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Original Article

Open, Active-Controlled Clinical Study to Evaluate the Correlation between Whole Body DEXA and BIA Muscle Measurements

Yong-Chan Ha[1], Shinjune Kim[2], Jun-Il Yoo[3]

[1]Department of Orthopaedic Surgery, Seoul Bumin Hospital, Seoul;
[2]Department of Biomedical Research Institute, Inha University Hospital, Inha University School of Medicine, Incheon;
[3]Department of Orthopaedic Surgery, Inha University Hospital, Inha University School of Medicine, Incheon, Korea

Corresponding author
Jun-Il Yoo
Department of Orthopaedic Surgery, Inha University Hospital, Inha University School of Medicine, 27 Inhang-ro, Jung-gu, Incheon 22332, Korea
Tel: +82-55-750-8688
Fax: +82-55-754-0477
E-mail: furim@hanmail.net

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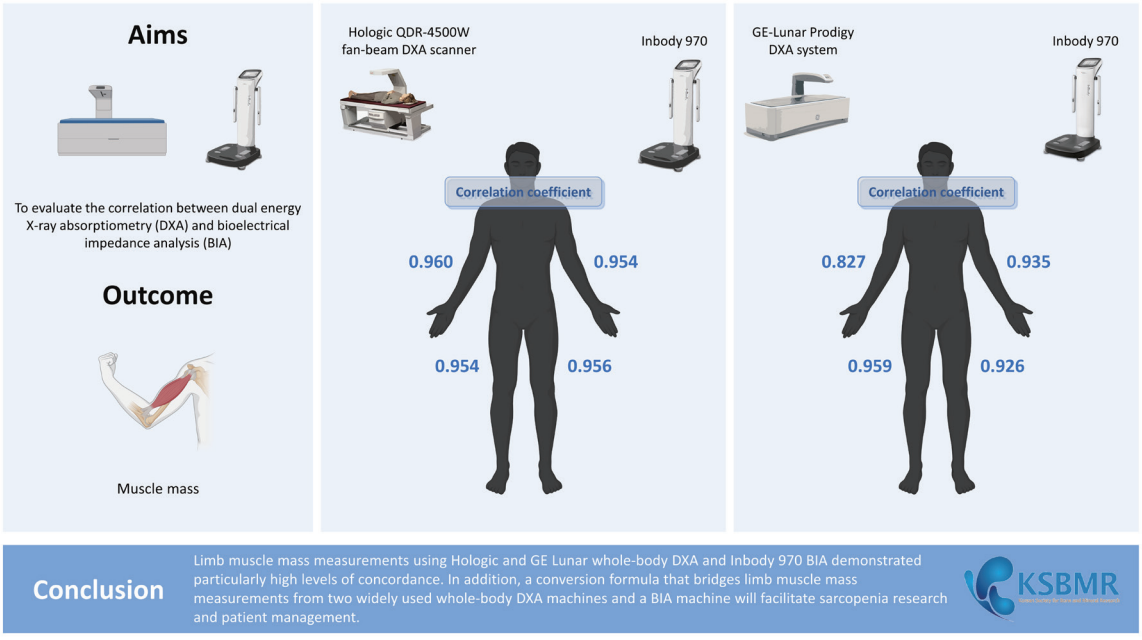
Background: Dual energy X-ray absorptiometry (DXA) is the gold standard for diagnosing sarcopenia. However, comparative studies using bioelectrical impedance analysis (BIA) would be required in the Korean population. This study aimed to evaluate the correlation between total-body bone density measuring devices (Hologic and GE Lunar) and a bioelectrical impedance measurement device (InBody 970) as well as the correlation between upper body muscle mass. **Methods:** A total of 119 participants were involved in this study, aged 20 to 70 years, with specific body mass index ranges and no severe health conditions used both DXA (or DEXA) and BIA technologies to assess body composition. The participants were scanned using a Hologic QDR-4500W DXA scanner and GE-Lunar Prodigy DXA systems, and the InBody 970 type of multi-frequency BIA machine. Statistical analysis was performed to determine the correlation between the devices, with a coefficient of at least 0.8. **Results:** The muscle mass measurement comparisons between the InBody 970 and Hologic devices demonstrated remarkably high correlation coefficients (exceeding 0.9) across all limbs. Similarly, the muscle mass comparison between the Inbody 970 and GE Lunar devices also revealed substantial correlation coefficients, ranging from 0.83 upwards, across all limbs. **Conclusions:** Limb muscle mass measurements using Hologic and GE Lunar whole-body DXA and Inbody 970 BIA demonstrated particularly high levels of concordance. In addition, a conversion formula that bridges limb muscle mass measurements from two widely used whole-body DXA machines and a BIA machine will facilitate sarcopenia research and patient management.

Key Words: Absorptiometry · Body composition · Calibration · Impedance · Muscle

INTRODUCTION

Sarcopenia is characterized by a decrease in muscle mass and physical function with age and increases the risk of frailty, disability, falls, fractures, and death. As the average lifespan of Koreans continues to increase and the aging population accelerates, it is estimated that approximately 700,000 to 1 million elderly individuals over 65 years of age are affected by sarcopenia.[1-4] This condition is emerging as a significant health issue that escalates medical and long-term care costs, especially in a super-aged society.[5-8]

Graphical Abstract



Since the first diagnostic criteria for sarcopenia were announced in 2010, numerous basic and clinical research results have been reported globally.[9-12] Recent updates include the 2019 European Sarcopenia Diagnosis and Management Guidelines and the 2020 Asian Sarcopenia Diagnosis and Management Guidelines.[13-15] These guidelines provide comprehensive recommendations for the diagnosis and management of sarcopenia, highlighting the importance of early detection and intervention.

Sarcopenia has been assigned a disease code in the International Classification of Diseases, Eleven Revision, and since 2021, the diagnosis of sarcopenia (M62.5) has been included in the 8th Korean Standard Disease Cause Classification.[16] With the international consensus on the diagnostic algorithms and criteria, and recognition as an official disease, there has been a global focus on the importance and value of sarcopenia.[9,17-19] This recognition underscores the need for standardized diagnostic approaches and effective treatment strategies to manage this growing health issue.

Dual energy X-ray absorptiometry (DXA or DEXA) is considered the gold standard for diagnosing sarcopenia; however, there is a need for comparative studies using bioelectrical impedance analysis (BIA), particularly in the Korean population.[20-23] DXA provides precise measurements of bone density and body composition but is limited by its high cost and accessibility issues. In contrast, BIA is a more affordable and accessible option, making it a valuable tool for widespread screening in clinical and community settings.

This study aimed to evaluate the correlation between the concordance of limb muscle mass between Hologic and GE Lunar, whole-body bone density-measuring instruments, and InBody 970, a bioelectrical impedance-measuring instrument. By assessing these correlations, the study seeks to determine if BIA can serve as a reliable alternative to DXA. Furthermore, it is necessary to understand the validity of the bioelectrical impedance measurement method for the diagnosis of sarcopenia. Such validation is crucial for adopting BIA in clinical settings, particularly for widespread and cost-effective screening of sarcopenia.

METHODS

1. Participants

A total of 119 participants, aged 20 to 70 years old, with a body mass index (BMI) greater than or equal to 17 kg/m^2 and less than or equal to 35 kg/m^2 with a negative preg-

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nancy test at the time of screening who voluntarily participated in the study and provided written consent were included (Approval no. 2106-029-468). During recruitment, 40 participants were selected for the 20 to 39 years age group, 40 participants for the 40 to 59 years age group, and 39 participants for the 60 to 70 years age group, with gender ratios and BMI ratios balanced and randomly sampled. The exclusion criteria were scoliosis, osteoarthritis, osteomalacia, or other clinical vertebral deformities; adverse events after previous DXA or radiography; pregnant or lactating women; those with artificial pacemakers or implanted cardiac pacemakers; and patients with mental illnesses, such as severe depression.

The Chung-Ang University Hospital Research Ethics Committee granted ethical approval for the study, and all participants provided their informed consent by signing a document prior to undergoing the scans.

2. DXA measurements

Each participant underwent two scans, utilizing both the Hologic QDR-4500W fan-beam DXA scanner (Hologic Inc., Bedford, MA, USA) and the GE-Lunar Prodigy DXA system (GE Medical Systems, Madison, WI, USA), in accordance with the standard scanning and positioning protocols specified by the respective manufacturers. Lines drawn through the glenohumeral joints separated the arms and trunk, while oblique lines through the hip joint, angled 45° from the body's sagittal plane, divided the trunk and legs.[24] A transverse line below the mandible served to exclude the head from the trunk area, which encompassed the thorax, abdomen, pelvis, and a segment of the medial thigh.[24] The android region of interest (ROI) was demarcated at the lower boundary of the pelvis, with its upper boundary extending above the pelvic cut to include 20% of the distance to the neck cut, and bounded laterally by arm cuts.[24] The gynoid ROI's upper limit was set at 1.5 times the height of the Android ROI below the pelvis, with a total height twice that of the Android ROI, and its lateral limits were defined by the external cuts of the legs.[24] To ensure uniformity across scans, manual ROI analysis was consistently carried out by the same experienced clinical densitometrists, certified by the International Society for Clinical Densitometry.[24]

3. BIA measurements

A single type of multi-frequency BIA (MF-BIA) machine, the InBody 970, was used to assess body composition. This machine measured the impedance of five body segments at frequencies of 1, 5, 50, 250, and 500 kHz, as well as at 1, 2, and 3 MHz. Participants were instructed to stand barefoot on the floor electrodes and grip the hand electrodes during the examination. Before electrode placement, each site was cleaned with an alcohol swab. Each measurement was performed twice and the mean value was used for subsequent analysis.

4. Statistical analyses

Statistical analysis was conducted to test the null hypothesis, which posited a correlation coefficient of 0.8 or higher between the two instruments for each measurement site. The sample size was calculated to require 116 participants by correcting the power according to the alternative hypothesis at a significance level and 80% of the power. The true (allowable) difference between the fat mass measurements was determined to be 1%, and the expected population standard deviation (SD) was 2% based on previous studies. The equivalence margin was set to 5%. Considering a final error rate of 5%, a total of 119 participants were selected as the final target group.[25] The sample size was determined using the website (http://riskcalc.org:3838/samplesize/).[25] The target group was recruited by distinguishing the distribution of age groups, BMI, and gender.

To evaluate accuracy, the study plotted differences between replicate DXA and BIA measurements from a given manufacturer against the estimated true value, employing Bland and Altman's method for calculating agreement limits. The study utilized the concordance correlation coefficient to assess the precision and accuracy of the correlation between the two devices. Correlation coefficients were categorized as follows: 0.2 to 0.4 indicated weak correlation, 0.4 to 0.6 indicated moderate correlation, 0.6 to 0.8 indicated strong correlation, and 0.8 to 1.0 indicated very strong correlation.[26] For establishing the conversion formula, the relationship between DXA and BIA measurements was characterized using linear regression analysis. All statistical analyses were conducted using R Statistical Software (version 3.4.1; The R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

A total of 119 participants were recruited, considering their age, sex, and BMI ratio, as outlined in Table 1. The analysis was conducted in two main contexts.

When comparing the Inbody and DXA measurements, a meticulous assessment of the muscle mass was performed. This involved using BIA with the InBody 970 device and comparing the outcomes with whole-body DXA measurements obtained using the Hologic device. The investigation revealed robust correlation coefficients of 0.95 or higher across all extremities, indicating a strong linear relationship between the two methods, as shown in Table 2 and Figure 1. To gauge disparities, muscle mass readings obtained from the Hologic device were subtracted from those derived from the Inbody 970. These discrepancies were then presented as average values for both the left and right arms and for legs, including the maximum and minimum limit values (±1.96 SD). These values were visualized using Bland-Altman plots tailored to each distinct site (Fig. 2). The analysis demonstrated that a substantial

Table 1. Recruitment status by age group and BMI of research participants

Variables	Age (yr)			Total
	20–39	40–59	60–70	
Male				
Normal (18.5 kg/m^2 ≤ BMI ≤ 23 kg/m^2)	10	10	9	29
Obese (23.0 kg/m^2 < BMI)	10	10	10	30
Female				
Normal (18.5 kg/m^2 ≤ BMI ≤ 23 kg/m^2)	10	10	10	30
Obese (23.0 kg/m^2 < BMI)	10	10	10	30

The data represent the number of patients.
BMI, body mass index.

Table 2. Correlation coefficient for muscle mass between the two devices (InBody 970 and Hologic)

Measurement area	Correlation coefficient (95% CI)
Muscle mass right arm	0.960 (0.94–0.97)
Muscle mass left arm	0.954 (0.94–0.97)
Muscle mass right leg	0.954 (0.93–0.97)
Muscle mass left leg	0.956 (0.94–0.97)

CI, confidence interval.

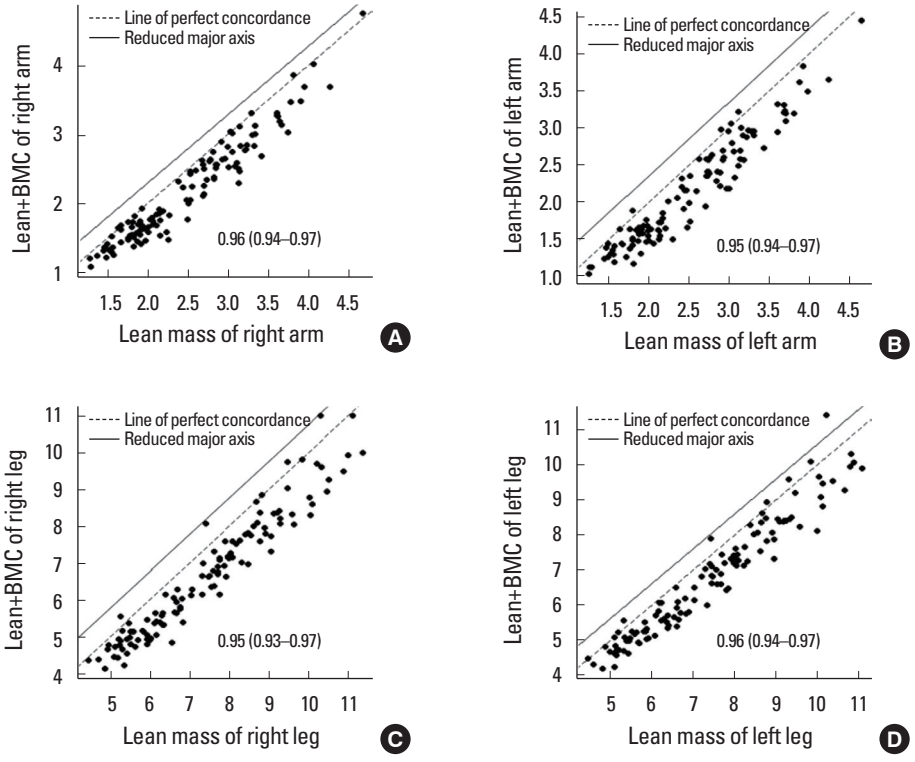

Fig. 1. Correlation coefficient for muscle mass between the InBody 970 and Hologic. (A) Right arm. (B) Left arm. (C) Right leg. (D) Left leg. BMC, bone mineral content.

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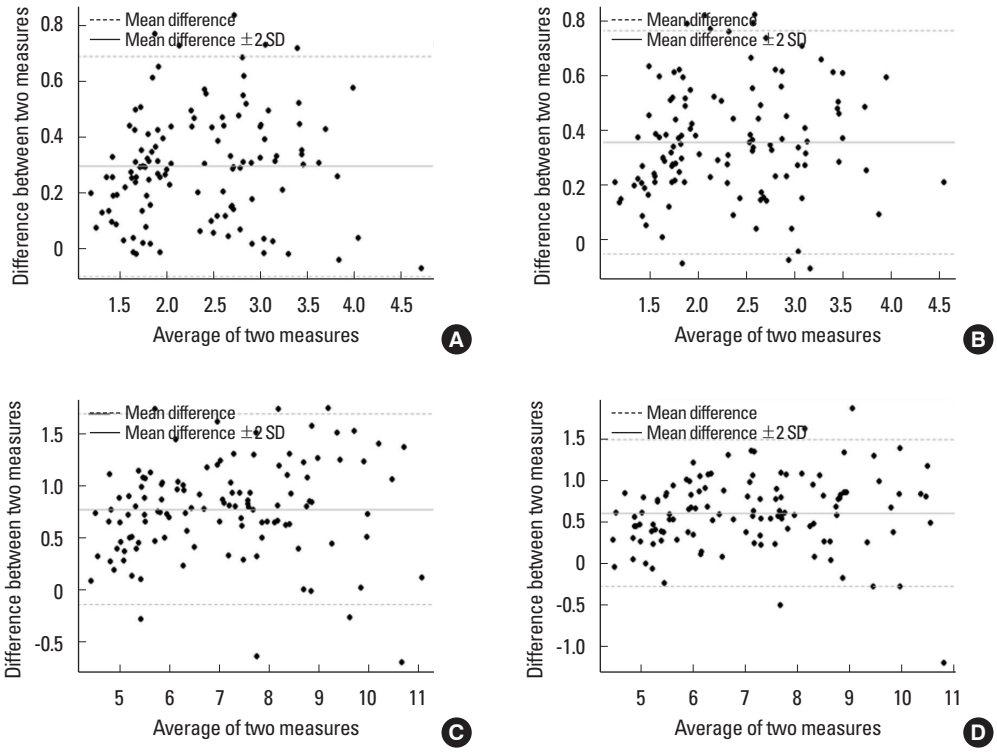

Fig. 2. Bland-Altman plots for muscle mass between the InBody 970 and Hologic. (A) Right arm. (B) Left arm. (C) Right leg. (D) Left leg. SD, standard deviation.

Table 3. Correlation coefficient for muscle mass between the two devices (InBody 970 and GE Lunar)

Measurement area	Correlation coefficient (95% CI)
Muscle mass right arm	0.827 (0.76–0.88)
Muscle mass left arm	0.935 (0.91–0.95)
Muscle mass right leg	0.959 (0.94–0.97)
Muscle mass left leg	0.926 (0.90–0.95)

CI, confidence interval.

proportion of the observed values fell within the ±1.96 SD range from the mean, highlighting the minimal differences between the two techniques.

Regarding the comparison between the InBody and GE Lunar measurements, the assessment of muscle mass involved comparing the BIA results obtained from the InBody 970 device with whole-body DXA measurements acquired using the GE Lunar device. The results indicated strong correlation coefficients of 0.93 or higher for most measurements, except for the right arm, which exhibited a correlation coefficient of 0.83, likely influenced by outliers (Table 3, Fig. 3). This underlines the substantial linear relationship between the Inbody and GE Lunar measurements.

To quantify divergence, the differences in muscle mass were computed by subtracting the InBody 970 measurements from those obtained with the GE Lunar device. These divergences were then presented as average values for both the left and right arms and both legs, along with the maximum and minimum limit values (±1.96 SD). As in the previous phase, these findings were complemented by Bland-Altman plots tailored for each measurement site (Fig. 4). Similarly, a notable proportion of the results were within the ±1.96 SD range from the mean.

Additionally, the study summarized the muscle mass conversion formulas for different limb segments in Table 4 for the GE Lunar and Inbody 970 devices, and in Table 5 for the Hologic and InBody 970 devices.

DISCUSSION

The principal findings of this study were that the correlation between the muscle mass measured by the Hologic device and the GE Lunar device and the muscle mass measured by the Inbody 970 device was high and suggested a conversion formula that is important for the evaluation of

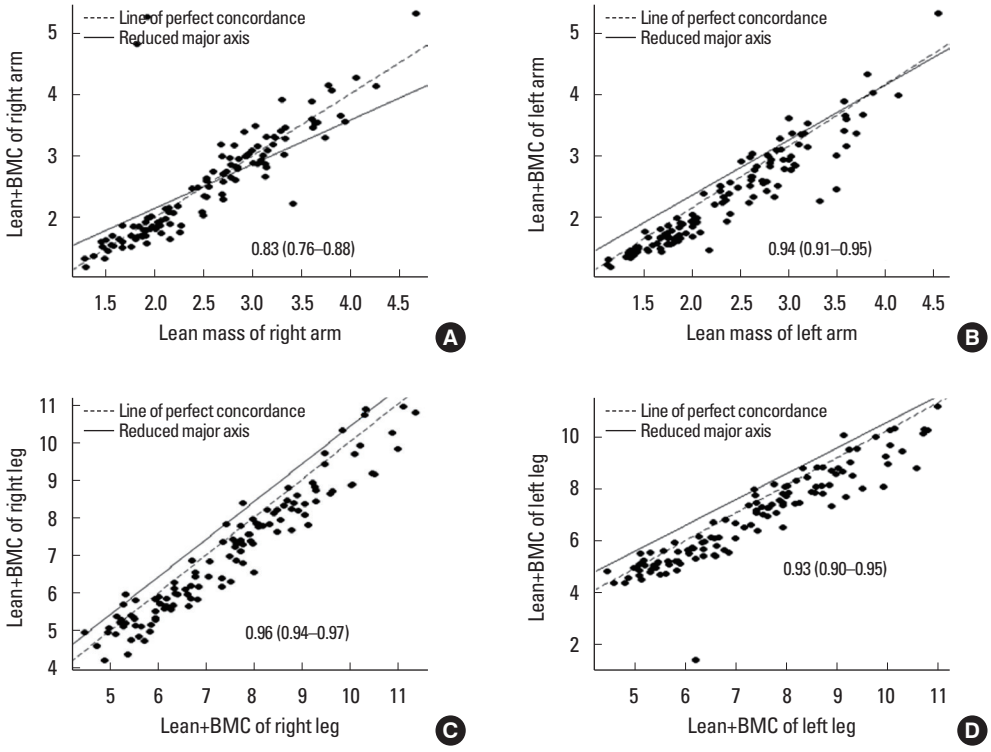

Fig. 3. Correlation coefficient for muscle mass between the InBody 970 and GE Lunar. (A) Right arm. (B) Left arm. (C) Right leg. (D) Left leg. BMC, bone mineral content.

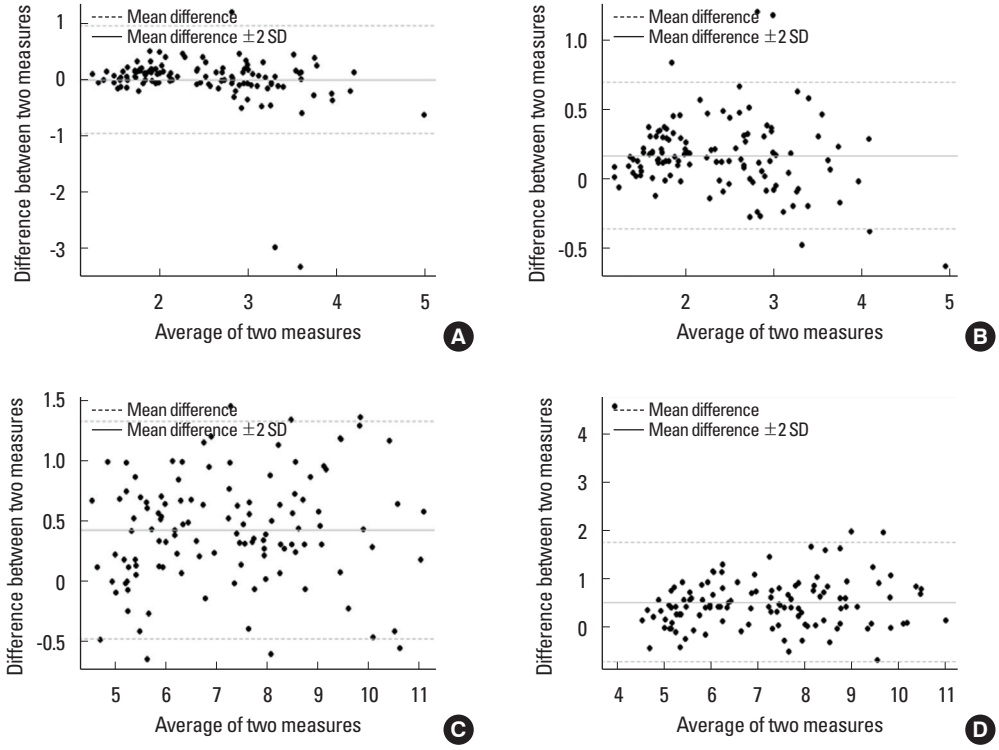

Fig. 4. Bland-Altman plots for muscle mass between the InBody 970 and GE Lunar. (A) Right arm. (B) Left arm. (C) Right leg. (D) Left leg. SD, standard deviation.

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Table 4. Conversion formula between InBody 970 and GE Lunar

Measurement area	Conversion formula
Muscle mass right arm	InBody_RA=0.8240×GE Lunar_RA+0.0001
Muscle mass left arm	InBody_LA=0.9310×GE Lunar_LA+0.0015
Muscle mass right leg	InBody_RL=0.9556×GE Lunar_RL+0.0023
Muscle mass left leg	InBody_LL=0.9220×GE Lunar_LL+0.0007

To standardize the units of the observed values, Z-score normalization was performed.
RA, right arm; LA, left arm; RL, right leg; LL, left leg.

Table 5. Conversion formula between InBody 970 and Hologic

Measurement area	Conversion formula
Muscle mass right arm	InBody_RA=0.9559×Hologic_RA-0.0009
Muscle mass left arm	InBody_LA=0.9500×Hologic_LA+0.0007
Muscle mass right leg	InBody_RL=0.9499×Hologic_RL-0.0011
Muscle mass left leg	InBody_LL=0.9525×Hologic_LL+0.0001

To standardize the units of the observed values, Z-score normalization was performed.
RA, right arm; LA, left arm; RL, right leg; LL, left leg.

sarcopenia between the mutual devices. To date, several cross-calibration studies on BIA and DXA have been reported.[27,28]

Yi et al. [21] conducted an analysis of the correlation between body composition measurements obtained from BIA (InBody 970) and GE Lunar equipment, particularly focusing on the agreement of appendicular lean mass, which showed a correlation of 0.95 or higher. These findings are consistent with our results, and in our study, we extended the analysis to include Hologic equipment. In addition, we provide conversion formulas that can be used in clinical settings. Analysis of skeletal muscle mass (whole-body or appendicular) plays an important role in evaluating patients for sarcopenia diagnosis, especially with the increasing global aging population. Although DXA is considered the gold standard for muscle mass measurement and shows a high correlation with magnetic resonance imaging (MRI), BIA is preferred owing to its non-invasiveness, cost-effectiveness, and comparability to more sophisticated imaging techniques such as computed tomography and MRI. However, it is crucial to note that BIA's accuracy can be influenced by factors such as hydration status, recent food intake, and electrolyte balance, which can lead to variability in measurements. Also, the original single-frequency BIA had measurement errors related to body water status and BMI. To address these accuracy issues, BIA was later developed into MF-BIA and further expanded to direct segmental multi-BIA (DSM-BIA), enabling more precise measurements of each body part. MF-BIA also overcomes the accuracy issues by analyzing intracellular fluid impedance more accurately.

Nevertheless, measurements obtained through MF-BIA have shown varying degrees of accuracy compared with DXA or MRI, and different studies have reported differences in the rate of sarcopenia diagnosis. Several previous studies have evaluated the correlation between MF-BIA and DXA for assessing muscle mass, with some variation in the results depending on the measured portion (lean body mass, appendicular lean mass).[29-31] However, Fang et al. [31] demonstrated a strong correlation between MF-BIA and DXA in estimating muscle mass ($r=0.969$, $P<0.001$) among elderly individuals. Similarly, Jeon et al. [32] found a strong correlation between MF-BIA and DXA for muscle mass estimation ($R^2=0.914$–0.917). Meier et al. [30] reported a correlation of 0.86 between DSM-BIA and DXA for muscle mass estimation after adjusting for age and sex. In the current study, we observed similar results in the same category, and we believe that MF-BIA could be useful in the management and diagnosis of sarcopenia.[30] Despite these correlations, the potential variability introduced by external factors like hydration status underscores the need for careful consideration when interpreting BIA results.

The research presented here encounters several constraints. Notably, there is a dearth of comparative studies on these devices, making it challenging to apply the study's outcomes universally. However, the high correlation coefficients suggest that BIA, particularly the InBody 970, can be a reliable and more accessible alternative to DXA for muscle mass assessment. This is particularly important in settings where DXA may not be readily available or feasible. Furthermore, the conversion formula enables the standardization of muscle mass measurements across different devices, facilitating the comparison of results from various studies and clinical settings. This standardization can lead to more consistent diagnoses and monitoring of sarcopenia and other musculoskeletal conditions. To broaden the implications of these findings across different ethnicities, it is essential to conduct further research, particularly involving Caucasian subjects. Moreover, the study utilized a limited number of participants, which may impact the robustness and generalizability of the results. Future studies should aim to include larger, more diverse

populations to validate these findings further and explore the impact of various physiological and external factors on BIA accuracy.

In conclusion, limb muscle mass measurements using Hologic and GE Lunar whole-body DXA and Inbody 970 BIA demonstrated a very high level of concordance. In addition, a conversion formula that bridges limb muscle mass measurements from two widely used whole-body DXA machines and a BIA machine will facilitate sarcopenia research and patient management.

DECLARATIONS

Funding

This research was supported by a fund (2021-11-007) by Research of Korea Disease Control and Prevention Agency.

Ethics approval and consent to participate

Ethical approval for the study was provided by the Chung-Ang University Hospital Research Ethics Committee, and informed signed consent was obtained from all participants before the scans were performed (Approval no. 2106-029-468).

Conflict of interest

No potential conflict of interest relevant to this article was reported.

ORCID

Yong-Chan Ha *https://orcid.org/0000-0002-6249-0581*
Shinjune Kim *https://orcid.org/0009-0004-9570-7830*
Jun-Il Yoo *https://orcid.org/0000-0002-3575-4123*

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