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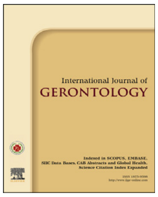

Original Article

Validity of Standing Posture Eight-electrode Bioelectrical Impedance to Estimate Body Composition in Taiwanese Elderly☆

Ling-Chun Lee [1 †], Kuen-Chang Hsieh [2 †], Chun-Shien Wu [3], Yu-Jen Chen [4], Jasson Chiang [5 **], Yu-Yawn Chen [6 *]

[1] *Graduate Institute of Sport Coaching Science, Chinese Culture University, Taipei,* [2] *Office of Physical Education and Sport, National Chung Hsing University, Taichung,* [3] *Center for General Education, I-Shou University, Kaohsiung,* [4] *Medical Research and Radiation Oncology, Mackay Memorial Hospital, Taipei,* [5] *Department of Physical Education Sports Affairs, Chinese Culture University, Taipei,* [6] *Department of Physical Education, National Taiwan Sport University, Taichung, Taiwan*

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SUMMARY

Background: Standing eight-electrode bioelectrical impedance analysis, which can be used to estimate percentage body fat (BF%) and lean soft tissue (LST) in the whole body and different body segments of elderly adults, is potentially an ideal method for clinical assessment of body composition.

Methods: In this study, dual-energy X-ray absorptiometry (DXA) was used as a criterion method to validate a standing eight-electrode bioelectrical impedance analysis device BC-418 (hereafter abbreviated as BIA_8; Tanita Corp., Tokyo, Japan). LST and BF% were measured in the whole body and various body segments (upper limbs, lower limbs, and trunk) of each participant using BIA_8 and DXA; correlation and differences between the LST and BF% results measured in the whole body and various body segments were compared. A total of 77 individuals, 42 males and 35 females, aged 55.2–76.8 years, were included in the analysis.

Results: The impedance indexes (h^2/Z) of hand to foot, and upper and lower limbs of the left side of the body measured by BIA_8 were highly correlated with the LST values in the corresponding body segment measured by DXA ($r = 0.96$, $r = 0.92$, and $r = 0.88$, respectively; all $p < 0.001$). LST values of the whole body and various body segments of participants measured using BIA_8 were highly and significantly correlated with the corresponding DXA data (all $r > 0.88$, $p < 0.005$); the whole body and segmental BF% measured by BIA_8 and DXA also showed a significant correlation ($r > 0.84$, $p < 0.005$). In addition, the agreement between the results of BIA_8 and DXA was assessed by Bland–Altman analysis; the bias and SD were, respectively, 1.89 kg and −4.25% in limb LST, and 2.18 kg and 4.06% in whole body BF%.

Conclusion: The results of this study showed that the impedance index and LST in the whole body, upper limbs, and lower limbs derived from DXA findings were highly correlated. The LST and BF% estimated by BIA_8 in whole body and various body segments were highly correlated with the corresponding DXA results; however, BC-418 overestimates the participants' appendicular LST and underestimates whole body BF%. Therefore, caution is needed when interpreting the results of appendicular LST and whole body BF% estimated for elderly adults.

1. Introduction

Body composition is a relatively important information source for diagnosing the nutritional status of the human body. Particularly, the body composition of elderly adults, whose physical state is frail and changes with aging. Fat-free mass (FFM), muscle mass, and muscle strength decline with age[1–4], whereas fat mass increases with age[2,5,6]. Several reference methods can be used to estimate human body composition, such as dual-energy X-ray absorptiometry (DXA), computed tomography, magnetic resonance imaging,

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* Correspondence to: Dr Yu-Yawn Chen, Department of Physical Education, National Taiwan Sport University, 16, Section 1, Shuan-Shih Road, Taichung 40404, Taiwan.

** Correspondence to: Dr Jasson Chiang, Department of Physical Education Sports Affairs, Chinese Culture University, Taipei, Taiwan.

E-mail addresses: jchiang@staff.pccu.edu.tw (J. Chiang), yu11.tw@yahoo.com.tw (Y.-Y. Chen).

† These authors contributed equally.

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air-displacement plethysmography, underwater weighing, neutron activation analysis, and dilution methods[7]. However, these methods have limitations when applied to elderly adults, whereas bioelectrical impedance analysis (BIA) can widely be used for estimating body composition of immobile elderly adults, because it is simple, easy to use, safe, noninvasive, mobile, and efficient[8,9].

A standing-posture BIA device, usually with built-in weight measurement and body composition features, is widely used in home health care, clinical applications, and epidemiological studies, but the established built-in predictive equations and the specific population for it to apply are only known by the manufacturer; the applicability is subject to certain restrictions[10]. Therefore, attention needs to be paid to its accuracy and precision of measurement results.

In the past, BIA mostly used a single hand-to-foot impedance measurement to represent the whole body impedance value of individuals, and also to estimate the elements of body composition such as whole body FFM, percentage body fat (BF%), total body water, and intracellular water. With increasing clinical applications and demand, the segmental BIA technique[11,12] was modified to a convenient standing segmental impedance measurement technique, which can also be applied to evaluate the functions of the upper limbs, lower limbs, and trunk[13–16]. The technique (or device) is able not only to estimate whole body BF%, but also to quantify the lean soft tissue (LST) in limbs, which can be applied to assess accurately the whole body skeletal muscle mass[17]. The results obtained using the existing standing segmental BIA in case of European elderly adults have been evaluated[18]. Although there are studies that examined the measurement results using similar devices in Asian adults[19,20], the number of related studies on Asian elderly adults are still very limited.

This study addresses the above issue by using DXA[21,22] and a standing eight-electrode bioelectrical impedance analysis device (BIA_8) to measure the impedance and body composition in whole body and different body segments of elderly adults who are healthy and mobile. Results of the studies conducted by Kohrt[23] and Salamone et al[24] indicated that DXA is an accurate criterion method for assessing body composition of elderly adults. Therefore, the correlation and agreement between the measurement results of the two methods were assessed.

2. Methods

2.1. Experimental design

Body composition of each participant was estimated using a standing segmental BIA_8 and DXA. This study was conducted at the Radiology Department of Jen-Ai Hospital in Dali, Taichung, Taiwan. The experimental protocol was approved by the Human Subject Research Ethics Committee of Jen-Ai Hospital.

2.2. Participants

A total of 42 male and 35 female elderly adults in Taiwan were recruited as participants. No alcohol was consumed 48 hours and no diuretics were taken 7 days prior to assessment. All participants had no medical history of endocrine, nutrition, or growth disorders, and not more than 3 kg of weight loss 6 months prior to the experiment.

2.3. Anthropometry

Participants were weighed by a Weight-Tronix (Scale Electronics Development, New York, NY, USA) electronic scale nearest to 0.1 kg. Their heights, without shoes, were measured by a Stadiometer (Holtain, Crosswell, Wales, UK) nearest to 0.5 cm. The formula used to calculate the body mass index (BMI) is as follows: weight (kg) divided by height (m) squared (kg/m^2).

2.4. BIA analysis

The standing eight-electrode BIA device BC-418 (Tanita Corp., Tokyo, Japan), with stainless-steel plates replacing traditional electrode patches, is used for measuring whole body and segmental impedance. Eight stainless-steel plates are located on a handgrip and on the built-in weight sensor base. Participants stand on the base and hold the handgrips with embedded electrodes; soles of both feet are in contact with the electrode plates through which a low voltage current passes during measurement. They were weighed, and impedance was measured using BIA_8 with sine-wave currents with single frequency 50 kHz and 550 mA.

BIA_8 can measure the impedance of five different body segments within a very short period of time. In this study, the whole body impedance was measured through the left hand to the left foot electrical pathway, and the impedance of each limb was measured by the electrode framework developed by Bracco et al.[12] Next, the derived impedance of five different body segments can be incorporated with other anthropometrics (height, weight, age, and sex) to estimate the LST and BF% in the total body, and left and right limbs. The appendicular LST (ALST) can be estimated by adding the LST of left and right limbs.

In order to ensure repeatability of the impedance measurements, within- and between-day coefficient of variations [CV%; (standard deviation (SD)/mean)%] of the impedances measured through the left hand to the left foot pathway were calculated. The impedance was measured 10 times in each of three male and three female participants within an hour the same day, so as to estimate the within-day CV%. Impedance measurements of those six individuals were performed on 5 consecutive days, so as to estimate the between-day CV%.

All BIA measurements were carried out in a room with good ventilation, fixed temperature, and controlled humidity. For each participant, BIA measurement was completed within 10 minutes.

2.5. Dual-energy X-ray absorptiometry

Each participant was scanned using DXA (Lunar Prodigy, GE, Madison, WI, USA) for measuring fat mass, bone mineral mass, BF%, and LST. During scanning, the participants were wearing a light cotton robe, lying down on a bed with the upper limbs stretched out, and lying flat on the side of the body; the two legs were lightly closed and toes pointed upward. Scans were performed using a whole body scan mode in the following order: head, upper limbs, lower limbs, and trunk. Each participant underwent approximately a 20-minute whole body scan; results were analyzed by the enCore 2003 software, version 7.0 (Lunar Prodigy, GE, Madison, WI, USA).

2.6. Statistical analysis

In this study, data were analyzed using SPSS version 12 (SPSS Inc., Chicago, IL, USA) statistical analysis software. Group data were expressed as mean ± SD. ALST and LST were measured in kilograms. The unit of body fat was measured in percentage (BF%). The level of significant differences was set at 0.05, unless explained otherwise.

The results of body composition parameters (ALST and BF%) measured by DXA and BIA_8 were compared using paired t test. Linear regression analysis was used for describing the relationship between the measurement results of DXA and BIA_8 (i.e., the ALST and BF% measured by BIA_8 and DXA). In addition, the agreement between the ALST and whole body BF% values measured by BIA_8 and DXA was assessed by Bland–Altman analysis[24].

For further comparison, the participants were divided into three subgroups: all participants, males, and females. The root-mean-square error was used to compare the differences between the LST values of the upper limbs, lower limbs, all limbs, trunk and head, and whole body measured by BIA_8 and DXA.

3. Results

3.1. Participant characteristics

Physical characteristics of the participants are shown in Table 1. All 77 participants are healthy elderly adults from the central Taiwan area, and aged 55.2–76.8 years (average 62.5 ± 5.6 years). Their body weight ranges from 42.0 kg to 103.2 kg, and BMI from 17.9 kg/m^2 to 36.8 kg/m^2 (average 26.0 ± 3.7 kg/m^2).

3.2. Impedance measurements

For the six participants, the within-day CV% for whole body impedance was 0.3–0.8% and the corresponding between-day CV% was 0.9–1.7%.

Impedances for the five body segments were measured by BIA_8, including hand-to-foot over the left side of the body, left and right upper limbs, and left and right lower limbs. In the BIA method, the conductive volume was determined by h^2/Z, where h represents the height of the participants, because a proportional relationship often existed between the length of the upper and lower limbs and the height of an individual[25]. Therefore, when measuring LST, h^2/Z_{F-H}, h^2/Z_{arm}, and h^2/Z_{leg} are used to represent the impedance index (BI) of whole body, upper limbs, and lower limbs, respectively. In the LST measurement, the correlation coefficient (r) between hand-to-foot BI and whole body LST, measured by DXA, was 0.96, between upper limb BI and LST was 0.92, and between lower limb BI and LST was 0.88. All are highly correlated, and $p < 0.001$.

3.3. Body composition

Table 2 shows the results of whole body and segmental LST (kg) estimated by DXA and BIA_8. The BIA_8 data for the upper limbs, lower limbs, trunk and head, and whole body LST were highly correlated with the corresponding DXA data ($r > 0.88$, all $p < 0.005$). Fig. 1A shows the relationship between results of BIA_8 and DXA in ALST ($ALST_{BIA} = 0.96ALST_{DXA} + 2.90$, $r = 0.92$, $p < 0.001$). Fig. 2A shows the results of Bland–Altman analysis, the mean bias, and the limits of agreement between ALST values measured by BIA_8 and DXA (bias = 1.89 kg, bias − 2SD = −2.47 kg, bias + 2SD = 6.26 kg).

Table 1
Physical characteristics of the participants.

	All participants ($n = 77$)	Male ($n = 42$)	Female ($n = 35$)
Age (y)	62.52 ± 5.62 (55.2, 76.8)	62.48 ± 5.31 (55.4, 73.0)	62.56 ± 6.04 (55.2,76.8)
Weight (kg)	69.35 ± 13.01 (42.0, 103.2)	75.91 ± 12.30 (57.0, 103.2)	61.69 ± 9.12 (42.0, 82.1)[a]
Height (cm)	162.92 ± 9.98 (142.5,191.0)	169.43 ± 7.29 (155.0, 191.0)	155.32 ± 6.84 (142.5, 176.0)[a]
BMI (kg/m^2)	26.04 ± 3.68 (17.9, 36.8)	26.43 ± 3.62 (19.9, 36.8)	25.61 ± 3.75 (17.9, 36.5)

Data are presented as mean ± SD (minimum, maximum).
ANOVA = analysis of variance; BMI = body mass index; SD = standard deviation.
[a] Significantly different from men (one-factor ANOVA): $p < 0.001$.

Table 2
Results of DXA and BIA total body and regional LST (kg) estimations.

Measured segment	DXA	BIA_8	r*	p (DXA vs. BIA)
Arm[a]	2.51 ± 0.83	2.54 ± 0.75	0.88	0.252
Leg[a]	7.90 ± 1.93	8.82 ± 2.10	0.88	0.000
ALST	20.83 ± 5.36	22.72 ± 5.57	0.92	0.000
Trunk + head	26.03 ± 5.48	25.96 ± 5.56	0.91	0.766
Total body	46.87 ± 10.65	48.68 ± 10.80	0.95	0.000

Data are presented as mean ± SD.
*All p values (DXA vs. BIA), p value of paired t test between results estimated by BIA and DXA; $p < 0.005$.
ALST = appendicular lean soft tissue; BIA = bioelectrical impedance; BIA_8 = eight-electrode bioelectrical impedance analysis device; DXA = dual-energy X-ray absorptiometry; LST = lean soft tissue; SD = standard deviation.
[a] $n = 154$.

Table 3 shows the results of whole body and segmental BF% estimated by DXA and BIA_8. The BIA_8 data of the upper limbs, lower limbs, trunk and head, and whole body LST were highly correlated with the corresponding DXA values ($r > 0.84$, all $p < 0.012$). The relationship between the BF% estimated by BIA_8 and DXA is shown in Fig. 1B ($BF\%_{BIA8} = 0.86BF\%_{DXA} + 0.40$, $r = 0.90$, $p < 0.001$). Fig. 2B shows the results of Bland–Altman analysis; the mean bias of

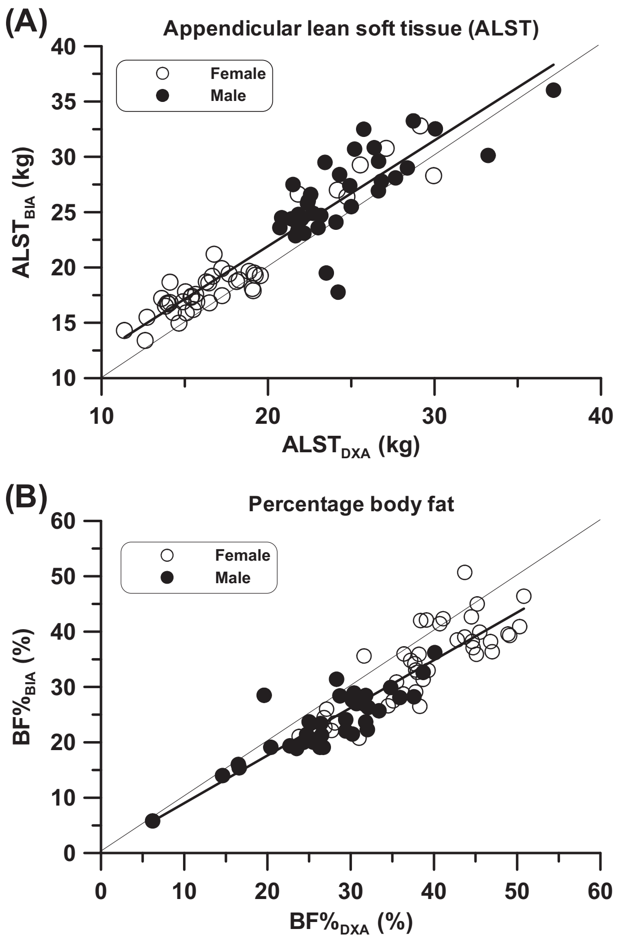

Fig. 1. (A) Plot of ALST estimated by BIA_8 versus that estimated by DXA ($ALST_{BIA} = 0.956\ ALST_{DXA} + 2.903$, $r = 0.920$, $p < 0.001$). Regression and lines of identity are shown in the figure. (B) Plot of BF% estimated by BIA_8 versus that estimated by DXA ($BF\%_{BIA} = 0.861\%\ BF\%_{DXA} + 0.400$, $r = 0.895$, $p < 0.001$). Regression and lines of identity are shown in the figure. ALST = appendicular lean soft tissue; BF% = percentage body fat; BIA = bioelectrical impedance; BIA_8 = eight-electrode bioelectrical impedance analysis device; DXA = dual-energy X-ray absorptiometry.

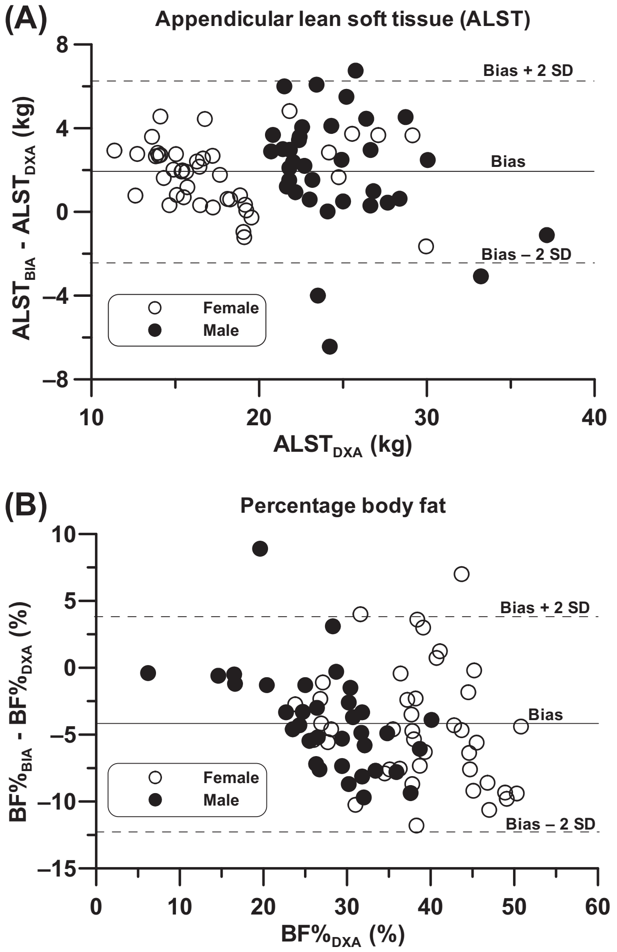

Fig. 2. (A) Bland and Altman plot comparing the differences in ALST values measured by BIA_8 and DXA (bias = 1.892 kg, bias − 2 SD = −2.472 kg, bias + 2 SD = 6.256 kg). (B) Bland and Altman plot comparing the differences in BF% values measured by BIA_8 and DXA (bias = −4.251%, bias − 2 SD = −12.385%, bias + 2 SD = 3.883%). ALST = appendicular lean soft tissue; BF% = percentage body fat; BIA = bioelectrical impedance; BIA_8 = eight-electrode bioelectrical impedance analysis device; DXA = dual-energy X-ray absorptiometry; SD = standard deviation.

whole BF% measured by BIA_8 and DXA was −4.25% (bias − 2 SD = −12.39%, bias + 2 SD = 3.88%). Table 3 shows that a significant difference existed between whole body BF% values measured by DXA and BIA_8 (33.56 ± 9.05% vs. 29.31 ± 8.70%, respectively). Furthermore, Table 3 shows that, compared to DXA, BIA_8 underestimated whole body and trunk BF% by −4.25% and 8.52%, respectively.

Table 3
Results of DXA and BIA whole body and regional BF% estimations.

Measured segment	DXA	BIA_8	r^*	p (DXA vs. BIA)
Arm[a]	26.62 ± 11.29	25.48 ± 9.43	0.85	0.016
Leg[a]	30.17 ± 0.15	28.82 ± 9.06	0.84	0.003
Trunk + head	38.85 ± 9.11	30.33 ± 9.05	0.87	0.000
Whole body	33.56 ± 9.05	29.31 ± 8.70	0.90	0.000

Data are presented as mean ± SD.
*All p values (DXA vs. BIA), p value of paired t test between results estimated by BIA and DXA; $p < 0.005$.
ALST = appendicular lean soft tissue; BF% = percentage body fat; BIA = bioelectrical impedance; BIA_8 = eight-electrode bioelectrical impedance analysis device; DXA = dual-energy X-ray absorptiometry; SD = standard deviation.
[a] $n = 154$.

The participants were categorized into the following groups for analysis: (1) 35 female participants as Group A; (2) 42 male participants as Group B; and (3) all 77 participants as Group C. Differences between segmental and whole body LST measured by DXA and BIA_8 are shown in Fig. 3, in which the corresponding root-mean-square errors of Groups A, B, and C are, respectively, 0.27 kg, 0.38 kg, and 0.34 kg in the arms; 0.98 kg, 1.61 kg, and 1.36 kg in the legs; 2.13 kg, 3.37 kg, and 2.87 kg in the limbs; 2.68 kg, 2.12 kg, and 2.39 kg in the head and trunk; and 3.31 kg, 4.00 kg, and 3.70 kg in the whole body.

4. Discussion

Information on body composition is very useful in clinical medicine, sport medicine, and other health-related fields[26–29]. There are plenty of methods that provide accurate results for body composition estimation, such as DXA, air-displacement plethysmography, and underwater weighing. However, these methods are costly and cannot be used frequently[30–32]. In most cases, BIA is the only viable technique for the estimation of body composition.

In most of the existing researches, assessment of body composition of elderly population was conducted with the patients in supine position[33,34]. Research on estimation of body composition of Asian elderly adults by standing BIA is still limited both in methodology and in application. Previous research reported that impedances measured in a supine position differ from those measured in a standing position[35]. Besides, body composition varies across different ethnic groups[36]. Therefore, research on the application of standing BIA in Asian elderly adults is needed. Tan et al.[37] were the first to use the standing BIA. In that study, the whole body and segmental resistance and reactance measured by stainless-steel plates and traditional gel electrodes in healthy adults were highly correlated.

Results of this study show that h^2/Z_{F-H}, h^2/Z_{arm}, and h^2/Z_{leg} estimated by segmental BIA_8 were highly correlated with the LST values of whole body, upper limbs, and lower limbs measured by DXA in Taiwanese elderly adults. Therefore, the whole body, upper limbs, and lower limbs LST estimated by the impedance index measured in BIA_8 are all highly correlated with DXA data. However, the correlation coefficient of BIA_8 in BF% estimation with DXA results was lower than that of LST.

The correlation between the ALST values estimated by BIA_8 and DXA in the upper and lower limbs was slightly lower than that between the ALST values in the whole body, and trunk and head. For estimating the body composition of upper and lower limbs, the

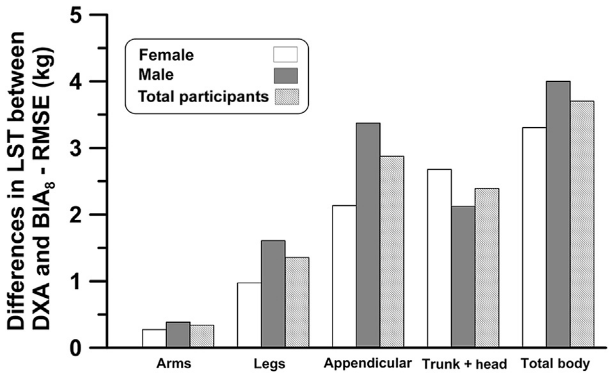

Fig. 3. Differences between LST values estimated based on DXA results and BIA_8 − RMSE (kg). BIA_8 = eight-electrode bioelectrical impedance analysis device; DXA = dual-energy X-ray absorptiometry; LST = lean soft tissue; RMSE = root-mean-square error.

predictive equation can be established by incorporating impedance and other anthropometrics as predictors through linear regression analysis; also, an artificial neural network model can be used to develop an equation that can yield better results for calculating upper and lower limbs body composition in elderly adults[38].

Pietrobelli et al[39] also used BC-418 (BIA_8) to evaluate the correlations between results of BIA and DXA for segmental and whole body BI and LST mass in 40 healthy individuals with a wider age range. In that study, correlation coefficients (r) of the whole body ($r = 0.99$), upper limbs ($r = 0.98$), and lower limbs ($r = 0.95$) exhibited a similar trend to that of our study; the whole body BI and LST with respect to upper and lower limbs had the highest correlation coefficient, whereas lower limbs had the lowest coefficient; however, all were highly correlated. The correlation coefficients (r) of the whole body $ALST_{BIA}$ and $BF\%_{BIA}$ against the DXA data were $r = 0.96$ and $r = 0.87$, respectively, which were similar to the results of our study. When comparing two different measurement methods, correlation analysis is not sufficient to verify the equivalence between the two methods[40]. Therefore, Bland–Altman analysis was used to compare between ALST and whole body BF% measured by BIA_8 and DXA. The ALST values estimated by BIA_8 was on average 1.89 kg higher than those measured by DXA; CV% was 9.0%. BF% measured by BIA_8 was on average 4.25% lower than that measured by DXA; CV% was 12.6%. Comparing both, the estimation error in BF% measured by BIA_8 was greater than that in ALST. To underestimate whole body BF% may result in a risk when apply the assessment results for obesity-related diseases screening. When examining the differences of the estimation errors in segmental and whole body LST between male and female groups, the result shows that the LST in the upper limbs, lower limbs, whole body, and limbs measured by BIA_8 in female elderly participants has an estimation error that is less than that in male participants.

Existing research results show that segmental BIA has a strong correlation with segmental BI and its corresponding FFM or LST[12,39,41]. The same result also applies to the participants of this study. When comparing segmental LST and BF% results obtained using DXA, the LST shows stronger correlation than BF%. One of the reasons might be that upper limbs, lower limbs, and trunk weight measurement, unlike the measuring of whole body BF%, does not have the precise weight as a calculating basis for two-component model; still an accurate and precise calculation method for measuring the weights of upper limbs, lower limbs, and trunk is lacking. Although LST and whole body BF% measured by BIA_8 show a relatively high correlation to DXA data, its mean (bias) CV% is close to 10%. This result affects the accuracy of standing BIA_8 results, irrespective of whether body composition or SM (skeletal muscle) of elderly adults is assessed.

Genton et al[33] compared the differences in estimation errors of four established predictive equations for measuring FFM between individuals having BMI >25 kg/m^2 and those having BMI <25 kg/m^2; the results of that study indicated that bias of FFM measurement increased with the participants' BMI. We also compared the errors in estimating whole body FFM by categorizing participants into normal (BMI <25 kg/m^2) and overweight or obese (BMI >25 kg/m^2) groups. The mean error in whole body FFM in male elderly adults estimated by BIA, using DXA data as the reference, was 2.02 kg in the normal group and 4.02 kg in the overweight or obese group. The results of our study indicated that the mean error was smaller in the normal group than in the overweight or obese group. The limit of agreement (mean ± 2SD) was −2.38–6.42 kg (range 8.80 kg) in the normal group and −0.23–8.62 kg (range 8.85 kg) in the overweight or obese group. Results of the t test show that the mean errors of the two groups were significantly different ($p < 0.01$).

The mean error of whole body FFM in female elderly adults estimated by BIA, when DXA data were used as the reference, was 2.15 kg in the normal group and 2.26 kg in the overweight or obese group. The results of our study indicated that the estimation error was smaller in the normal group than in the overweight or obese group. The limit of agreement (mean ± 2SD) was −1.31–5.62 kg (range 6.93 kg) in the normal group and −4.16–8.68 kg (range 12.84 kg) in the overweight or obese group. Results of the t test show that the mean error of the two groups was not significantly different ($p = 0.91$).

Compared with the reference DXA data, BIA results overestimated FFM both in male and female elderly adults, with a higher estimation error in the overweight or obese group.

5. Summary

The results of this study demonstrate that standing BIA_8 can be used to estimate LST and BF% of the total body and different body segments, whereas the reference method such as DXA is too costly or not available. According to the results of our study, the total body and segmental bioimpedance index and LST measured by BIA_8 show a strong correlation with the corresponding DXA results; however, standing BIA_8 somehow overestimates LST or underestimates total body BF% within a certain range; thus, its accuracy was reduced in case of ALST and total body BF% measurement in elderly adults. If the drawbacks can be eliminated, standing BIA_8 can be used as a viable alternative body composition assessment method for elderly adults both in research and clinical applications.

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