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Original Article

Assessing limb-specific reliability in body composition: a study on minimal detectable change using bioimpedance analysis

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Abstract. [Purpose] We aimed to assess the reliability of body composition measurements for individual limbs using a bioimpedance analyzer, with a focus on determining the minimal detectable change for each site. [Participants and Methods] This study included 55 healthy Japanese university students (28 men and 27 women). Each participant underwent two measurements using an InBody S10 body composition analyzer. Intraclass correlation coefficients and minimal detectable change values were calculated for muscle mass, water content, and phase angle at various limb sites. [Results] Muscle mass and water content measurements demonstrated high reliability across all limb sites, with intraclass correlation coefficients ranging from 0.996 to 0.998. Phase angle measurements also showed high reliability for the limbs, with values ranging from 0.936–0.975; however, reliability was lower for the trunk, with a value of 0.854. The minimal detectable change values indicated that detecting differences in trunk phase angle required a larger change than that required for limb sites. [Conclusion] Limb-specific measurements of body composition were highly reliable, showing stable and consistent muscle mass and water content. However, the low reliability of trunk phase angle measurements suggests that factors affecting trunk measurements warrant further exploration for accurate assessment.

Key words: Bioimpedance analysis, Reliability, Phase angle

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INTRODUCTION

Measurement of body composition plays a crucial role in health management and disease prevention. Bioimpedance analysis (BIA) has recently become the standard approach for assessing body composition[1)]. It is a noninvasive and simple technique that applies a weak electric current through the body to measure the varying electrical resistances of muscle, fat, bone, and other tissues[1)]. Moreover, it offers the advantages of being relatively low-cost and rapid. BIA-derived values such as muscle mass, extracellular water content, extracellular water ratio, and phase angle for each limb have been shown to provide clinically useful data[2)]. These values are widely used in patients with conditions such as stroke and orthopedic disorders as well as in healthy individuals and are recognized globally as valuable indicators[3)]. However, BIA results are influenced by factors such as sex, age, and race. Additionally, variables such as food and fluid intake, exercise prior to measurement, and posture during measurement can affect the body's water content and influence BIA results[4, 5)]. Without establishing the reliability of these measurements, the interpretation and clinical application of BIA data may be compromised, making a reliability evaluation essential.

The test-retest method is commonly used in reliability analysis as it assesses measurement consistency by repeating the same test on the same participants[6)]. This approach enables the evaluation of measurement stability and reproducibility.

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While existing studies report the validity of body composition analyzers, they often focus on assessing the whole body rather than individual limbs[7–9]. A limb-specific reliability assessment is essential for accurately tracking localized changes in muscle mass and water balance. Minimal detectable change (MDC) is a key measure for determining whether changes in measurements reflect meaningful differences[10]. Identifying limb-specific MDC allows the objective evaluation of individual changes, supporting clinical decision-making. Thus, evaluating body composition by limb is critical, and MDC data are vital for assessing physical changes from treatment or training interventions.

In this study, we aimed to assess the reliability of limb-specific measurements using a body composition analyzer with the test-retest method, and to determine the reliability and MDC of these measurements.

PARTICIPANTS AND METHODS

We included 55 healthy Japanese university students (28 males: mean age ± standard deviation (SD), 19.5 ± 1.1 years, mean height ± SD, 170.2 ± 4.9 cm, mean weight ± SD, 65.8 ± 9.1 kg, mean Body Mass Index (BMI) ± SD, 22.8 ± 3.5 kg/m^2 ; 27 females: mean age ± SD, 19.6 ± 1.1 years, mean height ± SD, 158.0 ± 4.6 cm, mean weight ± SD, 50.4 ± 7.6 kg, mean Body Mass Index (BMI) ± SD, 20.2 ± 3.1 kg/m^2). Participants with metal implants or artificial joints were excluded. Because of ethical considerations, body composition measurements, using the InBody S10 (InBody Inc., Seoul, South Korea), were conducted only after informed consent was obtained from each participant. The measurements included muscle mass (whole body, upper limbs, trunk, and lower limbs), fat mass, body water content (whole body, upper limbs, trunk, and lower limbs), and phase angle (PhA). The study was approved by the Research Ethics Review Committee of the International University of Health and Welfare (approval number: 21-Io-34-2), and complies with the ethical standards of the Declaration of Helsinki 1964 and its subsequent revisions.

Participants were instructed to wear light clothing and remove their shoes and socks in preparation for the measurements. Their height and weight were measured using a stadiometer and digital scale, respectively. Body composition measurements were conducted using the InBody S10 (InBody Japan) with participants seated, ensuring that their backs did not touch the chair, their arms hung naturally at approximately 15° from the torso, and their feet were shoulder-width apart. After the first measurement, the participants rested for 1 h in a seated position in the measurement room, followed by the second measurement conducted in the same manner. Participants were instructed to avoid eating, excessive fluid intake, and strenuous exercise within two hours prior to the measurement. Additionally, they were prohibited from consuming any fluids between the first and second measurements.

Descriptive statistics were calculated for age, height, and weight. To evaluate measurement reliability, the intraclass correlation coefficient (ICC) was calculated from the measured data using a two-way random effects model (2,1) to assess consistency. The MDC was determined using the following formula:

$$MDC = 1.96 \times SD_{diff} \times \sqrt{2}$$

Where, SD_{diff} is the standard deviation of the difference between measurements.

A Bland–Altman plot was used to visually assess measurement bias and consistency. In this plot, the mean of the two measurements is plotted on the horizontal axis, and the difference between the measurements is plotted on the vertical axis, with the mean difference and 95% confidence interval shown. Statistical analyses were performed using SPSS Statistics Version 29 (IBM Corp., Armonk, NY, USA), with the significance level set at 5% ($p<0.05$).

RESULTS

Table 1 presents the results. The ICC(2,1) ranged from 0.854 to 0.998 for all items. Muscle mass and water content each showed an ICC of 0.998, while PhA demonstrated an ICC of 0.974.

The MDC95 values were 1.13 kg for muscle mass, 0.87L for water content, and 0.36° for PhA. The trunk PhA had an MDC95 of 1.74°.

The ICC for muscle mass and water content in the limbs ranged from 0.996 to 0.997. The ICC for PhA in the limbs ranged from 0.936 to 0.975, whereas the ICC for the trunk was 0.854.

Figure 1 presents the Bland–Altman plot for left leg muscle mass as an example. A high level of consistency was observed in the measurements, with no evidence of fixed or proportional bias. Further analysis of fixed and proportional biases across all measurement items confirmed the absence of such biases in any of the evaluated items.

DISCUSSION

Our study provides a detailed evaluation of the reliability of body composition measurements for each limb site. While previous studies have examined overall reliability, they have not sufficiently assessed measurement errors at specific body sites. Our findings offer new insights into clinical and practical assessments by highlighting the differences in measurement errors across body regions.

Table 1. Body composition measurements: reliability, 95% confidence intervals, and minimal detectable change (MDC) by limb and trunk

		Muscle mass	Right arm muscle mass	Left arm muscle mass	Trunk muscle mass	Right leg muscle mass	Left leg muscle mass	Fat mass	Body water content	Right arm water content	Left arm water content
First average measured value		43.81	2.25	2.19	19.63	7.35	7.34	11.64	34.04	1.75	1.70
Second average measured value		43.61	2.24	2.18	19.56	7.32	7.31	11.86	33.89	1.74	1.69
Twice average		43.71	2.24	2.18	19.60	7.34	7.33	11.75	33.96	1.74	1.70
95% CI of mean	Lower limit	41.31	2.06	2.00	18.49	6.91	6.91	10.23	32.11	1.60	1.56
	Upper limit	46.14	2.43	2.36	20.72	7.78	7.75	13.29	35.84	1.89	1.84
Average of two-times difference		−0.19	−0.01	−0.01	−0.07	−0.03	−0.03	0.23	−0.15	−0.01	−0.01
95% CI of the mean of the two-times difference	Lower limit	−0.33	−0.03	−0.03	−0.15	−0.07	−0.06	0.07	−0.26	−0.02	−0.02
	Upper limit	−0.05	0.01	0.00	0.01	0.00	0.01	0.38	−0.04	0.01	0.00
Intra-class correlation coefficient		0.998	0.996	0.996	0.997	0.997	0.997	0.995	0.998	0.996	0.996
MDC95		1.13 kg	0.12 kg	0.12 kg	0.64 kg	0.25 kg	0.24 kg	1.13 kg	0.87 L	0.10 L	0.09 L

		Trunk water content	Right leg water content	Left leg water content	Phase Angle (PhA)	Right Arm PhA	Left arm PhA	Trunk PhA	Right leg PhA	Left leg PhA
First average measured value		15.25	5.71	5.71	6.07	5.60	5.32	8.72	6.58	6.49
Second average measured value		15.20	5.69	5.69	6.04	5.57	5.28	8.79	6.51	6.38
Twice average		15.23	5.70	5.70	6.05	5.59	5.30	8.76	6.54	6.43
95% CI of mean	Lower limit	14.37	5.37	5.37	5.84	5.41	5.10	8.34	6.27	6.14
	Upper limit	16.09	6.04	6.02	6.27	5.77	5.49	9.18	6.82	6.73
Average of two-times difference		−0.05	−0.02	−0.02	−0.03	−0.02	−0.04	0.08	−0.07	−0.10
95% CI of the mean of the two-times difference	Lower limit	−0.12	−0.05	−0.05	−0.08	−0.07	−0.08	−0.17	−0.16	−0.21
	Upper limit	0.01	0.01	0.01	0.02	0.02	0.00	0.32	0.03	0.00
Intra-class correlation coefficient		0.997	0.997	0.996	0.974	0.973	0.975	0.854	0.940	0.936
MDC95		0.49 L	0.19 L	0.21 L	0.36°	0.31°	0.32°	1.74°	0.71°	0.79°

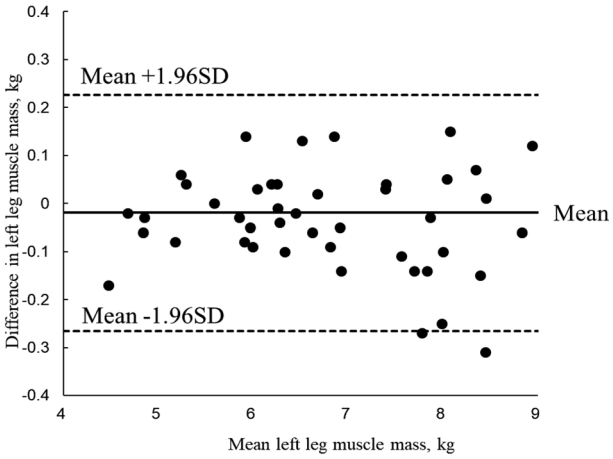

Fig. 1. Bland–Altman plot showing the difference in left lower limb muscle mass measured twice against the mean. The solid line represents the mean and the broken line the 2SD.

The measurements of muscle mass and water content for all limb sites demonstrated high reliability, with ICC(2,1) values ranging from 0.996 to 0.998. The MDC95 values ranged from 0.12 to 0.64 kg for muscle mass and from 0.10 to 0.49 L for water content. The high reliability of limb measurements offers significant clinical benefits, as it enables accurate tracking of localized changes in muscle mass and water content.

These MDC values provide critical benchmarks for both research and clinical applications.

First, in the context of research, MDC values can be employed as a foundational reference when designing intervention studies. Specifically, they can be used to calculate the required sample size, ensuring adequate statistical power to detect intervention effects that exceed the MDC. This approach enhances the robustness and validity of research findings by distinguishing true changes from measurement error.

Second, in clinical and sports settings, MDC values enable the effective monitoring of rehabilitation and training outcomes. By using MDC as a threshold, clinicians can identify substantial changes in body composition, even in cases where statistical significance is not achieved. For example, tracking improvements in limb-specific muscle mass or water content can support tailored interventions to prevent muscle atrophy or optimize training regimens during rehabilitation.

By incorporating MDC as a practical tool, this study not only highlights its importance in reliability assessments but also underscores its utility in enhancing individualized care and evidence-based practice.

This is particularly useful for individualized interventions in sports and rehabilitation settings, where precise adjustments to training and therapy can be based on small but meaningful changes in body composition. Monitoring limb-specific muscle changes can prevent muscle atrophy in injured athletes and guide tailored load adjustments during rehabilitation. The consistency of muscle mass and water content measurements across sites supports their utility in clinical practice, enabling precise and individualized interventions.

In contrast, PhA measurements showed marked differences in reliability between limb and trunk sites. The reliability of body composition measurements may also be influenced by factors related to the measurement protocol and equipment calibration. Small variations in device calibration or participant positioning can lead to discrepancies, particularly in measurements that are more sensitive, such as trunk PhA. Ensuring consistent calibration and adhering to standardized protocols is therefore essential to maintain measurement accuracy and reduce variability across sessions. While PhA reliability was high for the limbs, with ICC(2,1) values ranging from 0.936 to 0.975, the trunk ICC(2,1) value was only 0.854, indicating relatively low reliability. The MDC95 for the trunk PhA was also higher at 1.74°, suggesting greater measurement error compared to limb sites. These findings imply that PhA measurements of the trunk are more susceptible to measurement conditions, making it difficult to detect small changes. This discrepancy may be influenced by the unique physiological characteristics of the trunk, which warrant further investigation in future studies.

This study has several limitations. Participant variability, including hydration status, baseline muscle composition, and day-to-day physiological fluctuations, may have influenced the reliability results, particularly in trunk measurements. Future studies should consider controlling for these variables to enhance measurement consistency.

Although previous studies have addressed the reliability of body composition measurements, our results emphasize the importance of site-specific reliability assessments. Differences in measurement accuracy between the limbs and trunk suggest the need for tailored approaches for clinical body composition assessment. Addressing the lower reliability of trunk PhA measurements may lead to improvements in measurement procedures and device settings. Future research could explore how various external factors, such as hydration status, body temperature, or device calibration, impact trunk measurements

to improve their reliability. Additionally, studies involving diverse populations, including different age groups, genders, and athletic levels, would be beneficial for assessing the generalizability of our findings. Such investigations could help refine measurement techniques and expand the applicability of body composition assessments in various clinical and sports settings.

Conflicts of interest

The authors declare no conflicts of interest.

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