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Original Article

Validation of Three Bioelectrical Impedance Analysis for the Assessment of Appendicular Lean Tissue in Older Community-Dwelling Adults

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SUMMARY

Background: Lean soft tissue (LST) of limbs is quickly measured by bioelectrical impedance analysis (BIA). This study, compared the accuracy of different standing multi-segments BIA devices by dual-energy X-ray absorptiometry (DXA) reference in older community-dwelling Taiwan adults.
Methods: The subjects recruited elderly people over 60 years old (46 males and 55 females) in Taiwan. The study used Tanita BC418MA (BC418), Biospace InBody230 (InBody230), Tanita MC-780MA (MC780), and DXA to measure the LST of upper limbs, lower limbs, and extremities. Ordinary least product regression and mean absolute percent error (MAPE) was taken as the overall effect indicators of the study.
Results: In the study group the average percent body fat (PBF%) of 101 elderly people was 34.4 ± 7.1%. The correlation coefficient (r) and standard error of the estimate (SEE) of BC418, InBody230, and MC780 relative to the LST (LST_{app}) of DXA in the appendicular were 0.873, 0.734, 0.885, and 2.08 kg, 2.73 kg, 2.60 kg, respectively. The average differences between the three BIA devices and DXA were 5.677 kg, 3.343 kg, and 4.511 kg, respectively. The corresponding limits of agreement (LOA) were 0.320 to 11.053 kg, -2.841 to 9.528 kg, and -0.274 to 9.296 kg, respectively. The MAPE were 38.05–47.82%, 22.40–30.99% and 31.30–39.38%.
Conclusion: The standing multi-segment BIA device is a convenient device for measuring the LST in the limbs of older community-dwelling adults having different measurement accuracy and limitations due to different brands and models. When applied to clinical evaluation, the application needs to be carefully used.

1. Introduction

Sarcopenia is a syndrome of the elderly characterized by decreased skeletal muscle mass (SMM) and its functional deterioration. Worldwide incidence of sarcopenia is increasing year by year, and it is an important risk factor affecting the health and quality of life in the elderly.[1] The common causes of sarcopenia are the effects of abnormal growth in childhood, malnutrition, sedentary, insufficient physical activity, chronic diseases, long-term bed rest, aging, and the intake of certain drugs, etc.[2] Sarcopenia may occur at all ages, and it may be combined with other causes in elderly patients.[3] Currently no unified diagnostic criteria prevail for the evaluation of sarcopenia, but the common diagnostic indicators are muscle mass, muscle strength, and the ability of muscle activity.[4]

BIA uses tiny currents to enter the human body to directly measure the conduction and impedance of vital molecules in the human body, and then construct the estimation equations for body muscle mass, skeletal muscle mass (SMM), and appendicular skeletal muscle mass (ASMM).[5,6] BIA has the advantages of convenience, simplicity, and low cost for the screening of sarcopenia. Compared with DXA, BIA overestimated the SMM of non-Caucasian elderly people, and the pure error was greater than the estimation error.[7] Roubenoff et al.[5] reported that the muscle estimation equation suitable for young people may be overestimated when applied to the elderly.

Compared with the published BIA estimation equations, the built-in equations of commercial or well-known BIA devices are mostly commercial secrets. Therefore, it also limits its scope of application. Many studies have investigated the use of a single BIA device on SMM or LST,[6,8–10] and the results have shown that there is inconsistent accuracy or overestimation or underestimation of the measurement results. For actual clinical applications or epidemiological investigations and studies, confusion often arises in result access. This study used the built-in equations of different BIA devices to compare the measurement results of the LST of the extremities by the same reference standard in Taiwan elderly.

2. Method

2.1. Subject

This study is a cross-sectional study from October 2020 to De-

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cember 2020, completed in the rehabilitation department of Puzi Hospital of the Ministry of Health and Welfare, Taiwan. The subjects of the study were elderly people over 60 years old, comprising of 46 males and 55 females (male: 69.9 ± 6.8 years old; female: 70.5 ± 5.7 years old). Subjects participated voluntarily, and their health conditions were evaluated and screened by well-trained medical personnel. The exclusion criteria included electrolyte abnormalities, cancer or inflammation, severe cardiovascular or pulmonary disease. Alcoholic beverages were forbidden within 48 hours before the test, and diuretics were avoided for 7 days. This study was approved by the Human Testing Committee (IRB-1090125) of the Caotun Sanatorium of the Ministry of Health and Welfare and registered in the Chinese Clinical Trial Registry (ChiCTR-OOC-16008825). All subjects understood the purpose and methods of this study and signed a consent form before the trial.

2.2. Anthropometric measurement

The subject had minimal clothes with no shoes. The weight was measured with an electronic scale (Tanita BC-418MA, Tokyo, Japan), with an accuracy of 0.1 kg. The height rod (Holtain, Crosswell, Wales, UK) was used to measure height with an accuracy of 0.5 cm. The BMI was calculated as weight (unit: kg) divided by the square of height (unit: m).

2.3. Bioimpedance measurement

Subjects were fasted overnight, avoided strenuous exercise and indoor normal temperature (26–28 °C) environment, removed possible interference resistance and empty urine, and used the following standing segmental BIA including 50 KHz single frequency Tanita BC418MA (Tanita Corporation, Tokyo, Japan), dual-frequency 20, 100 KHz-InBody230 (Biospace Ltd, Calif., USA), triple frequency 5, 50, 250 KHz-Tanita MC780MA (Tanita Corporation, Tokyo, Japan) performed body composition measurement. With the input of the height, age, gender, and other variables of the subject, the LST of the left, upper right, and lower limbs was estimated. The sum of the lean and soft tissues of the upper and lower limbs (respectively referred to as LST_{arms}, LST_{legs}) is the Appendicular LST (LST_{app}).

2.4. Dual energy X-ray absorptiometry (DXA)

In this study, DXA from Discovery W (Hologic Inc.-Bedford, MA, USA) was used to scan the whole body in pencil beam mode to measure the fat-free mass (FFM), lean soft tissue (LST, the amount of bone-removed minerals), and fat mass (FM) of the whole body and different parts of the body composition (software version 5.67).

2.5. Statistical methods

All data were represented by average, standard deviation, minimum and maximum values. The Shapiro-Wilkr test analyzes the population distribution of the data. The data comparison between men and women was by Student's t-test. Lin's concordance correlation coefficient (CCC) was used to evaluate the agreement between DXA and BIA in the LST measurement results, and the range is from -1 to 1.[11] We have considered the statistical analysis of difference between two independent means. With an effect size of 0.5, an alpha err prob of 0.05, and a power of 0.95, the minimum sample size required is 88.

The LST measured by the BIA device and DXA used ordinary least products regression models to evaluate the standard error of the estimates (SEE) and coefficient of determination (r^2) and to determine whether the BIA device has a fixed bias or a proportional bias in the LST measurement result.[12] Bland-Altman analysis was used to determine the degree of agreement between methods, and regression analysis was used to determine the trend and significance of the differences between devices. The intra-class correlation (ICC) was used to evaluate the reliability of the measurement results of the two devices. Mean absolute percent error (MAPE) was used to evaluate the overall effect of different BIA devices on the LST measurement results, and the statistical significance was set as $p < 0.05$.

3. Results

Table 1 summarizes the data of the subjects' characteristics. In

Table 1
Anthropometric characteristics and body composition measurements of elderly determined by DXA (reference method), BIA.

	Total (n = 101)		Male (n = 46)		Female (n = 55)	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Age (years)	70.2 (6.8)	61.0–93.0	69.9 (6.8)	62.0–93.0	70.5 (5.7)	61.0–85.0
Height (cm)	159.1 (7.4)	148.0–178.1	164.4 (7.2)	150.0–178.0	155.8 (5.3)	148.0–169.0
Weight (kg)	60.4 (10.7)	42.2–83.8	66.2 (10.2)	42.2–83.3	56.7 (9.5)	44.0–83.8
BMI (kg/m^2)	23.8 (3.5)	15.0–34.2	24.6 (4.0)	14.9–34.2	23.3 (3.2)	18.1–34.1
DXA						
LST_{arms} (kg)	3.8 (1.1)	2.3–7.0	4.5 (1.1)	2.7–7.0	3.4 (0.9)	2.3–6.0
LST_{legs} (kg)	9.9 (2.5)	6.3–16.4	11.5 (2.4)	7.6–16.4	8.8 (2.0)	6.4–14.8
LST_{app} (kg)	13.7 (3.6)	8.6–23.4	16.0 (3.4)	10.3–23.4	12.2 (2.9)	8.6–20.8
PBF (%)	34.4 (7.1)	16.8–47.9	30.6 (8.0)	16.8–34.2	36.7 (5.4)	27.4–47.9
BC418						
LST_{arms} (kg)	4.0 (1.0)**	2.7–6.6	4.8 (0.9)*	2.7–6.2	3.5 (0.8)*	2.8–6.6
LST_{legs} (kg)	15.3 (3.7)**	8.4–19.6	18.2 (3.8)**	11.1–23.1	13.5 (2.3)**	11.0–22.7
LST_{app} (kg)	19.7 (4.7)**	13.8–29.3	23.0 (4.6)**	13.8–29.1	17.1 (3.0)**	13.8–29.3
PBF (%)	28.7 (7.3)**	13.4–48.8	25.1 (8.8)**	13.4–48.8	30.9 (5.1)**	20.4–39.8
InBody230						
LST_{arms} (kg)	4.3 (1.3)**	2.4–7.2	5.4 (1.0)**	3.8–7.2	3.5 (0.8)*	2.4–5.7
LST_{legs} (kg)	12.7 (2.9)**	8.4–19.6	15.2 (2.7)**	9.4–19.6	11.2 (1.7)**	8.4–16.1
LST_{app} (kg)	17.0 (4.0)**	11.2–26.6	20.6 (3.5)**	13.7–26.6	14.8 (2.4)**	11.2–21.5
PBF (%)	29.2 (7.4)**	5.0–48.7	27.2 (7.4)**	15.5–48.7	30.5 (7.3)**	5.0–40.1
MC780						
LST_{arms} (kg)	3.9 (1.0)	2.7–6.4	4.7 (0.8)*	2.8–6.0	3.6 (0.7)*	2.7–6.4
LST_{legs} (kg)	14.2 (3.4)**	9.5–21.9	16.8 (3.2)**	11.0–21.9	12.6 (2.4)**	9.5–21.6
LST_{app} (kg)	18.2 (4.3)**	12.2–28.1	21.6 (3.9)*	14.5–27.9	16.1 (3.10)**	12.2–28.1
PBF (%)	29.1 (7.4)**	13.4–50.1	25.6 (8.9)**	13.5–50.1	31.3 (5.2)**	23.3–43.8

Abbreviations: LST, lean soft tissue; BC418, Tanita BC418; MC780, Tanita MC780; BMI, body mass index; DXA, dual-energy X-ray absorptiometry; PBF, percent body fat; app, appendicular.
* $p < 0.05$, by repeated-measure ANOVA with Student's independent *t*-test; ** $p < 0.01$, by repeated-measure ANOVA with Student's independent *t*-test.

total 101 subjects were 61.0 to 93.0 years old, with an average age of 70.2 ± 6.9 years old, with a weight range of 42.2 to 83.8 kg, and a body mass index (BMI) of 15.0 to 34.2 kg/m^2. The percent body fat (PBF%) measured by DXA was 34.4 ± 7.1%.

Table 1 lists the results of LST_{arms}, LST_{legs}, and LST_{app} in different groups using DXA, BC418, InBody230, and MC780, respectively. The measurement results of MC780 between LST_{arm} and DXA showed no significance, and the measurement results of the other different multi-frequency BIA devices and DXA were all significantly different.

In Table 2, the coefficient of determination (r^2), concordance correlation coefficient (CCC), standard error of the estimate (SEE), and ordinary least products regression represent the correlation, measurement accuracy, fixed bias, and proportional bias between BIA and DXA, respectively. Fixed and proportional bias, respectively. Table 2 shows that the determination coefficients of LST_{arms}, LST_{legs}, LST_{app}, and DXA measured by BIA were from 0.369 to 0.683, and CCC was 0.299 to 0.777

Table 3 shows the measurement data of different BIA devices and DXA in LST_{arms}, LST_{legs}, and LST_{app}, and shows the mean, standard deviation (SD), limits of agreement (LOA), and the corresponding regression analysis intercept, slope, and Bland-Altman plot difference, significance, MAPE, etc. In LST_{amrs}, BC418 and MC780 had a smaller mean and SD, and the MAPE of BC418 was also smaller than that of InBody230. But in LST_{legs}, InBody230 has a smaller mean and SD of the difference, and the MAPE of InBody230 was also smaller. The MAPE of LST_{app} has a similar situation. The MAPE of BC418, InBody230 and MC780 were 38.05–47.82%, 22.40–30.99% and 31.30–39.38%, respectively.

Figure 1(a)–(c) were the regression lines and scatter diagrams of the measurement results of DXA, BC418, InBody230, and MC780 in LST_{arms}, LST_{legs}, and LST_{app}, respectively. The black solid line in the figure is the identity line, and the green, red, and blue dashed lines represent the regression lines of BC418, InBody230, and MC780, respectively.

4. Discussion

This study verified the measurement results of different standing multi-segment BIA devices on the LST of the limbs of the elderly, and explored the relationship between the LST measurement results of this type of device on the upper limbs, lower limbs, and extremities.

There have been many related studies on the standing multi-segment BIA applied to the verification of ALST or appendicular skeletal muscle mass (ASMM). Among them, Lee et al.[9] applied InBody770 to 507 subjects with an average of 63.7 ± 10.4 years in South Koreans. The results of comparison with DXA showed that the average difference in ASMM was 2.0 ± 1.1 kg. The LOA was -0.16 to 4.2 kg, and the ICC was 0.972. Brewer et al.[13] used Inbody770 to compare DXA with 160 young athletes in the United States. The results showed that the average difference in FFM of the upper and lower limbs was -1.3 and -6.6 kg, and the LOA was -3.1 to 0.5 kg,

Table 2
Correlation of appendicular lean mass estimates using ordinary least products regression.

	r^2	a	95% CI	b	95% CI	Fixed bias	Proportional bias	SEE	CCC
LST_{arms}									
BC418	0.727	0.497	-0.175, 1.169	0.824	0.663, 0.986	Yes	Yes	0.67	0.873
InBody230	0.569	1.591	0.823, 2.348	0.521	0.348, 0.693	Yes	Yes	0.87	0.670
MC780	0.718	0.429	-0.262, 1.121	0.858	0.668, 1.028	No	No	0.67	0.877
LST_{legs}									
BC418	0.758	1.406	-0.169, 2.982	0.551	0.451, 0.651	No	Yes	1.48	0.399
InBody230	0.546	2.369	0.216, 4.522	0.587	0.422, 0.752	Yes	Yes	1.88	0.517
MC780	0.796	1.000	-0.511, 2.518	0.622	0.518, 0.725	No	Yes	1.39	0.480
LST_{app}									
BC418	0.762	1.723	-0.487, 3.933	0.617	0.506, 0.728	No	Yes	2.08	0.596
InBody230	0.539	3.733	0.890, 6.637	0.581	0.418, 0.750	Yes	Yes	2.73	0.573
MC780	0.783	1.319	-0.856, 3.496	0.679	0.563, 0.795	No	Yes	2.60	0.589

Abbreviations: r^2, coefficient of determination; CCC, concordance correlation coefficient; a, b, coefficients in ordinary least products regression model: E(A) = a + b(B); a, (y axis) intercept; b, slope; fixed bias, if 95% confidence interval (CI) for a does not include 0; proportional bias, if 95% confidence interval (CI) for b does not include 1; SEE, standard error of the estimate.

Table 3
Comparison of measurement results of different BIA devices on DXA.

	Difference			Regression			Absolute percentage error	
	Mean	SD	LOA	Intercept	Slope	p	Mean	95%CI
LST_{arms}								
BC418	0.209	0.693	-1.150, 1.570	1.143	-0.245	0.0016	9.33%	6.74%, 15.17%
InBody230	0.458	1.058	-1.619, 2.528	1.585	-0.296	0.0135	14.60%	11.03%, 17.98%
MC780	0.127	0.688	-1.221, 1.475	1.198	-0.280	0.0002	9.02%	5.42%, 14.10%
LST_{legs}								
BC418	5.467	2.215	1.125, 9.810	3.555	0.194	0.0782	58.10%	51.54%, 63.03%
InBody230	2.889	2.210	-2.38, -0.503	5.265	-0.241	0.0271	30.64%	27.60%, 36.47%
MC780	4.384	1.882	-0.106, 1.495	3.202	0.120	0.2025	46.89%	42.38%, 49.66%
LST_{app}								
BC418	5.677	2.743	0.302, 11.053	4.688	0.072	0.4561	44.29%	38.05%, 47.82%
InBody230	3.343	3.155	-2.841, 9.528	6.729	-0.247	0.0240	24.67%	22.40%, 30.99%
MC780	4.511	2.441	-0.274, 9.296	4.432	0.006	0.9469	35.37%	31.30%, 39.38%

Abbreviations: LOA, limits of agreement: the lower and upper limits of agreement with 95%; Parameters of the regression of the differences against the reference value: intercept and slope with 95% CI, and p-value for slope; Absolute percentage error: the absolute percentage error (APE) is calculated as 100 × ABS[(y – ref)/ref] where y is the observation and ref is the reference value.

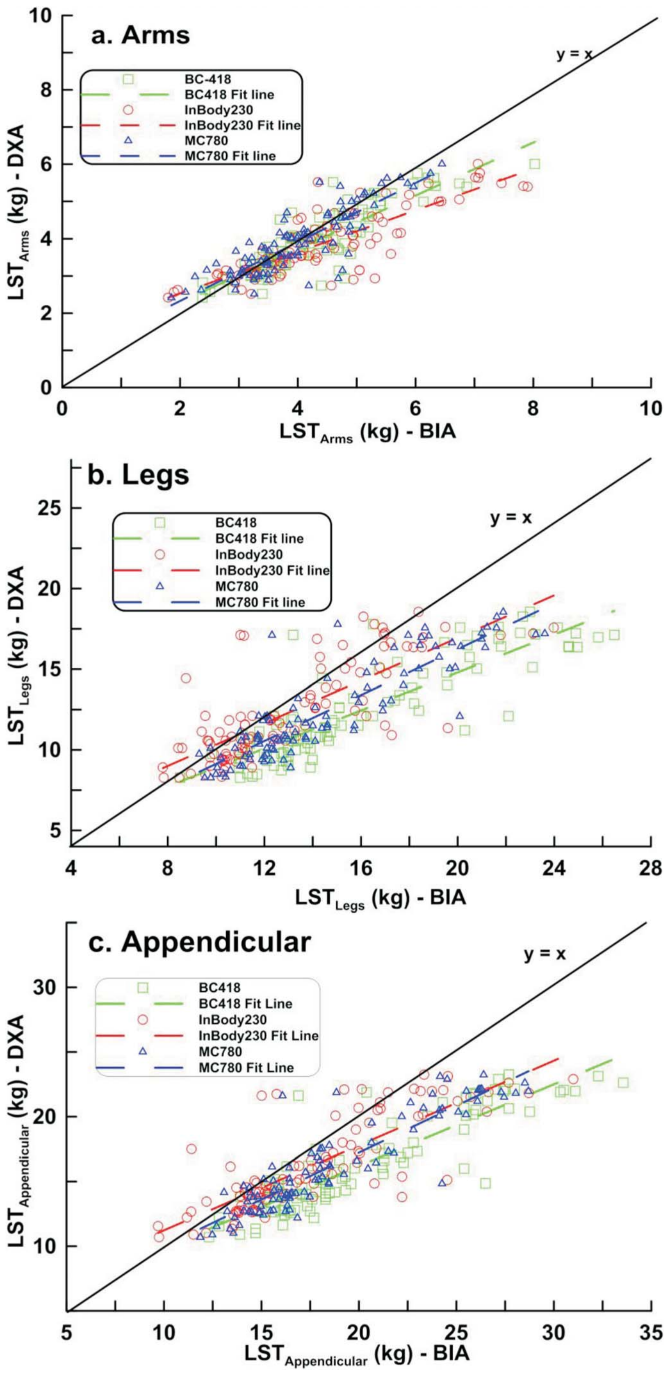

Figure 1. Correlation between dual-energy X-ray absorptiometry results and estimate of ALST in older either BC418, InBody230, or MC780 (a) upper limbs LST; (b) lower limbs LST; (c) appendicular LST.

-15.3 to 2.2 kg, respectively. Karelis et al.[14] used Inbody230 to compare DXA with 51 male and 94 female adults in Canada, and the results showed that the average difference of appendicular FFM was 11.9 kg, and the LOA was -36.3 to 12.5 kg. Kim et al.[15] In South Korea, 285 male and 435 female elderly people participated. The results of the Inbody 3.0 comparison with DXA showed that the average difference of ASMM was -0.75 and -0.18 kg, and the LOA was -3.8 to 2.1 kg, -2.2 to 1.9 kg, respectively. The above studies indicated that the FFM of the upper and lower limbs, FFM, and ASMM of the limbs in different types of multi-segment BIA were underestimated. The correlation between the muscle-mass measurement (kg/m^2) of BC418, InBody230, and MC780 in appendicular skeletal mass index (ASMI) and DXA for sarcopenia is 0.808, 0.887, 0.837, respectively. The average difference is overestimated by 1.45 kg/m^2, 0.65 kg/m^2, and 1.09 kg/m^2 respectively. If BIA is applied to the assessment of sarcopenia, it is still necessary to proceed with caution.

The traditional single-frequency BIA device is a lying position measurement does not have the disadvantage of body water distribution variation when compared with the standing multi segment BIA device. Although the two different methods have the same principle and purpose, the estimation process is completely different. The equations in the BIA device are mostly commercial secrets, and the corresponding user groups require a lot of verification to have application value. Studies by Medici, Malavolti, Pietrobelli et al.[16–18] showed that the resistance or resistance index (RI) measured by different limbs is highly correlated with the body composition of the corresponding limbs. Therefore, there was a certain theoretical basis for multi-segment BIA to measure the muscle mass of the limbs. Hence, it is inconclusive as to which of the two is better in estimating the LST of the limbs or the SMM of the whole body.

Three different multi-segment BIA devices discussed in this study directly compared the LST measurement results of their upper and lower limbs with DXA. Different models and brands of LST_{arms}, LST_{legs}, or the LST_{app} obtained by the addition of the two have different accurate in different statistical methods and error indicators. The measurement of the BIA device on LST_{legs} affects LST_{app} more than it affects LST_{arms}. The LST in the lower limbs of the human body is about 3 times that of the LST in the upper limbs. Therefore, the measurement accuracy of LST_{legs} is particularly important when the multi-segment BIA device is used in the measurement of LST_{app}. Among the three BIA devices discussed in this study, Inbody230 has poorer statistical results and higher errors in LST_{arms} compared to other devices. But the results of Inbody230 in LST_{legs} in Bland-Altman plots were better than other devices. Therefore, in the measurement results of LST_{app}, the results of Inbody230 in MAPE were better than Tanita BC418 and Tanita MC780.

There were many verification studies of BIA devices, and different races and ethnic groups have different accuracy results. In addition to the different built-in equations of the BIA device itself, these results must also consider factors such as the consistency of the operator during operation and the control of the measurement environment.[19] Even in the same device, age, ethnic group, and ethnicity, factors such as the degree of obesity and hydration of the subject must be considered. Under well test specifications, the results provided by the BIA device measurement may have a certain reference value or can be used as a basis for clinical diagnosis. We have applied the Yamada's equations developed for the Tanita MC780 device with frequencies of 5, 50, 250 KHz to our data. In the new analysis, the correlation of appendicular skeletal muscle mass between BIA and DXA was 0.916, the LOA was -1.564 to 4.090 kg, and there was no proportional bias. The above results are significantly better than the appendicular skeletal muscle mass measurement of the BIA device explored in this study.

Yamada et al.,[20] the authors validated the cut-off of sarcopenia in Tanita MC980, InBody770 and GE Lunar DXA in male and female Japanese participants aged 18-40 years, showing no prevalence of low muscle mass according to Asian Working Group for Sarcopenia (AWGS) cutoff by Tanita MC980 and DXA. However, the prevalence of low muscle mass was 21.4% in female and 6.6% in male using raw InBody770 data. After applying the Yamada's equation to the original Inbody770 impedance data, the adjusted Inbody770 cutoffs matched with those obtaining using Tanita MC980 and DXA and were acceptable for diagnosing sarcopenia. Yamada et al.[20] reported a significantly lower value of muscle mass estimated by InBody770 as compared to TanitaMC980. Possible reason for the discrepancy may due to the different regression equation between different manufacturer. Validation study for each BIA device is recommended prior to clinical use. Our study provided a validated method for assessing limb lean mass in elderly people with mobility impairments using BIA. Although the level of accuracy varied between BIA models, the BIA is still a convenient and acceptable tool for assessing changes in muscle mass. It has the potential for health promotion and disease investigation in patients with suspicious sarcopenia.

This research was conducted on elderly people who were older community-dwelling Taiwan adults. The results of this study cannot be extended to other races and elderly patients who were inadequate, and other BIA devices of different brands and models. In addition, this research should include different races and degrees of obesity. However, this study do not have a large enough sample to perform a combined analysis of potential variables.

5. Conclusion

The standing multi-segment BIA device can be used as a convenient device for measuring the LST in the limbs of older community-dwelling adults. However, different BIA devices have different measurement accuracy and limitations due to different brands and models. If relevant applications are used in clinical evaluation, careful judgment is required. The estimation accuracy of the multi-segment BIA device in the lower extremity, LST is the main factor for the accuracy of the extremity LST measurement.

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Conflict of interest

The authors declare non conflict of interests.

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