures set by Hologic. The DXA System underwent daily calibration by standardizing the use of quality control phantoms by the manufacturer. As with the MFBIA measurements, DXA assessments were also performed as single assessments in the course of a routine clinical evaluation.

**Statistical Analysis**

Statistical analyses were performed using SPSS version 31.0 (IBM Corp., Armonk, NY, USA) and Microsoft Excel (Microsoft Corp., Redmond, WA, USA). Body composition and participant characteristics were summarized using descriptive statistics. The Shapiro-Wilk test was used to check the normality of continuous variables, as well as histogram and Q-Q plots. Approximately normally distributed variables were expressed as mean ± standard deviation and symmetry. Bland-Altman analysis was the primary method used to assess the agreement between MFBIA and DXA, with mean bias and limits of agreement (bias ± 1.96 SD) calculated. To assess proportional bias, measurement differences were regressed onto their means. Paired t-tests or Wilcoxon signed-rank tests were used. Signed percentage error was calculated as (MFBIA - DXA) / DXA × 100, where negative values indicate underestimation by MFBIA. Pearson correlation coefficients and linear regression analyses were used to describe associations between MFBIA-derived and DXA-derived body composition estimates. In addition, Lin's concordance correlation coefficient was calculated to assess agreement between methods by simultaneously evaluating correlation and deviation from the line of identity. Root mean square error (RMSE) was calculated for BF% to quantify the average individual-level prediction error of MFBIA relative to DXA. Because the study was designed primarily as a method-comparison (agreement) study, emphasis was placed on estimation of mean bias and limits of agreement rather than hypothesis-testing power alone. Accordingly, sample adequacy was considered mainly in terms of estimation precision. Exploratory sex-stratified analyses were conducted to assess whether the magnitude of bias differed between male and female participants; however, given the modest sample size and unequal sex distribution, these subgroup analyses were interpreted cautiously. Because the female subgroup was small (n = 12), sex-specific analyses were considered exploratory only and were not used to derive correction factors. A p-value of <0.05 was considered statistically significant.

**Results**

***Descriptive Statistics and Sample Characteristics***

Forty-five participants were included (73% male, 27% female; mean age 50.6 ± 14.1 years). Table 1 presents the descriptive statistics for anthropometric and body composition measures obtained by MFBIA and DXA. Height and weight were similar between the two methods. In contrast, **MFBIA** consistently yielded lower estimates for fat-related measures. Mean fat mass measured by **MFBIA** was 24.45 ± 9.65 kg compared with 26.95 ± 8.77 kg measured by **DXA,** corresponding to a mean difference of -2.51 kg. Mean body fat percentage was 30.32 ± 8.08% with **MFBIA** and 33.86 ± 7.79% with **DXA,** yielding a mean bias of -3.54%. **Body mass index (BMI, kg/m²) values were comparable between methods.** The mean signed percentage error for body fat percentage was -10.82%, indicating systematic underestimation by MFBIA relative to DXA (Figure 1).

**Table 1. Descriptive characteristics and body composition measurements obtained using MFBIA and DXA**

| Variable | Mean ± SD | Median | Range | Min | Max |
|---|---|---|---|---|---|
| **Age (years)** | 50.58 ± 14.11 | 50.19 | 57 | 26 | 83 |
| **Height (m) MFBIA** | 1.73 ± 0.09 | 1.73 | 0.36 | 1.53 | 1.89 |
| **Weight (kg) MFBIA** | 80.28 ± 13.92 | 80.00 | 72.00 | 49.00 | 121.00 |
| **BMI (kg/m²) MFBIA** | 26.76 ± 3.66 | 26.70 | 18.60 | 18.90 | 37.50 |
| **Fat Mass (kg) MFBIA** | 24.45 ± 9.65 | 23.40 | 48.94 | 9.50 | 58.44 |
| **Body Fat (%) MFBIA** | 30.32 ± 8.08 | 30.40 | 36.60 | 15.80 | 52.40 |
| **Height (m) DXA** | 1.73 ± 0.09 | 1.73 | 0.39 | 1.50 | 1.88 |
| **Weight (kg) DXA** | 80.37 ± 13.88 | 80.20 | 71.90 | 49.00 | 120.90 |
| **BMI (kg/m²) DXA** | 26.87 ± 3.63 | 26.90 | 18.50 | 18.90 | 37.40 |
| **Fat Mass (kg) DXA** | 26.95 ± 8.77 | 25.48 | 45.22 | 13.17 | 58.39 |
| **Body Fat (%) DXA** | 33.86 ± 7.79 | 33.40 | 37.50 | 17.10 | 54.60 |
| **Body Fat % Difference (MFBIA − DXA)** | -3.54 ± 2.66 | -3.80 | 13.70 | -9.70 | 4.00 |
| **Percentage Error (%)** | -10.82 ± 8.40 | -10.72 | 43.09 | -28.30 | 14.81 |
| **Weight Difference (kg)** | 0.09 ± 0.44 | 0.00 | 2.00 | -1.00 | 1.00 |
| **Weight Difference (%)** | 0.12 ± 0.55 | 0.00 | 2.76 | -1.54 | 1.22 |

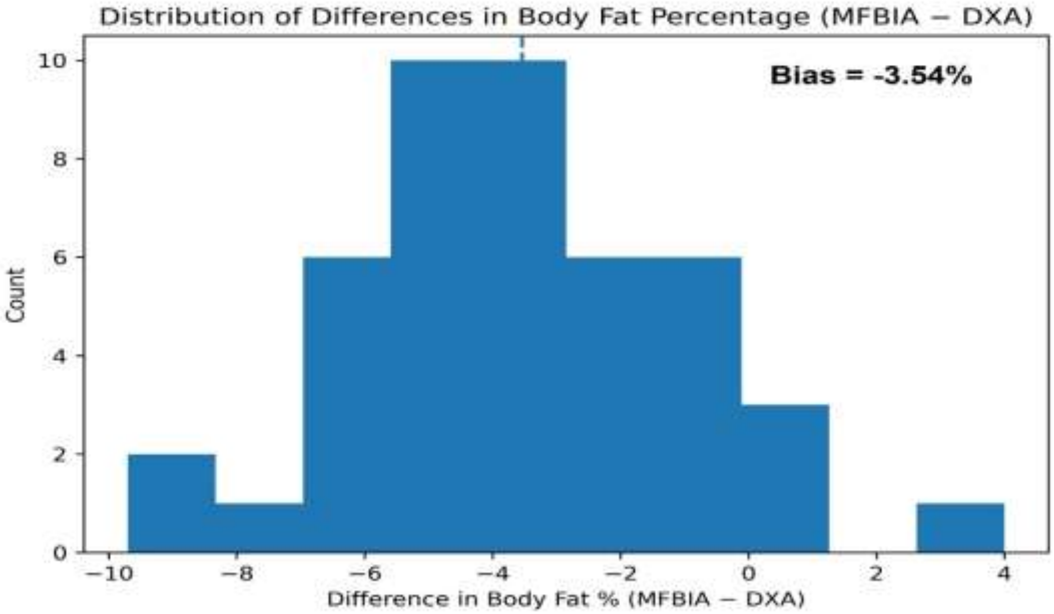

**Figure 1. Distribution of differences in body fat percentage between MFBIA and DXA.**

Histogram showing the distribution of paired differences in body fat percentage (MFBIA - DXA). The dashed vertical line represents the mean bias (-3.54%). Negative values indicate underestimation by MFBIA relative to DXA

### ***Agreement Between MFBIA and DXA Measurements***

Bland-Altman analysis demonstrated minimal mean differences between MFBIA and DXA for body weight and BMI (mean weight difference = 0.09 kg; mean BMI difference ≈ 0.11 kg/m²). For body fat percentage, the mean bias (MFBIA - DXA) was -3.54%, with 95% limits of agreement ranging from -8.75% to +1.67%. For fat mass, the mean bias was -2.51 kg, with corresponding limits of agreement from -8.41 to +3.40 kg (Figure 2).

By definition, the limits of agreement represent the range within which approximately 95% of individual differences between methods are expected to lie. The dispersion of differences appeared relatively constant across the measurement range, and regression of the differences on the means did not indicate evidence of proportional bias.

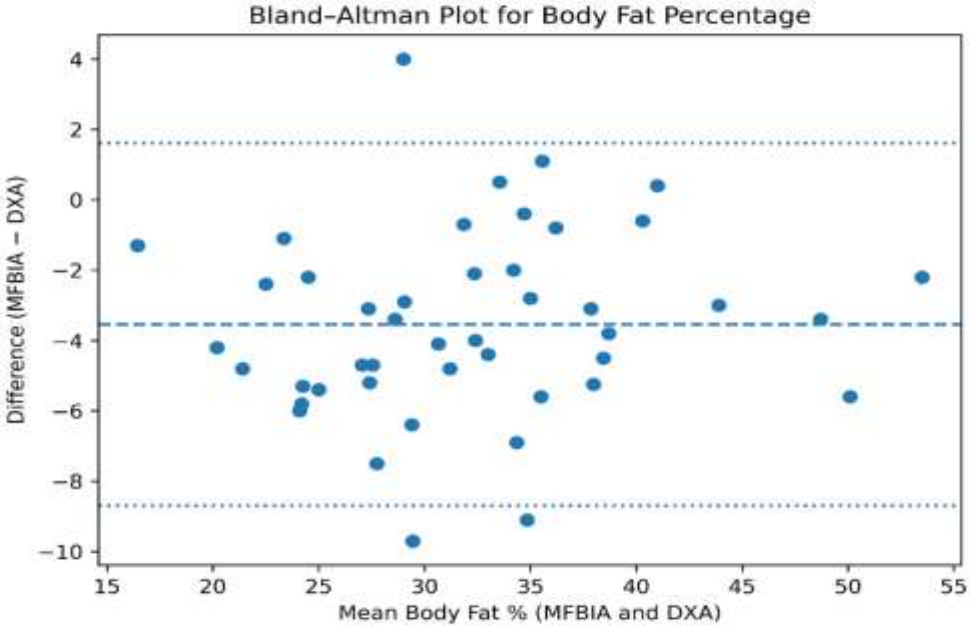

**Figure 2. Bland-Altman analysis of agreement between MFBIA and DXA for body fat percentage**

The dashed horizontal line represents the mean bias, and the upper and lower dashed/dotted lines represent the 95% limits of agreement (bias ± 1.96 SD). Negative differences indicate underestimation by MFBIA relative to DXA.

### ***Statistical Comparisons and Association***

Statistical analysis showed significant systematic differences between MFBIA and DXA for fat-related measures. MFBIA significantly underestimated fat mass compared with DXA (Wilcoxon signed-rank $p < 0.001$; $r = 0.731$), and body fat percentage also differed significantly between methods (paired t-test $p < 0.001$; Cohen's $d = -1.33$) (Table 2).

Despite this bias, MFBIA and DXA body fat percentage values showed a strong positive correlation (Pearson $r = 0.945$, $p < 0.001$; Figure 3). The regression equation was:

DXA BF% = 1.02 × (MFBIA BF%) + 2.74

Lin's concordance correlation coefficient for body fat percentage was 0.859, showing moderate-to-strong agreement between MFBIA and DXA, but lower than Pearson's correlation because of systematic bias. The model showed strong predictive performance ($R^2 = 0.892$; RMSE = 4.41 percentage points), reflecting association rather than true measurement agreement.

**Table 2. Mean Bias and Effect Size for Body Fat Percentage (MFBIA vs. DXA)**

| Parameter | Value | 95% CI |
|---|---|---|
| **Mean Bias (MFBIA − DXA), %** | -3.54 | -4.34 to -2.74 |
| **Standard Deviation** | 2.66 | – |
| **Standard Error of Mean** | 0.40 | – |
| **p-value** | < 0.001 | – |
| **Cohen's d** | -1.33 | -1.73 to -0.93 |
| **Hedges' g** | -1.31 | -1.70 to -0.91 |

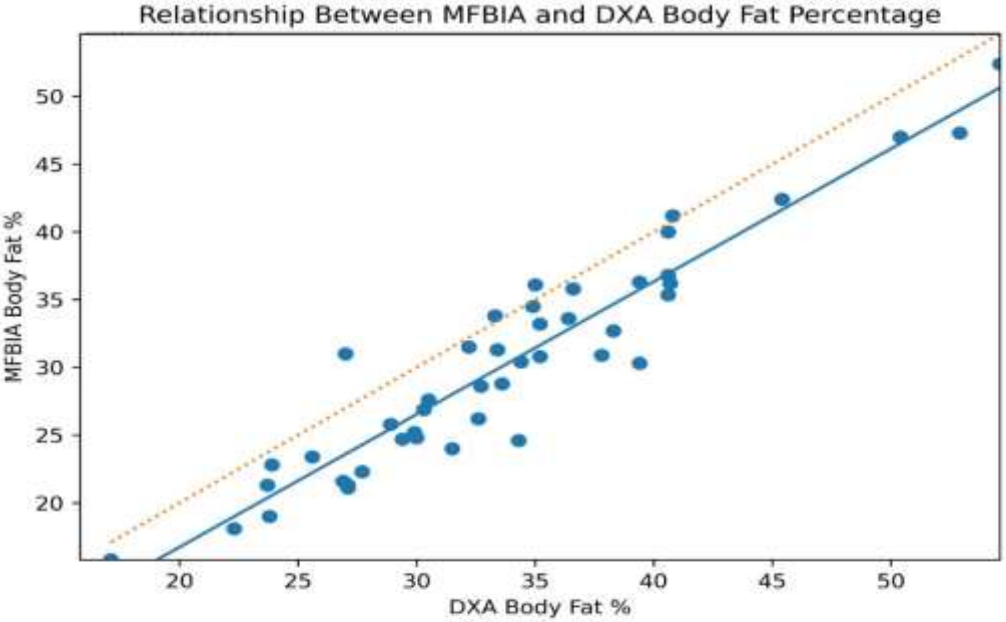

**Figure 3. Relationship between MFBIA and DXA-derived body fat percentage.**

Scatter plot showing the relationship between body fat percentage measured by MFBIA and DXA. The solid line represents the linear regression fit, and the dotted line represents the line of identity. A strong positive association was observed ($r = 0.945$, $p < 0.001$), with an RMSE of 4.41 percentage points.

***Subgroup Analyses***

Sex-stratified analyses were not emphasized due to the limited number of female participants (n = 12), which restricts the reliability of subgroup comparisons. Therefore, no definitive conclusions regarding sex-specific differences can be drawn from this dataset. Due to the small and uneven distribution of participants across ethnic groups, ethnicity-stratified statistical analyses were not performed.

## Discussion

The present study evaluated agreement between body fat percentage (BF%) estimates obtained using the MFBIA (seca mBCA multi-frequency bioelectrical impedance analysis system) and those derived from dual-energy X-ray absorptiometry (DXA) in a clinical adult cohort. The key observation was that MFBIA consistently underestimated BF% relative to DXA. The mean bias for BF% was -3.54%. Given a mean DXA-derived BF% of approximately 33.9%, this indicates an approximate 10% relative underestimation. Bland-Altman analysis also showed limits of agreement ranging from -8.75 to +1.67 percentage points, suggesting that the difference between the two methods may be considerably greater at the individual level. Relative to the mean DXA value, this equates to an approximate ±15% relative agreement interval. These findings indicate that MFBIA-derived BF% measurements should not be viewed as equivalent to DXA measurements when precise individual-level evaluation of adiposity is necessary.

Earlier investigations comparing bioelectrical impedance analysis with criterion reference methods have described comparable findings. Bosy-Westphal et al. reported that foot-to-foot BIA devices may show systematic biases of up to approximately 3% in BF% estimation when evaluated against DXA and MRI (Bosy-Westphal et al., 2008). Similarly, Ling et al. found that direct segmental multi-frequency BIA demonstrated good agreement with DXA for total and segmental fat mass in a middle-aged population, although detectable bias in BF% estimates was present (Ling et al., 2011). Together, these studies support the broader observation that impedance-based techniques often correlate well with reference methods, but systematic variation in absolute adiposity estimates remains common. Studies directly assessing the MFBIA platform have reported similar observations. Day et al. showed that MFBIA demonstrated a degree of agreement with DXA across different BMI categories; however, the two methods were not interchangeable across the full range of adiposity. Likewise, Lahav et al., in a larger adult cohort covering a broad BMI spectrum, reported strong group-level agreement between MFBIA and DXA, while noting that individual-level differences should be interpreted with caution (Lahav et al., 2021). Collectively, these findings align with the results of the present study and highlight the importance of assessing agreement rather than depending solely on correlation.

Sex-specific physiological differences may also affect the accuracy of impedance-based body composition estimates. In the present study, exploratory analyses indicated a possible greater underestimation of BF% in females compared with males; however, the limited size of the female subgroup prevents robust sex-specific conclusions. Similar findings have been described in previous studies. Kyle et al. reported that BIA-derived adiposity estimates may vary between males and females because of physiological factors, including differences in fat distribution and hormonal effects (Kyle et al., 2015). Feng et al. and Sun et al. also showed that differences in visceral and subcutaneous fat distribution may affect the performance of impedance-based prediction models across sexes (Feng et al., 2024; Sun et al., 2005). Nevertheless, because the present study included a relatively small number of female participants, these results should be interpreted cautiously. The limited number of participants with obesity in this cohort should also be considered. Only four participants were categorized as obese, restricting the ability to determine whether the degree of bias varied across adiposity groups. Earlier studies assessing the MFBIA platform and other BIA devices have generally included wider BMI ranges and have indicated that prediction equations may perform differently in individuals with greater adiposity. Variations in body shape, fat distribution, and fluid compartment characteristics may affect impedance-based estimates. Therefore, the underestimation observed in the present study may not fully reflect device performance in populations with a higher proportion of individuals with obesity.

A key methodological issue in interpreting differences between MFBIA- and DXA-derived estimates is that bioelectrical impedance analysis does not directly quantify fat mass. Rather, impedance data are combined with proprietary prediction equations that use anthropometric and demographic variables to estimate body composition. As a result, disagreement between MFBIA-derived and DXA-derived BF% estimates should not automatically be interpreted as an error in impedance measurement itself. Instead, systematic bias may result from limitations of the proprietary equations used to transform impedance values into body composition estimates. Since these equations are usually developed in specific calibration cohorts, their accuracy may be reduced when applied to populations with different physiological profiles. Although systematic bias was observed, MFBIA-derived BF% indicated a better correlation with DXA-derived measurements ($r = 0.945$), and regression analysis showed that MFBIA explained 89.2% of the variance in DXA-derived BF%. However, statistical analysis demonstrated significant systematic underestimation, with a paired difference between methods ($t = -8.93$, $p < 0.001$), a large effect size (Cohen's $d = -1.33$), and a mean signed percentage error of -10.82 ± 8.40%.

Bland-Altman testing showed minimal mean differences between MFBIA and DXA for body weight and BMI, supporting good agreement for these parameters. However, for adiposity-related measures, particularly fat mass and BF%, the observed bias and wide limits of agreement indicate that clinically meaningful individual-level differences may occur. These discrepancies may affect interpretation when body composition estimates are used to classify adiposity or cardiometabolic risk. Overall, these observations align with earlier measurement-accuracy studies, showing that multi-frequency BIA can provide reasonable group-level estimates compared with DXA, but may still show systematic bias and notable individual-level variability. Therefore, MFBIA-derived body fat estimates should be interpreted with consideration of method-specific limitations, especially when compared with DXA.

## Limitations

This study has several limitations. The relatively small sample size and unequal distribution across sex, ethnicity, age, and BMI categories limited the ability to perform robust stratified analyses. While exploratory sex-specific comparisons were feasible, ethnicity and BMI-specific inferential analyses were not conducted to avoid underpowered or potentially misleading conclusions. The study population was drawn from a clinical setting and consisted predominantly of middle-aged and older adults, which may limit generalizability to younger populations. In addition, bioelectrical impedance analysis relies on proprietary prediction equations that may be influenced by population-specific physiological characteristics; therefore, the contribution of device-specific algorithms to the observed underestimation of body fat percentage could not be directly assessed. Although the sample size allowed estimation of overall bias and limits of agreement between MFBIA and DXA, it was not sufficiently large to support robust subgroup analyses, particularly by sex, and these findings should therefore be interpreted cautiously. Repeated within-session MFBIA measurements were not obtained; therefore, test-retest reproducibility and technical error of the impedance-derived body composition estimates could not be quantified in this study.

Hydration status is an important determinant of bioelectrical impedance–derived body composition estimates because the method assumes relatively constant hydration of the fat-free mass. Although participants were assessed under routine clinical conditions and individuals with conditions expected to substantially alter body fluid balance were excluded, standardized measurements of hydration or extracellular water status were not performed. Consequently, the potential influence of hydration variability on the observed differences between MFBIA and DXA measurements could not be evaluated. Despite these limitations, the consistency of results across multiple analytical approaches supports the robustness of the observed systematic bias.

## Conclusion

Among adult participants in this study, MFBIA-derived BF% showed a strong association with DXA measurements but consistently underestimated body fat. The mean bias was -3.54 percentage points, with limits of agreement from -8.75 to +1.67 percentage points, indicating that MFBIA and DXA should not be considered interchangeable for precise individual-level BF% assessment.

Although MFBIA may be beneficial as a practical body composition tool in clinical settings, its BF% estimates should be interpreted cautiously, particularly when used for adiposity or cardiometabolic risk classification. Larger studies in more diverse populations are needed to better define its accuracy across different demographic and adiposity groups.

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## Statements and Declarations

### Ethic approval

This retrospective study used fully deidentified routine clinical data obtained from Life Core Private Clinic LLC, Abu Dhabi, United Arab Emirates. According to institutional policy and applicable regulations, research involving exclusively anonymized data did not require formal Ethics Committee/Institutional Review Board approval or informed consent.

### Conflict of Interest

Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

### Authors Contribution

MRQ conceived the study. MRQ, SHSM, MMA, FA, SRU, ZP, FUA, and MMK contributed to data acquisition, analysis, interpretation of data, and critical revision of the manuscript. MRQ and FUA prepared the initial draft. All authors approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

### Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author(s) used ChatGPT (OpenAI) to assist with language refinement and restructuring for clarity. After using this tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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