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ORIGINAL ARTICLE

Regional and total body bioelectrical impedance analysis compared with DXA in Icelandic elderly

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Background/Objectives: The aims were (1) to compare fat free mass (FFM) estimates from regional hand-held bioelectrical impedance analysis (HHBIA) with conventional BIA (CBIA) and dual energy X-ray absorptiometry (DXA) and (2) to develop a population specific equation for FFM prediction in Icelandic elderly.
Subjects/Methods: DXA, CBIA and HHBIA data were available for 98 free-living Icelandic elderly (age = 73.0 ± 5.6 years, body mass index = 28.8 ± 5.2 kg/m^2). Participants were randomized into a development block (n = 50) and validation block (n = 48). A population specific equation for FFM prediction was calculated using CBIA-derived resistance and anthropometric data from the development block and then compared with other BIA equations (Deurenberg, Segal, company-specific equations) and DXA estimates using the validation block.
Results: The correlations between BIA methods and DXA were very high, that is, >0.9; however, mean differences compared with DXA were quite variable, ranging from −5.0 (Deurenberg) to +2.5 (Segal, HHBIA) and +3.3 kg (CBIA). Mean difference of the population-specific equation was below 0.1 kg. The standard deviations of the differences ranged from 2.6 to 3.3 kg. The limits of agreement of the BIA methods were similar and between 9.9 and 12.9 kg.
Conclusions: In Icelandic elderly, HHBIA and CBIA produce similar FFM estimates when using company-specific prediction equations. CBIA provides the additional possibility to use a population-specific prediction equation, which yields best results. However, limits of agreement were wide and similar of all employed BIA methods, which indicates principal limitations of BIA analysis in the determination of FFM.
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Keywords: bioelectrical impedance analysis; dual energy X-ray absorptiometry; elderly

Introduction

It is important to evaluate body composition as it has a strong impact on health and disease (Carlsson *et al.*, 2009). In the elderly, body composition changes are often associated with malnutrition, sarcopenia and disability (Sonn *et al.*, 1998; Boult *et al.*, 1999). Moreover, body composition assessment could be a useful tool in clinical management to measure fat free mass (FFM) changes due to nutritional therapy or physical rehabilitation (Volkert *et al.*, 1992; Fried *et al.*, 2001).

Bioelectrical impedance analysis (BIA) is a commonly used method for estimating body composition, based on a two-component body composition model. BIA measures the impedance or resistance to a small electrical current as it travels through the body's water pool. An estimate of total body water is acquired from which total body FFM is calculated, using the assumption that 73% of the body's FFM is water (Lee and Gallagher, 2008).

The conventional BIA (CBIA) approach requires the application of adhesive electrodes on one hand and one foot, the use of a current-introducing and voltage-sensing electronic device with the individual in a supine position and an operator of the device. These factors limit the use of whole-body impedance instruments for personal use (Lukaski and Siders, 2003). The use of regional impedance measurements is attractive for its practicality and convenience for routine, personal monitoring of body composition at home (Lukaski and Siders, 2003). Currently, there is a lack of data describing the validity of the devices that measure regional impedance in order to estimate whole-body composition (Lukaski and Siders, 2003).

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In general, validity of BIA is influenced by several factors, for example, gender, age, race, ethnicity or disturbances of fluid distribution (Rush *et al*., 2006; Tattersall, 2009). Fixed prediction equations used in BIA devices work reportedly well in populations for which they have been developed for (Fuller *et al*., 1994). However, their validity or use in other populations might be questioned (Parker *et al*., 2003) considering that variance in anthropometric measures (skinfold thicknesses, girths, lengths and breadths) have been discussed to affect body impedance (Leppik *et al*., 2004). When data on resistance and body composition from a reference method are available for a population of interest, development of population specific equations by regression analysis is a manageable amount of work and could lead to an acceptable alternative equation.

The present analysis uses body composition data from the currently ongoing IceProQualita study, a randomized controlled intervention study, which investigated the effects of protein consumption and resistance exercise on muscle mass and -power in free living Icelandic elderly.

The aims of the present analysis were:

(1) to compare FFM estimates derived from regional impedance measurements (hand-held BIA, HHBIA) to FFM estimates from CBIA and dual energy X-ray absorptiometry (DXA); it was also investigated whether differences in body fat distribution affect the estimates of HHBIA; and

(2) to develop a population specific equation for FFM prediction using CBIA-derived resistance and regression analysis, to cross-validate this equation and to compare it with other BIA equations and DXA estimates.

Subjects and methods

Subjects

A total of 238 volunteers participated in the IceProQualita study. DXA, CBIA and HHBIA data were available for 98 participants. All participants were 65 years of age and older. Exclusion criteria were low cognitive function (MMSE <19 points) and pharmacological interventions with exogenous testosterone or other drugs known to influence muscle mass. Participants had also to be free of any musculoskeletal disorders or other disorders that could affect their ability to complete the training and testing. When cardiovascular symptoms were detected during screening, the participant's physician was asked whether the subject might participate or not. Furthermore, participants had to be weight stable and all women postmenopausal. The study was approved by the National Bioethics Committee of Iceland, and an informed written consent was obtained from all participants.

Anthropometric measurements

Subjects were told to avoid strenuous exercise and alcohol consumption the day before the measurements. No medication, for example, diuretics, was taken on the measurement days. All anthropometric measurements (waist circumference, body weight, body height) were done using standard procedures as outlined in the research protocol. Body weight was measured in light underwear on a calibrated scale (model number 708; Seca, Hamburg, Germany). The subjects' height was measured with a calibrated stadiometer (model number 206; Seca). Body mass index was calculated from height and weight (kg/m^2). For the measurement of waist circumference, subject stood erect with the abdomen relaxed, arms at the sides, feet together and with their weight equally divided over both legs. The lowest rib margin was first located. Then the iliac crest was palpated in the midaxillary line. A flexible tape was then applied horizontally midway between the lowest rib margin and the iliac crest and tied firmly so that it stayed in position around the abdomen about the level of the umbilicus.

FFM was estimated by HHBIA (Body Fat Monitor BF 306, Omron Healthcare UK Ltd, Milton Keynes, UK), CBIA (Bodystat 1500, Bodystat Ltd, Douglas, Isle of Man, British Isles) and by DXA (Hologic QDR-2000 plus, Hologic Inc., Waltham, MA, USA).

The DXA measurements were conducted at the Icelandic Heart Association, Kopavogur, Iceland. The two BIA measurements were conducted at our research unit. Measurements of BIA and DXA were done within 2 h. HHBIA delivered body fat % only; therefore, FFM was calculated as body weight−body fat, where body fat (kg) was calculated from body fat % $\times$ body weight. CBIA delivered both body composition estimates on the basis of a company-specific equation (Bodystat homepage, 2010), as well as resistance (ohm). Disposable Short Electrodes from Bodystat were used for CBIA measurements. Further FFM estimates were calculated using anthropometric variables, resistance (from CBIA) and the equations from Segal *et al*. (1988) and Deurenberg *et al*. (1990) (Table 1).

Statistical analysis

The data were entered into the SPSS statistical package, version 11.0 (SPSS, Chicago, IL, USA). Data are described as mean $\pm$ s.d. Data were checked for normal distribution using the Kolmogorov–Smirnov test. A *P*-value of less than 0.05 was regarded as statistically significant.

In order to develop and to validate FFM prediction equations on the basis of our own data, data of the participants were randomized into two $\sim$equally large blocks: development ($n=50$) and validation ($n=48$).

Development. An equation for the prediction of FFM was developed using simple regression analysis on the data (body weight, height, resistance, age, gender) from the development block. This equation was called IPQ (which stands for IceProQualita, see Table 1).

Validation. FFM of the validation group was estimated using the IPQ equation. All BIA estimates (HHBIA, CBIA, Segal,

Table 1 FFM prediction formulas

Segal	
Male	$0.00132 \times \text{height}^2 - 0.04394 \times \text{resistance} + 0.30520 \times \text{weight} - 0.16760 \times \text{age} + 22.66827$
Female	$0.00108 \times \text{height}^2 - 0.02090 \times \text{resistance} + 0.23199 \times \text{weight} - 0.06777 \times \text{age} + 14.59453$
Deurenberg	
Male	$0.671 \times \text{height}^2/\text{resistance} + 7$
Female	$0.671 \times \text{height}^2/\text{resistance} + 3.9$
IPQ	
Male	$7.610 - 0.0855 \times \text{age} + 0.273 \times \text{weight} + 0.148 \times \text{height} - 0.00746 \times \text{resistance} + 7.998$
Female	$7.610 - 0.0855 \times \text{age} + 0.273 \times \text{weight} + 0.148 \times \text{height} - 0.00746 \times \text{resistance}$

Abbreviations: FFM, fat free mass; IPQ, IceProQualita.
Age is measured in years, weight in kg, height in cm and resistance in ohm.

Table 2 Characteristics of the participants

	All (N = *98*)	*Development* (n = *50*)		*Validation* (n = *48*)	
	Mean ± *s.d.*	*Male* (n = *21*) *Mean* ± *s.d.*	*Female* (n = *29*) *Mean* ± *s.d.*	*Male* (n = *20*) *Mean* ± *s.d.*	*Female* (n = *28*) *Mean* ± *s.d.*
Age (years)	73.0 ± 5.6	75.0 ± 6.6	72.1 ± 5.5	74.4 ± 4.9	71.5 ± 4.8
Height (cm)	169.4 ± 9.2	175.9 ± 6.2	163.7 ± 4.2	178.6 ± 8.6	163.7 ± 6.4
Body weight (kg)	83.0 ± 18.1	98.1 ± 17.4	74.0 ± 15.4	90.5 ± 14.8	75.4 ± 13.8
BMI (kg/m^2)	28.8 ± 5.2	31.8 ± 5.4[a]	27.7 ± 6.0	28.3 ± 3.7	28.1 ± 4.5
Waist (cm)	100.1 ± 15.6	115.0 ± 9.9[a]	91.6 ± 17.5	106.2 ± 10.1	95.7 ± 13.8
DXA fat (kg)	31.2 ± 9.9	34.0 ± 11.0	30.1 ± 10.5	29.1 ± 7.5	31.9 ± 10.2
DXA fat%	37.5 ± 7.0	34.9 ± 6.2	39.8 ± 6.4	31.7 ± 4.3	41.4 ± 6.2

Abbreviation: DXA, dual energy X-ray absorptiometry.
[a]Significant difference between development and validation, $P < 0.05$.

Deurenberg, IPQ) were then compared with DXA results. Regression analyses were performed to assess the correlations between the DXA and the BIA estimates. Mean differences ($FFM_{BIA} - FFM_{DXA}$) were calculated. Limits of agreement (Bland and Altman, 1986) were used to further investigate the agreement between the measurements, where limits of agreement were defined as mean difference ± 1.96 × s.d.

Body fatness values (from DXA) were used in regression models to predict mean differences of the various BIA methods compared with DXA. The slopes from these functions were examined whether they were different from zero.

Participants were grouped into tertiles of their waist circumference (men and women separately). Simple analysis of variance, including Bonferroni *post hoc* test, was used to investigate whether waist circumference was associated with FFM prediction bias of HHBIA.

Results

In all, 98 participants were included in the present analysis. The characteristics of the study subjects can be seen in Table 2.

In Table 3 FFM of the participants according to various measurements can be seen. The correlations (adjusted r^2) between the methods were very high, that is, >0.9; however, mean differences compared with DXA were quite variable, with the highest difference observed with the Deurenberg equation. The standard deviations of the biases ranged from 2.6 to 3.3 kg. The limits of agreement of the BIA methods were between 9.9 and 12.9 kg (Figures 1a–e).

Table 3 Lean body mass of the participants according to various measurements

Body composition methods	*Adjusted r2*	*Lean body mass (kg)* *Mean* ± *s.d.*	*Mean difference compared with DXA* *Mean* ± *s.d.*
DXA		48.4 ± 10.3	
CBIA	0.968	51.5 ± 13.0	3.3 ± 3.3
HHBIA	0.928	50.6 ± 11.4	2.5 ± 3.3
Segal	0.942	50.7 ± 10.6	2.5 ± 2.5
Deurenberg	0.919	43.3 ± 10.6	−4.9 ± 3.0
IPQ	0.948	48.3 ± 8.9	0.0 ± 2.6

Abbreviations: CBIA, conventional bioelectrical impedance analysis; DXA, dual energy X-ray absorptiometry; HHBIA, hand-held bioelectrical impedance analysis; IPQ, IceProQualita.

The mean bias between HHBIA and DXA was not significantly different between the tertiles of waist

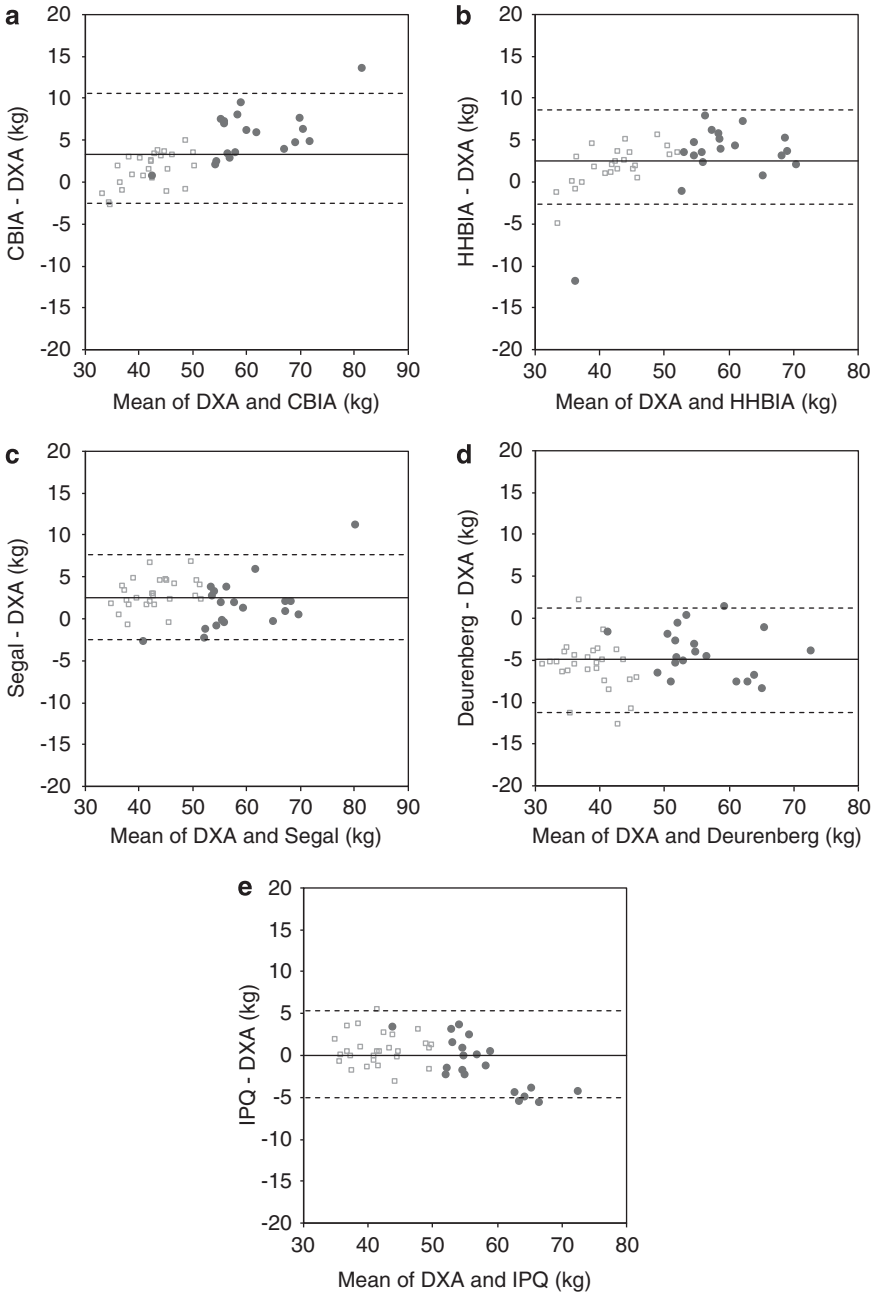

Figure 1 (**a**–**e**) Bland–Altman plots comparing various FFM measurements to DXA. The plain lines show mean differences between methods, the dotted lines represent the limits of agreement (mean difference ± 1.96 × s.d.). ● = men, □ = women.

circumference: T1 (85.6 ± 10.8 cm) = 1.11 ± 4.75; T2 (99.1 ± 8.9 cm) = 3.61 ± 2.80; T3 (114.1 ± 10.9 cm) = 3.37 ± 2.24.

Discussion

In the present study, we measured FFM in Icelandic elderly using HHBIA and CBIA and compared these estimates with results from DXA. There were two main focuses, that is, (1) to investigate how HHBIA compares with CBIA and DXA and (2) how a population-specific prediction equation compares with company-specific equations. In addition to the company-specific equations used by the BIA devices, we also used two equations previously described in literature, that is, from Segal *et al*. (1988) and Deurenberg *et al*. (1990) The Segal equation was originally validated against densitometry in the general population (1567 adults aged 17–62 years). The Deurenberg equation was evaluated in elderly (35 healthy

men and 37 healthy women, aged 60–83 years) also against densitometry.

The correlations between the BIA estimates and DXA were very high; however, this does not mean the different methods yielded similar results. Mean FFM according to the Deurenberg equations was approximately 5 kg below the DXA estimates. Other authors have reported a similar bias (Lupoli *et al*., 2004). Both the equation by Segal and HHBIA overestimated FFM by 2.5 kg, CBIA by 3.3 kg, but the bias of the IPQ equation was below 0.1 kg. It has to be emphasized that the development and the validation of the IPQ equation were not done in the same participants. However, participants used in the development and validation were similar in age, body fatness and gender, and of the same ethnicity, which can explain the small mean difference between DXA and IPQ. Several factors can influence the different reliability of the BIA equations in FFM estimation as the variables used and the characteristics of the samples from which the formulas are derived (Lupoli *et al*., 2004). A prediction formula developed on one ethnic or age group may not be accurate when applied to another ethnic or age group. Again, this highlights the potential population specificity of developed descriptive body composition methods (Heymsfield *et al*., 2000).

The limits of agreement ranged from 9.9 (Segal) to 12.9 kg (HHBIA), which does not seem to be clinically acceptable. The similar limits of agreement of different BIA methods (also reported by others, for example, Nunez *et al*., 1997; Janssen *et al*., 2000; Lukaski and Siders, 2003) indicate that this wide limits are a principal limitation of BIA analysis in FFM prediction.

Lukaski and Siders (2003) have tested an Omron HBF 301 impedance meter (Omron Body Fat Analyzer HBF-301, Vernon Hills, IL, USA) with hand electrodes and compared with DXA measurements in participants 20–60 years old. The HBF 301 underestimated fat tissue mass percentage by 6.3 points in women and by 2.3 points in men. Estimated from Figure 3 in their article limits of agreement were ~20% body fat, which translates into ~15 kg (assuming body weight of 78 kg according to Table 2 in their publication). They found decreasing body fat % with increasing body fat content. The bias was attributed to hand electrodes that require voluntary squeezing of the grips, which may be variable and dissymmetric (Jaffrin, 2009).

The use of regional impedance measurements to predict whole-body composition has been questioned, because regional measurement assumes that conductor volume is equally distributed in the upper and lower body and that regional impedance reflects whole-body impedance (Baumgartner *et al*., 1989), which might not be the case easily visualized by the exemplified apple and pear body fat distributions. However, in our study, body fat distribution, determined as waist circumference with a range of 87.0–131.5 cm and 69.4–138.9 cm in men and women, respectively, was not associated to HHBIA bias.

In the present analysis, we used DXA as gold standard. DXA assumes a constant hydration of the FFM, whereas in the elderly, this value may change (Lupoli *et al*., 2004). However, methods like underwater weighing were not available in this work, and in addition thereto, underwater weighing is not feasibile in elderly subjects. In the present study, we did not measure within-day or between-day variability of regional BIA. However, Nunez *et al*. (1997) reported a within-day variability of about 1% and a between-day variability of 2.1% in determining impedance, using a regional BIA device (foot-to-foot), which seems acceptable.

In elderly Icelandic subjects, HHBIA and CBIA produce similar FFM estimates when using company-specific prediction equations. CBIA provides the additional possibility to use other, population-specific prediction equations. The FFM prediction using a population-specific equation yields best results. However, limits of agreement were wide and similar of all employed BIA methods, which indicates principal limitations of BIA analysis in the determination of FFM.

Conflict of interest

The authors declare no conflict of interest.

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