Original Paper DOI: 10.5604/20831862.1224097 Biol. Sport 2016;33:399-405

Total body composition estimated by standing-posture 8-electrode bioelectrical impedance analysis in male wrestlers

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ABSTRACT: Standing-posture 8-electrode bioelectrical impedance analysis is a fast and practical method for evaluating body composition in clinical settings, which can be used to estimate percentage body fat (BF%) and skeletal muscle mass in a subject's total body and body segments. In this study, dual-energy X-ray absorptiometry (DXA) was used as a reference method for validating the standing 8-electrode bioelectrical impedance analysis device BC-418 (BIA_8, Tanita Corp., Tokyo, Japan). Forty-eight Taiwanese male wrestlers aged from 17.9 to 22.3 years volunteered to participate in this study. The lean soft tissue (LST) and BF% in the total body and body segments were measured in each subject by the BIA_8 and DXA. The correlation coefficients between total body, arm, leg segments impedance index (BI, ht^2/Z) and lean soft tissue mass measured from DXA were r = 0.902, 0.453, 0.885, respectively ($p < 0.01$). In addition, the total body and segmental LST estimated by the BIA_8 were highly correlated with the DXA data (r = 0.936, 0.466, 0.886, $p < 0.01$). The estimation of total body and segmental BF% measured by BIA_8 and DXA also showed a significant correlation ($r > 0.820$, $p < 0.01$). The estimated LST and BF% from BIA_8 in the total body and body segments were highly correlated with the DXA results, which indicated that the standing-posture 8-electrode bioelectrical impedance analysis may be used to derive reference measures of LST and BF% in Taiwanese male wrestlers.

CITATION: Cheng M-F, Chen Y-Y, Jang T-R et al. Total body composition estimated by standing-posture 8-electrode bioelectrical impedance analysis in male wrestlers. Biol Sport. 2016;33(4):399–405.

Received: 2015-12-08; Reviewed: 2016-04-17; Re-submitted: 2016-07-26; Accepted: 2016-10-11; Published: 2016-11-10.

Key words:
Body composition
Dual energy X-ray
Absorptiometry
Wrestlers
Bioimpedance index

INTRODUCTION

Body composition information includes percentage body fat (BF%), lean soft tissue (LST) and skeletal muscle mass (SM), which can be used to evaluate the growth and nutritional status of children. Moreover, body composition measurements are commonly used in research on athletes [1]. The body composition of athletes and their athletic ability, such as maximal oxygen uptake and endurance, are variable [2], and the relationship between the body composition of athletes and their exercise capacity has been studied previously [3, 4]. The body composition of athletes may affect athletic performance and also serve as a reference for the long-term exercise training of athletes. In addition, a change in body composition may also be used to monitor adaptation to training programmes [5, 6].

There are many methods for measuring body composition. The traditional gold standard is the underwater weighing method. Air-displacement plethysmograph and dual-energy X-ray absorptiometry (DXA) are relatively new reference methods. However, the cost and inaccessibility of these methods limit their use. Simpler methods such as a skinfold caliper or bioelectrical impedance analysis (BIA) are still common methods for clinical application [7]. Specifically, BIA is widely used in clinical medicine, sports medicine and weight reduction programmes [8, 9].

In recent years, significant improvements of BIA devices changed the measuring position from a supine position to a standing position, and the contact electrodes were modified from patch-type to stainless steel plates [10, 11]. The standing-posture BIA system used for body composition measurements can be divided into two modes: (1) the hand-to-hand mode in which the path of current flows through two arms and (2) the foot-to-foot mode in which the path of current flows through two legs [12, 13]. The foot-to-foot mode in BIA systems is usually incorporated into digital electronic scales, simultaneously measuring impedance and body weight with a force sensor. Body weight measurements recorded with the scale are more accurate than a subject's self-reported weight; therefore, the estimation of body composition is more accurate.

The standing-posture BIA system utilizes multi-segmental impedance [14] by combining hand- and foot-contact plates with a fixed measuring circuit to easily and efficiently quantify the arm, leg and total body resistance, reactance and impedance [12, 13]. Furthermore, it estimates body composition for the arm, leg, trunk and total body.

Researchers have reported a high correlation between the limb impedance measured by the segmental BIA system and the appendicular lean soft tissue (ALST) estimated by DXA in healthy subjects; therefore, the BIA system is able to derive reference measurements of ALST [15, 16]. The Kim equation can be used to calculate the total body skeletal muscle mass from the reference measurements of ALST [17]. Therefore, if segmental BIA can obtain accurate measurement of ALST in athletes, the estimation of skeletal muscle mass can be convenient and meaningful.

Many studies have utilized the standing-posture 8-electrode BIA to measure body composition of healthy individuals [15, 18], adolescents [19], elderly individuals [20], obese women [21], and peritoneal dialysis patients [22]. However, the research on body composition of athletes is limited because body composition varies with different sport disciplines. Therefore, when using BIA to measure an athlete's body composition, the specific sport discipline should also be taken into account.

In this study, segmental and total body compositions were estimated with a standing-posture 8-electrode BIA in young male wrestlers, and the results were compared to DXA measurements.

MATERIALS AND METHODS

Subjects. The subjects were 48 young male wrestlers in Taiwan who had been training in professional wrestling for over 9.6 (±1.4) years with more than 12.2 (±2.3) hours of physical training per week. The physical characteristics of the subjects are shown in Table 1. All subjects were active male wrestlers at the highest level of competition in Taiwan at the time of the study. The subjects were 17.9 to 22.3 years of age, with an average of 20.1± 1.2 years. Their body weight was between 56.4 and 121.6 kg, and their BMI was 20.7 to 37.5 $kg \cdot m^{-2}$ (average 25.4 ± 3.8 $kg \cdot m^{-2}$). Alcohol was not consumed within 48 hours prior to the assessment. Diuretics were restricted for 7 days prior to the assessment. The subjects did not train for 24 hours prior to the assessment, and defecated and urinated within 30 minutes. All subjects had no medical history of endocrine, nutrition or growth disorders.

Experimental design

The body composition of each subject was estimated using standing-posture segmental BIA_8 and DXA. The study was conducted at the Radiology Department of the Jen-Ai Hospital in Dali, Taichung, Taiwan. Prior to the study, the research programme and experimental procedure were approved by the Human Subject Research Ethics Committee of Jen-Ai Hospital.

Anthropometry

The subjects were weighed to the nearest 0.1 kg with a Weight-Tronix (Scale Electronics Development, New York, USA) electronic scale. The height, without shoes, of each subject was measured with a stadiometer (Holtain, Crosswell, Wales, UK) to the nearest 0.5 cm. The formula used to calculate body mass index (BMI) was weight (kg) divided by height (m) squared ($kg \cdot m^{-2}$).

Bioelectrical impedance analysis

The standing-posture 8-electrode bioelectrical impedance analysis device BC-418 (BIA_8, Tanita Corp., Tokyo, Japan) was used for measuring total body and segmental impedance with stainless steel plates to replace the traditional electrode patches. Eight stainless steel plates are located on the handgrip and the base, which has an integrated weight sensor. When conducting measurements, the subjects stood on the base with both feet in contact with the electrode plates and held the hand grips with the embedded electrodes, and a low voltage current passed through the body. The impedance was measured in a single frequency (50 kHz, 550 mA) using BIA_8 with sine wave currents as the subjects were simultaneously weighed.

BIA_8 can measure the impedance of five segments of the body within a very short period of time. The total body impedance was measured with the electrical pathway that runs from the left hand to the left foot. The impedance of each limb was measured with the electrical currents from the electrode framework developed by Organ *et al*. [14]. The LST and BF% of the total body, arms and legs can be estimated with a prediction equation using impedance of the five body segments and other predictive variables, such as height, weight, age, and gender. Appendicular LST (ALST) can be estimated with the sum of the left and right limb LST. The BIA_8 measurement of each subject was repeated three times to obtain the mean value of the estimates. To ensure the reliability of impedance measurements in this study, the within- and between-day impedance coefficients of variation (CV_S%, [SD/mean] × 100%) were assessed. Impedance measurements were acquired 10 times within an hour in each of five subjects to estimate within-day CV_S%. Those five subjects took impedance measurements on five consecutive days to estimate the between-day CV_S%.

TABLE 1. Results of the DXA and BIA_8 total body and regional LST (kg) estimations

	All subjects (n = 48)	$BF\%_{DXA}$ < 10% (n =19)	$BF\%_{DXA}$ >10% (n =29)
Age (years)	20.1 ± 1.2 (17.9, 22.3)	20.0 ± 1.2 (18.7, 22.3)	20.2 ± 1.3 (17.9, 22.3)
Weight (kg)	73.7 ± 14.0 (56.4,121.6)	70.0 ± 6.6 (56.8, 82.1)	77.7 ± 15.7 (56.4, 121.6)
Height (cm)	170.0 ± 5.7 (156.5, 181.7)	169.6 ± 4.1(160.0, 175.2)	170.2 ± 6.2(156.5, 181.7)
BMI ($kg \cdot m^{-2}$)	25.4 ± 3.8 (20.7, 37.5)	23.2 ± 1.7 (20.7, 27.8)	26.7 ± 4.1 (22.2, 37.5)

Note: All values are the mean± SD; minimum and maximum values are in parentheses.

BIA_8 measurements of all subjects were carried out in a temperature- and humidity-controlled room. Each subject completed the BIA measurement within ten minutes. ALST and LST were measured in kg. Body fat was measured as a percentage (BF%). The total BF% was measured by DXA and BIA_8. All subjects were divided into three groups for further comparison: all subjects; $BF\%_{DXA} < 10\%$ and $BF\%_{DXA} > 10\%$. RMSE/mean was used to evaluate (measure) the differences between the BIA_8 and LST_{DXA} measurements of the arms, legs, trunk and head, and total body. The five segmental body impedances were measured by the BIA_8, including hand-to-foot over the left side of the body, left arm, right arm, left leg, and right leg. The conductive volume was determined by h^2/Z, in which h represents the height of subjects and Z represents impedance. Because a proportional relationship often exists between the length of the arms and legs and the height of an individual [23], h^2/Z_{F-H}, h^2/Z_{arm} and h^2/Z_{leg} were used to represent the impedance index (BI) of the total body, arms, and legs, respectively.

Dual energy X-ray absorptiometry

Each subject was scanned using a DXA system (GE, Lunar Prodigy, USA) to measure fat mass, bone mineral mass, BF% and LST. Scans were performed while the subjects were wearing light cotton robes, lying on a bed with the arms stretched out flat on the side of the body and with their legs lightly closed with their toes pointed upward. Scans were performed using the total body scan mode, which scanned the subject in the following sequence: head, arms, legs, and trunk. Each subject underwent an approximately 20-minute total body scan and the results were analyzed with enCore 2003 Version 7.0 software.

Statistical analysis

The data were analysed using SPSS Version 16 (SPSS Inc., Chicago, IL, USA) and MedCalc Version 11.5 (MedCalc Software Inc., Mariakerke, Belgium). Group data are expressed as the mean ± SD. Pearson's correlation coefficient, Lin's concordance correlation coefficient (CCC) [24] and linear regression analysis were used to examine the relationship between the results from the DXA and BIA_8 measurements.

In the Bland-Altman plot, the x axis value $ALST_{DXA}$ and $BF\%_{DXA}$ reference value were measured by DXA and y axis value $ALST_{BIA8}$-$ALST_{DXA}$ and $BF\%_{BIA8}$-$BF\%_{DXA}$ were acquired from the difference between BF% and ALST that was measured by BIA_8 and DXA. Furthermore, regression analysis was applied using x and y axis data as independent and dependent variables [25]. Also, the differences between the two methods were calculated by $CV_R\%$ ([RMSE / mean] × 100%). And, the paired *t*-test was used to compare the mean difference between the results measured by the two methods. The level of significance was < 0.05 unless otherwise mentioned.

RESULTS

Impedance measurements. The within-day $CV_S\%$ for total body impedance in five subjects was 0.3 to 0.8%, and their between-day $CV_S\%$ was 0.9 to 1.7%. In the above-mentioned LST measurement, the correlation coefficient (*r*) between the hand-to-foot BI and the total body LST was 0.903; the leg BI and LST was 0.891; and the arm BI and LST was 0.473. All the *P*-values were less than 0.01.

Body composition

Limits of agreement (95% confidence interval, mean ± 2 SD), Pearson's correlation coefficients, Lin's concordance correlation coefficients, and bias results between DXA and BIA_8 for the lean soft tissue of arms, legs, appendicular, trunk and head, and total body LST are shown in Table 2.

Figure 1a shows the relationship between ALST estimated with the BIA_8 and DXA. Figure 1b shows the Bland-Altman plot of the relationship between the BIA_8 and DXA measurements of ALST.

Limits of agreement (95% confidence interval, mean ± 2 SD), Pearson's correlation coefficients, Lin's concordance correlation coefficients, and bias results between DXA and BIA_8 for the BF% of arms, legs, appendicular, trunk and head, and total body LST are shown in Table 3, respectively. Figure 2a shows the relationship between BF% estimated with the BIA_8 and DXA. Figure 2b shows the Bland-Altman

TABLE 2. Results of the DXA and BIA_8 total body and regional LST (kg) estimations.

Measured segment	DXA(kg)	BIA_8(kg)	r^*	CCC	LOA (kg)	Bias (kg)	LOA (%)	Bias(%)	$p(LST_{DXA}$ vs. $LST_{BIA8})$
Arm#	3.3±0.6	3.3 ± 0.5	0.466	0.455	2.13 to 4.44	3.29	64.53 to 135.23	99.88	0.450
Leg#	11.9±1.7	11.1± 1.4	0.886	0.764	-0.70 to 2.39	0.85	-6.44 to 21.57	7.57	< 0.001
ALST	28.7±3.5	30.4± 4.2	0.897	0.797	-1.99 to 5.54	1.78	-6.93 to 19.28	6.18	0.027
Trunk + head	30.7±4.1	29.2± 3.9	0.857	0.795	-5.81 to 2.75	-1.53	-19.91 to 9.43	-5.24	0.063
Total body	59.4±7.2	59.6±7.8	0.936	0.932	-5.24 to 5.72	0.24	-8.83 to 9.64	0.41	0.876

ALST, appendicular lean soft tissue; results are expressed as the mean ± SD. *All *P*-values are < 0.01; #, *n* = 96 ;CCC, concordance correlation coefficients; LOA (limits of agreement, 95% confidence interval); Bias (DXA and BIA8 mean difference); LOA(%), (LOA(kg) / DXA(kg) × 100% , unit: %); Bias(%),(Bias(kg) / DXA(kg) × 100% , unit: %); $p(LST_{DXA}$vs.$LST_{BIA8})$, *p*-value of paired *t*-test between results estimated by BIA_8 and DXA.

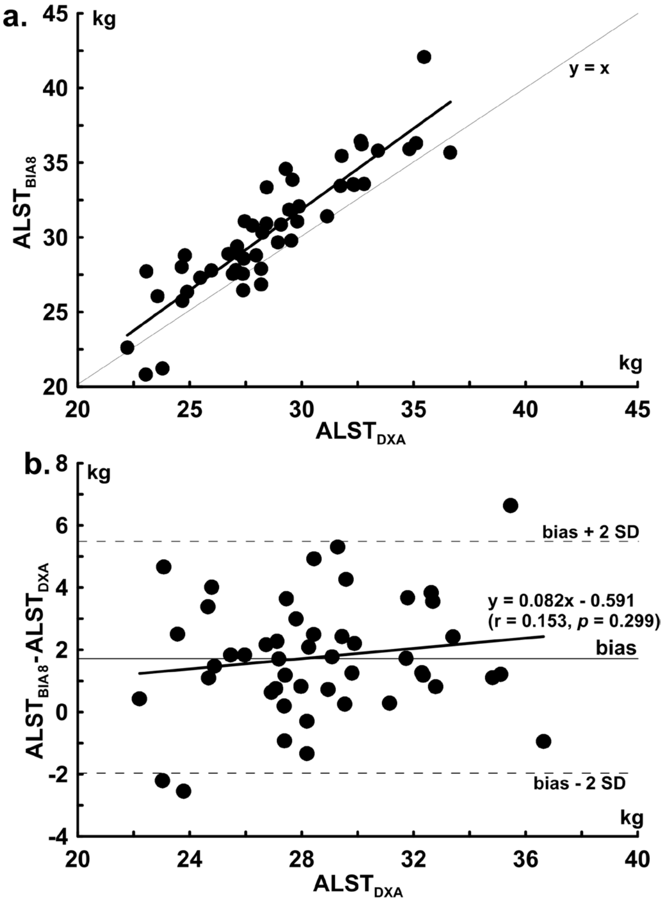

FIG. 1. (a) Plot of ALST estimates with the BIA_8 vs. DXA ($ALST_{BIA8} = 1.08\ ALST_{DXA} - 0.60$, $r = 0.897$, $p < 0.001$). The regression and identity lines are also shown.
(b) Bland-Altman plot of ALST estimates with the BIA_8 and DXA (bias = 1.77 kg, bias - 2 SD = -1.99 kg, bias + 2 SD = 5.54 kg).

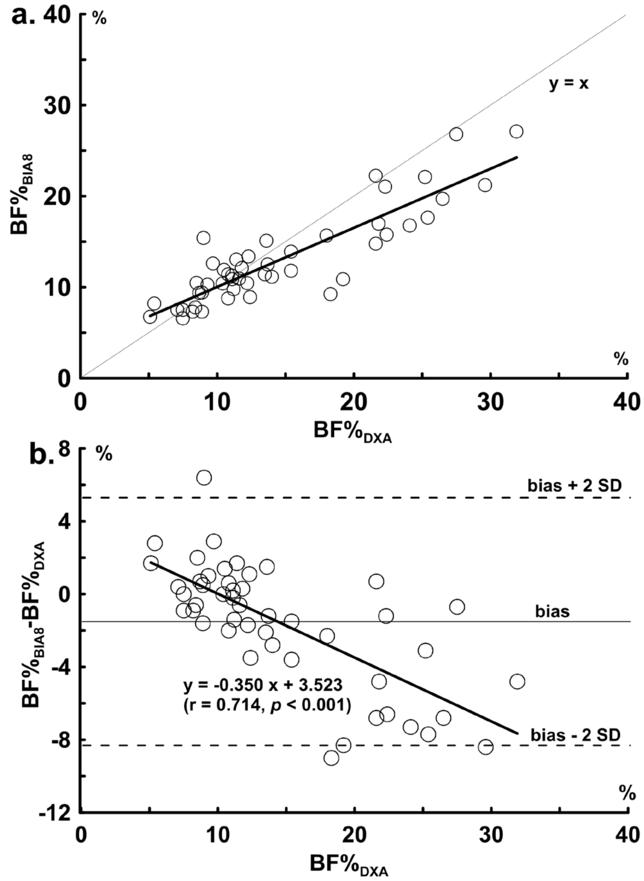

FIG. 2. (a) Plot of BF% estimates with the BIA_8 vs. DXA ($BF\%_{BIA8} = 0.65\ BF\%_{DXA} + 3.53$, $r = 0.886$, $p < 0.001$). The regression and identity lines are also shown.
(b) Bland-Altman plot comparing the differences between the BIA_8 and DXA measurements of BF% (bias = -1.58%, bias – 2 SD = -8.37%, bias + 2 SD = 5.21%).

plot of BF% measured with the BIA_8 and DXA. The DXA and BIA_8's LST and BF% CCC are shown in Tables 2 and 3.

Subjects were divided into three groups for further comparison: $BF\%_{DXA} < 10\%$ in Group A ($n = 19$); $BF\%_{DXA} > 10\%$ in Group B ($n = 29$); and all subjects in Group C ($n = 48$). The physical characteristics of the subjects are shown in Table 1. The differences between the LST measurements of DXA and the BIA_8 in total body and body segments are shown in Figure 3 (results presented as RMSE/mean × 100 % – CV_R%). The corresponding CV_R% of groups A, B and C were: 11.6%, 19.7% and 17.3% in the arms; 2.56%, 4.42% and 3.88% in the legs; 6.17%, 10.18% and 8.90% in all the limbs; 13.54%, 5.67% and 8.55% in the head and trunk; and 3.74%, 5.00%, 4.57% in the total body, respectively.

TABLE 3. Results of the DXA and BIA_8 total body and regional BF% (%) estimations.

Measured segment	DXA(%)	BIA_8(%)	r*	CCC	LOA(kg)	Bias (kg)	LOA(%)	Bias(%)	p($BF\%_{DXA}$ vs. $BF\%_{BIA8}$)
Arm#	7.3 ± 4.8	10.3±4.4	0.827	0.687	-2.45 to 8.42	2.98	-33.70 to 115.88	41.09	< 0.001
Leg#	14.3 ±7.1	14.5±4.8	0.903	0.767	-8.01 to 8.45	0.22	-56.42 to 59.50	1.54	0.079
Trunk + head	17.1 ± 7.9	12.4±5.6	0.866	0.662	-12.84 to 3.49	-4.68	-75.78 to 20.58	-27.60	< 0.001
Total body	14.6 ± 6.9	13.0±5.1	0.886	0.820	-8.24 to 5.06	-1.59	-57.03 to 35.03	-11.00	0.204
Total body	59.4±7.2	59.6±7.8	0.936	0.932	-5.24 to 5.72	0.24	-8.83 to 9.64	0.41	0.876

ALST, appendicular lean soft tissue; results are expressed as the mean ± SD. *All P-values are < 0.01; #, $n = 96$; CCC, concordance correlation coefficients; LOA (limits of agreement, 95% confidence interval); Bias (DXA and BIA8 mean difference); LOA(%), (LOA(kg) / DXA(kg) × 100% , unit: %); Bias(%),(Bias(kg) / DXA(kg) × 100% , unit: %); p-value of paired t-test between results estimated by BIA_8 and DXA.

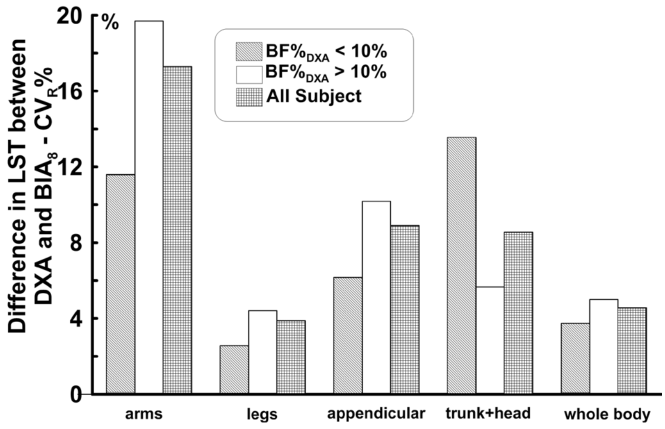

FIG. 3. Differences in LST between DXA and BIA - CV_R% in each segment $BF\%_{DXA} < 10\%$, $BF\%_{DXA} > 10\%$ and total group bar chart.

DISCUSSION

Body composition information is commonly used in clinics, sports medicine and other health-related settings [26-28]. Many methods provide assessments of body composition, such as DXA, air-displacement plethysmography, and underwater weighing. However, these methods are costly and cannot be frequently used [29-32]. In most cases, BIA is the only viable method for evaluating body composition. Relying exclusively on the correlation between the results of two measurement methods is insufficient to evaluate the equivalence of the methods [25]. Therefore, the Bland-Altman analysis was used to assess the agreement between the BIA_8 and DXA results. Although the segmental and total body composition can be obtained by the BIA_8, a comparison of the BIA_8 with reference methods is necessary to ensure whether BIA_8 can derive reference measurements in different body segments. Hence, the Bland-Altman analysis and CV_R% were used to validate BIA_8.

This study used DXA as a reference method. The results showed that the LST and BF% in the leg and total body of male wrestlers measured with the standing BIA_8 were highly correlated with the DXA data. The total body and leg BI were also highly correlated with total body and leg LST_{DXA} measurements, respectively. However, the arm BI was only moderately correlated with the arm LST_{DXA} measurements. Hence, the arm LST values measured by the BIA_8 and DXA only show a moderate correlation. The limits of agreement between the two methods in LST were 2.13 to 4.44 kg, which was not the one with the largest bias or widest limits of agreement when compared with other body segments' measurement results such as the ALST, trunk and head, or total body. However, the limits of agreement of the arms were 64.5 to 135.2% if indicated by CV_R%. The LST measuring results in BIA_8 and DXA in upper arms showed no significant difference, but LST in legs and ALST showed a significant difference.

The $BF\%_{BIA8}$ in the arms and legs, trunk and head, and total body are highly correlated ($r > 0.827$, $p < 0.01$) with the DXA measurements. The limits of agreement of the arm BF% measured with the BIA_8 were -2.3 to 8.4% compared to the DXA value and were not significantly larger than the LST results of other body segments measured by the BIA_8. However, if indicated by CV_R%, the limits of agreement of the arm BF% were -33.7 to 115.9%, which were significantly higher than those of the other body segments or the total body.

McBride [33] suggests the CCC scale value for CCC: a value of CCC < 0.90 is poor and 0.90 to 0.95 is considered acceptable. In the present study, other than whole body LST, the CCC value is higher than 0.90. When CCC was used as the threshold value, the LST and BF%, BIA_8 and DXA measurements showed insufficient concordance.

In Figure 2b, the *p* value indicates that when $BF\%_{DXA}$ decreases $BF\%_{BIA8}$-$BF\%_{DXA}$ would change and show a significant difference and proportional error. This conclusion suggests that the measurements of wrestlers' BF% resulted from the BIA_8 measuring error, which also appears to have a linear relationship. Therefore, a correction needs to be made to accurately estimate wrestlers' BF%.

A study conducted by Yoon [34] indicates that world champion male wrestlers usually have superior muscular body features with a low body fat percentage that is below 10%; therefore the threshold of BF% was set to 10% in the present study. The LST results were compared in subgroups categorized by BF%: Group A ($BF\%_{DXA} < 10\%$), Group B ($BF\%_{DXA} > 10\%$), and Group C (all subjects). The estimation error in the arms was the largest compared to other body segments, regardless of their subgroups, whereas the LST of the legs and total body measured with the BIA_8 had low estimation errors.

The findings of this study indicated that LST estimated by the BIA_8 should be treated with caution, regardless of the values for the correlation, confidence interval, absolute bias or CV_R%. The correlation between the arm BI (h^2/Z_{arm}) and LST in our study was $r = 0.466$. Our data can be compared to the research results of Pietrobelli *et al*. [15] on the arm and body composition in healthy subjects in which the correlation between the arm LST measured by the BIA_8 and DXA was $r = 0.96$ while the correlation between BI and LST was $r = 0.97$. Bracco *et al*. [35] reported that the arm BI and fat-free mass (FFM) were moderately correlated, $r = 0.55$. In our study, the reason for the high estimation error in the arm LST may be that the arm BI and LST measured by BIA_8 were not highly correlated in young wrestlers.

The average weight of the LST of a single arm of the subjects in this study was 3.3 ± 0.6 kg, and the average weight of a single leg was 11.9 ± 1.7 kg. The arm LST weight was 27.3% of the leg. Although the accuracy of the LST and BF% measurements in the arms by the BIA_8 in young male wrestlers in this study was inadequate, the BIA_8 was capable of deriving reference measures of LST in the legs and total body.

Existing standing-posture BIA originated from the study by Tan *et al*. [11], which described the characteristics of the stainless steel plate to measure segmental and total body resistance and reactance in healthy subjects. The results showed that the estimated values from studies that used stainless steel plates were highly correlated with those that used electrode patches. Pietrobelli *et al*. [15] also used the BC-418 to analyze the ALST and BF% of 40 healthy subjects with a wider age range. The results were very similar to the results of our study apart from the arms, indicating that BIA_8 could derive reference measures of body composition in young, elite wrestlers, but the results from arm measurements should be used with caution.

In this study, the total BF% was measured by the BIA_8 and DXA in all subjects. The paired *t*-test analysis shows that the absolute differences between these two methods regarding the LST and BF% in legs and total body were insignificant. The limits of agreement between these two methods were also not very large. Although BIA_8 could deliver reference measurements of LST in all subjects (group C), when comparing the results in different BF% subgroups, the difference between the two methods was smaller in subjects with higher BF% (group B) than those with lower BF% (group A). Trunk and head LST were not included in our calculations.

CONCLUSIONS

The results of this study demonstrate that the standing-posture BIA_8 can be used to estimate the segmental and total body LST, BF%, and total body SM if DXA or magnetic resonance imaging (MRI) are too costly or difficult to conduct. The BI measured by the BIA_8 and the LST measured by DXA were highly correlated, indicating that the BIA_8 can obtain reference measures of ALST and total body SM in young wrestlers. If the accuracy of the arm LST measurements can be improved, the standing-posture BIA_8 may be a potential alternative to assess the body composition of young elite wrestlers in Taiwan and other clinical applications.

Acknowledgements

This study was supported by grants from National Science counsel, NSC95-2413-H-028-003, and Hualien Armed Forces General Hospital, HAFGH-805-C102-12, Taiwan.

Conflict of interests: the authors declared no conflict of interests regarding the publication of this manuscript.

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