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Prediction of lean body mass from multifrequency segmental impedance: influence of adiposity

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Abstract The aim of the study was to determine the influence of adiposity on the relationship between bioelectrical impedance (BIA) measurements of body segments and estimation of body composition by dual-energy X-ray absorptiometry (DXA). Multiple frequencies of whole body and segmental impedances were measured in 68 normal-weight and obese subjects (46 women and 22 men), mean age 37.2±14.8 years (range, 18–69). Total and appendicular lean body mass (LBM) assessed by DXA correlated significantly with total and segmental impedance values adjusted for stature in both obese and normal-weight subjects. Best fitting equations for the prediction of appendicular LBM from segmental impedance measurements were derived for the arm and leg with and without the inclusion of adiposity (the percentage of body fat measured by DXA) in the regression models. Best prediction was obtained at low frequency for the arm and high frequency for the leg. Adiposity appears to significantly influence the prediction of leg LBM by BIA. These preliminary observations need further validation to provide an accurate assessment of appendicular LBM assessment by BIA.

Key words Segmental bioelectrical impedance • Dual-energy X-ray absorptiometry • Lean body mass

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Introduction

Segmental body composition assessment by bioelectrical impedance analysis (BIA) may represent a simple, inexpensive, and relatively accurate method to assess body composition in healthy and obese subjects [1, 2]. Bracco et al. [2] demonstrated that the height impedance index (H^2/Z) is the best single predictor of lean body mass (LBM) as measured by dual-energy X-ray absorptiometry (DXA). These authors derived segmental equations for body composition by BIA for a sample of 51 normal and overweight women at three frequencies (0.5, 50 and 100 kHz). However, the relative errors calculated by the authors were high: 15.9%–16.9% for arm LBM and 11.9%–12.7% for leg LBM. More recently, Pietrobelli et al. [3] explored multiple regression models for predicting appendicular skeletal muscle mass using BIA at increasing electrical frequencies in healthy women and men. The authors found a strong correlation between arm and leg skeletal muscle mass and H^2/Z. Age was a significant, independent predictor at all measured frequencies. However, since relative adiposity tends to increase with age, this could play a role in determining tissue conductivity [4].

The aim of the present investigation was to determine the influence of adiposity on the relationship between BIA measurements of body segments and estimation of body composition by DXA in normal, overweight and obese subjects.

Materials and methods

Subjects

The study enrolled 68 healthy, Caucasian volunteers (aged 18–69 years; BMI 18.7–39.8 kg/m^2) from university and hospital staff. The group consisted of 22 men and 46 women who were unselected in terms of body composition. Informed consent was obtained from each subject and the experimental procedures were approved by the university's institutional review board.

Multifrequency segmental bioimpedance

Impedance (Z) was measured using a multifrequency BIA system (Human-IM DIP, DS-Medigroup, Milan, Italy). Segmental impedance measurements were made as reported by Organ et al. [5]. Two injector electrodes were positioned on the mid-dorsum of the left hand just proximal to the metacarpal-phalangeal joint line, and on the mid-dorsum of the left foot just proximal to the metatarsal-phalangeal joint line. Four voltage recorder electrodes were positioned, two on the mid-dorsum of the wrist of both arms centered on a line joining the bony prominences of radius and ulna, and two on the mid-anterior ankle of both feet centered on a line joining the bony prominences of medial and lateral malleoli.

Impedance index was calculated as height squared divided by segmental impedance (m^2/ohm) and as segmental length squared divided by segmental impedance (cm^2/ohm). Segmental lengths were derived from DXA measurements.

Dual-energy X-ray absorptiometry

Bone mineral content (BMC), bone mineral density (BMD) and soft tissue composition (lean and fat content) were determined by DXA. DXA measurements were performed with a total body scanner (Model DPX, Lunar, Madison, WI, software version 3.6) that uses a constant potential X-ray source at 12.5 fJ and a K-edge filter to achieve a congruent beam of stable dual-energy content (40 and 70 keV). DXA measures an Rst value, which is theoretically related to the soft tissue composition. The coefficient of variation (CV) for bone measurements was less than 1% on this instrument: for five subjects scanned six times over a 9-month period, the CV was 2.2 for fat mass and 1.1 for fat-free mass [6, 7]. Total and regional body composition were used in the analysis. Total body scans as well as regional body scans (left and right extremities, trunk, abdominal region) were evaluated.

Statistical methods

Statistical analysis was carried out using the SPSS/PC software program (SPSS, 1990). Values are given as means and standard deviations. The level of two-tailed significance was 0.05. Correlations were Pearson's product moment correlations. Multiple regression analysis was performed to study the relationship between arm and leg lean body mass measured by DXA and bioelectrical values. Arm and leg LBM was set as dependent variable in regression analyses and impedance index, age, gender and body fat were potential independent variables in multiple regression analysis models.

Results

A summary of the physical characteristics of the participants together with the results of the determination of fat and lean body mass by DXA is shown in Table 1. The study sample purposely covered a broad range of body weights, body mass indexes and body fatness in order to test the influence of adiposity on bioelectrical impedance measurements. Women were significantly older and fatter than men. However, since the sample of men was rather small, we decided to also perform the subsequent analyses on the whole group. Body fat (% weight) correlated significantly with age (r=0.67; p<0.01).

Table 1 Characteristics of the study population. Values are means (SD)

	Women (n=46)	Men (n=22)	Total (n=68)
Age (years)	40.8 (14.3)	29.7 (13.3)	37.2 (14.8)
Weight (kg)	75.6 (13.6)	85.3 (14.8)	78.7 (14.6)
Height (cm)	161.0 (6.7)	179.4 (7.6)	167.0 (11.2)
BMI (kg/m^2)	29.3 (5.6)	26.6 (5.2)	28.4 (5.5)
Waist-to-hip ratio	0.82 (0.08)	0.89 (0.08)	0.84 (0.09)
DXA body weight (kg)	74.3 (13.3)	84.5 (14.5)	77.6 (14.5)
LBM (kg)	41.0 (4.6)	62.6 (8.4)	48.0 (11.8)
Fat (kg)	30.8 (11.2)	18.3 (10.9)	26.7 (12.5)
Fat (%)	40.1 (9.4)	20.7 (9.8)	33.8 (13.2)
Arm LBM (kg)	4.65 (0.91)	8.37 (1.62)	5.8 (2.1)
Arm fat (kg)	5.64 (2.74)	2.76 (2.26)	4.7 (2.9)
Leg LBM (kg)	13.52 (1.88)	21.05 (3.40)	15.9 (4.3)
Leg fat (kg)	10.01 (3.32	5.58 (3.07)	8.6 (3.8)
Trunk LBM (kg)	20.11 (2.32)	29.50 (3.71)	23.1 (5.2)
Trunk fat (kg)	14.15 (5.58)	9.24 (5.44)	12.6 (6.0)

DXA, dual-energy X-ray absorptiometry; *LBM*, lean body mass

The segmental bioelectrical impedance values (Table 2) revealed that the arms and legs contributed to 50% and 47%, respectively, of whole body impedance whereas they represented only 12% and 33% of total LBM as determined by DXA. The trunk averaged 5% of total impedance but represented 48%.

There was an excellent correlation between the measured whole body resistance and the sum of the segmental BIA measurements up to 100 kHz (Table 3). At 300 kHz the difference increased to an average value of 37.1 ohm.

Appendicular lean body mass measured by DXA was significantly correlated with the segmental impedance index adjusted by stature at all measured frequencies (Table 4). The correlations were not improved when limb length was substituted for height in the calculations of the impedance index (data not shown). The highest correlations were found at 5 kHz for arm LBM (r=0.932) and at 50 and 100 kHz for leg LBM (r=0.87).

Table 5 gives the best fitting prediction formulas for appendicular lean body mass with and without the inclusion of adiposity in the regression model.

Table 2 Bioelectrical characteristics of the study population. Values are means (SD)

	Women (n=44)		Men (n=22)	
Whole body resistance (ohm)				
1 kHz	625	(81)	530	(63)
5 kHz	616	(78)	523	(60)
10 kHz	603	(76)	507	(60)
50 kHz	545	(70)	445	(58)
100 kHz	518	(68)	419	(57)
300 kHz	497	(64)	401	(55)
Arm resistance (ohm)				
1 kHz	314	(43)	246	(31)
5 kHz	312	(42)	243	(30)
10 kHz	307	(41)	234	(32)
50 kHz	283	(40)	206	(34)
100 kHz	273	(39)	195	(35)
300 kHz	274	(42)	195	(38)
Leg resistance (ohm)				
1 kHz	287	(43)	263	(34)
5 kHz	283	(44)	262	(33)
10 kHz	276	(41)	254	(32)
50 kHz	244	(36)	222	(29)
100 kHz	232	(34)	211	(29)
300 kHz	235	(36)	217	(31)
Trunk resistance (ohm)				
1 kHz	29	(4)	29	(7)
5 kHz	29	(4)	27	(5)
10 kHz	28	(4)	25	(5)
50 kHz	26	(4)	22	(5)
100 kHz	25	(4)	21	(5)
300 kHz	27	(6)	25	(8)

Table 3 Difference (ohms) between whole body resistance and sum of segmental measurements in the global sample (n=68 subjects)

	Mean (SD)	95% confidence interval	*p*
1 kHz	4.3 (10.1)	1.8–6.8	0.001
5 kHz	6.6 (9.9)	4.2–9.0	0.000
10 kHz	6.7 (8.1)	4.7–8.7	0.000
50 kHz	5.3 (5.0)	4.1–6.5	0.000
100 kHz	9.5 (5.4)	8.2–10.8	0.000
300 kHz	37.1 (6.6)	35.5–38.7	0.000

Table 4 Correlation coefficients for appendicular lean body mass and segmental impedance index in the global sample (n=68). All values are $p<0.001$

	H^2/Z_1	H^2/Z_5	H^2/Z_{10}	H^2/Z_{50}	H^2/Z_{100}	H^2/Z_{300}
LBM (kg)						
Arms	0.911	0.932	0.924	0.874	0.833	0.788
Legs	0.847	0.837	0.850	0.871	0.873	0.825
Trunk	0.623	0.734	0.710	0.654	0.670	0.636

Table 5 Best fitting equations for the prediction of appendicular lean body mass from segmental impedance measurements without and with the inclusion of the percentage of body fat measured by DXA in the regression model

	Without adiposity		With adiposity	
	Coefficient	*p* value	Coefficient	*p* value
Arms				
$H^2/Z_{5\ arm}$ (cm^2/ohm)	61.57	<0.0001	60.417	<0.0001
Sex[a]	623.37	0.111	920.89	0.045
Age (years)	-1.23	0.856	-8.21	0.347
Body fat (%)	–	–	16.29	0.208
Intercept (g)	-498.6	0.408	-770.7	0.228
R^2	0.87	–	0.88	–
SEE (g)	765	–	761	–
Legs				
$H^2/Z_{50\ leg}$ (cm^2/ohm)	95.74	<0.0001	101.68	<0.0001
Sex[a]	3220.3	<0.0001	1953.35	0.01
Age (years)	-49.74	0.001	-19.43	0.266
Body fat (%)	–	–	-70.32	0.008
Intercept (g)	5185.9	<0.0001	6129.75	<0.0001
R^2	0.87	–	0.88	–
SEE (g)	1583	–	1508	–

[a] Women=0; men=1; *SEE*, standard error of estimate; R^2, coefficient of determination

Discussion

The analysis of segmental impedance values shows that the limbs determine the major part of body impedance at the selected frequencies (1, 5, 10, 50, 100 and 300 kHz), with the trunk constituting only a small part of the whole body impedance.

The present investigation confirms the significant relationship between impedance index and lean body mass measured by DXA [2, 3, 7, 8, 9], but the prediction models were different for the arms and legs. Best prediction for the leg was found at high frequency (50 kHz). An improvement in the leg prediction model at increasing frequency is in agreement with previous studies [2, 3]. However our study does not suggest the usefulness of frequencies higher than 50 kHz. The arm model differs in several respects from the leg model and from other similar studies. In fact, best prediction was obtained at low frequency (5 kHz) and age did not enter as a significant predictor at any frequency.

The fact that arm LBM prediction can be obtained at lower frequency than for the leg is in agreement with previous studies. Pietrobelli et al. [3] suggested the frequencies of 50 kHz and 300 kHz for the arms and legs, respectively. However, the sample examined in the present study is different because it is larger and presents a wider range of ages and adiposity. The differences in samples studied can partly explain the differences in frequencies.

Relative adiposity tends to increase with age, and this trend was confirmed in our subjects. The inclusion of the percent of body fat measured by DXA did not greatly improve the precision of the equation, but made the age factor not significant in the leg model (in the arm model, age was never significant). This was expected because the factors age and adiposity are correlated (r=0.67). The inclusion of adiposity in the model, however, foresees the use of DXA. For this reason, the equation which did not include adiposity is more practical for routine application.

There are several differences in limb tissue composition and geometry that need to be considered. Fat percentage (calculated as the ratio between limb fat and total soft tissues measured by DXA) is higher in the arms (42%) than in the legs (35%) in the present sample. This may have led to a higher impedance value in the arm than in the legs (on average 258±52 vs. 237±35 ohm at 50 kHz, $p<0.001$). Limb geometry is different between arms and legs and this difference was accentuated in our sample because of a gynoid fat distribution (mean waist-to-hip ratio was 0.84±0.09 in the whole sample). It is possible that these differences influence appendicular conduction pathways and therefore explain differences in prediction models.

The relative errors of limb LBM predicted by the equations in Table 5 are 13% for the arms and 10% for the legs, slightly less than previously reported by Bracco et al. [2] (15.9%–16.9% for the arm and 11.9%–12.7% for the leg) but still remain rather high errors.

In summary, the relationship between appendicular lean body mass and bioelectrical impedance is not age-dependent if the model includes adiposity in a group that differs widely in age (18–69 years) and adiposity (BMI range, 18.7–39.8). At this time there is no clear explanation why LBM prediction performs better at lower frequency for the arms than for the leg. This preliminary observation needs further validation to provide an accurate assessment of appendicular lean body mass assessment by BIA.

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