

## Cross-calibration of eight-polar bioelectrical impedance analysis versus dual-energy X-ray absorptiometry for the assessment of total and appendicular body composition in healthy subjects aged 21–82 years

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**Summary.** *Aim:* To calibrate eight-polar bioelectrical impedance analysis (BIA) against dual-energy X-ray absorptiometry (DXA) for the assessment of total and appendicular body composition in healthy adults.

*Research design:* A cross-sectional study was carried out.

*Subjects:* Sixty-eight females and 42 males aged 21–82 years participated in the study.

*Methods:* Whole-body fat-free mass (FFM) and appendicular lean tissue mass (LTM) were measured by DXA; resistance (*R*) of arms, trunk and legs was measured by eight-polar BIA at frequencies of 5, 50, 250 and 500 kHz; whole-body resistance was calculated as the sum *R* of arms, trunk and legs.

*Results:* The resistance index (RI), i.e. the height<sup>2</sup>/resistance ratio, was the best predictor of FFM and appendicular LTM. As compared with weight (Wt), RI at 500 kHz explained 35% more variance of FFM ( $R_{\text{adj}}^2 = 0.92$  vs 0.57), 45% more variance of LTM<sub>arm</sub> ( $R_{\text{adj}}^2 = 0.93$  vs 0.48) and 36% more variance of LTM<sub>leg</sub> ( $R_{\text{adj}}^2 = 0.86$  vs 0.50) ( $p < 0.0001$  for all). The contribution of age to the unexplained variance of FFM and appendicular LTM was nil or negligible and the RI × sex interactions were either not significant or not important on practical grounds. The percent root mean square error of the estimate was 6% for FFM and 8% for LTM<sub>arm</sub> and LTM<sub>leg</sub>.

*Conclusion:* Eight-polar BIA offers accurate estimates of total and appendicular body composition. The attractive hypothesis that eight-polar BIA is influenced minimally by age and sex should be tested on larger samples including younger individuals.

### 1. Introduction

Sarcopenia, i.e. a decrease in skeletal muscle mass (SMM) and strength, is a common feature of ageing (Roubenoff 2000). Sarcopenia may impair the ability of the body to cope with stress and disease and contribute to morbidity and mortality in the elderly (Dutta 1997). However, the prevalence of sarcopenia is not known and this is of obstacle to the understanding of its prognostic significance (Dutta 1997).

The reference methods for the assessment of SMM are computed tomography (CT) and magnetic resonance imaging (MRI) (Lukaski 1996). Dual-energy X-ray absorptiometry (DXA) compares well with CT and MRI and has been proposed for the assessment of SMM owing to its lower cost and higher availability (Fuller *et al.* 1999a, 2002, Visser *et al.* 1999, Wang *et al.* 1999a; Elia *et al.* 2000, Levine 2000, Shih *et al.* 2000). The three-compartment DXA model separates body mass into fat mass (FM), lean tissue mass (LTM) and bone mineral content (BMC), with the sum of LTM and BMC representing fat-free mass (FFM) (Pietrobelli *et al.* 1996). At the appendicular level, LTM is synonymous with SMM so that DXA provides a simple means of estimating SMM (Wang *et al.* 1999a). A limitation of DXA is, however,

that different densitometers and software versions give different estimates of body composition (Lohman 1996).

CT, MRI and DXA cannot be employed for population studies, mainly because of logistical problems. Segmental bioelectrical impedance analysis (BIA) offers a simple means of estimating appendicular LTM and is probably the best candidate for the assessment of SMM at the population level (Chumlea *et al.* 1995, Heymsfield *et al.* 2000). Calibration studies of BIA versus DXA have shown that four-polar BIA gives accurate estimates of appendicular LTM or FFM in adult subjects (Heymsfield *et al.* 1998, Pietrobelli *et al.* 1998, Fuller *et al.* 1999b, Nunez *et al.* 1999, Elia *et al.* 2000, Lukaski 2000, Tagliabue *et al.* 2000). However, while four-polar whole-body BIA has undergone many calibration studies in the elderly (Steen *et al.* 1987, Deurenberg *et al.* 1990, Brodowicz *et al.* 1994, Visser *et al.* 1995, Fuller *et al.* 1996, Roubenoff *et al.* 1997, Vache *et al.* 1998, Bussolotto *et al.* 1999, Hansen *et al.* 1999, Dittmar and Reber 2001, Genton *et al.* 2001, Kyle *et al.* 2001), segmental BIA has not undergone a systematic evaluation. Pietrobelli *et al.* (1998) found, however, that age influences the estimate of LTM obtained from segmental four-polar BIA. This is not completely unexpected because BIA, like other indirect techniques, relies on assumptions that are partly age-dependent (Heymsfield *et al.* 2000). Another problem is whether anthropometry, and especially body weight (Wt), contributes more than BIA to the estimate of body composition. In a recent study using four-polar BIA at 50 kHz, we have found, for instance, that BIA was not superior to Wt in assessing total and leg FFM in anorexic women (Bedogni *et al.*, in press). Use of frequencies > 50 kHz may, however, improve the estimate of total and appendicular body composition from BIA because of better penetration of the electrical current into intracellular water and thus muscle cells (Wang *et al.* 1999b; Deurenberg *et al.* 2002).

Recently, an eight-polar impedance meter has been made available on the market (InBody 3.0, Biospace, Seoul, Korea). We found this method attractive for three reasons: (1) the use of very practical tactile electrodes for measuring segmental resistances at multiple frequencies, (2) the absence of need to standardize the subject's posture before BIA, and (3) the rapidity of measurement. These characteristics have the potential to reduce measurement times as compared with four-polar BIA and make this instrument ideal for epidemiological studies (Bedogni *et al.* 2002). The present study aimed at calibrating eight-polar BIA versus DXA in a sample of healthy subjects aged 21–82 years.

## 2. Materials and methods

### 2.1. Subjects

Eligible for the study were white Caucasian subjects of both sexes fulfilling the following criteria: (1) age  $\geq 18$  years; (2) body mass index (BMI)  $\geq 18.5 \text{ kg m}^{-2}$ ; (3) absence of chronic (e.g. diabetes) and acute (e.g. influenza) disease, as determined by clinical history and physical examination; (4) menstrual cycle between the 6th and 10th day for fertile women; (5) no use of drugs known to interfere with body water homeostasis. Subjects aged  $\leq 50$  years were recruited mainly among the personnel working at the Departments of Biomedical Sciences and Geriatrics and those aged > 50 years among the subjects visited at the Outpatient Clinic of the Department of Geriatrics. The study procedures had been approved by the local Ethical Committee and all subjects gave informed consent.

### 2.2. Anthropometry

All anthropometric measurements were performed by the same operator following the *Anthropometric Standardization Reference Manual* (Lohman *et al.* 1988). Weight (Wt) was measured to the nearest 100 g and height (Ht) to the nearest 0.1 cm using an electronic balance with an incorporated stadiometer (Tanita, Tokyo, Japan). BMI was calculated as  $Wt \text{ (kg)}/Ht \text{ (m)}^2$ .

### 2.3. Eight-polar BIA

Resistance ( $R$ ) of arms, trunk and legs was measured in fasting conditions ( $\geq 8$  h) at frequencies of 5, 50, 250 and 500 kHz with an eight-polar tactile-electrode impedance meter (InBody 3.0, Biospace, Seoul, Korea). This instrument makes use of eight tactile electrodes: two are in contact with the palm (E1, E3) and thumb (E2, E4) of each hand and two with the anterior (E5, E7) and posterior aspects (E6, E8) of the sole of each foot (figure 1).

The subject stands with his soles in contact with the foot electrodes and grabs the hand electrodes. The sequence of measurements, controlled by a microprocessor, proceeds as follows. An alternating current (a.c.) of  $250 \mu\text{A}$  of intensity ( $I$ ) is applied between E1 and E5. The recorded voltage difference ( $V$ ) between E2 and E4 is divided for  $I$  to obtain the resistance of right arm ( $R_{RA}$ ). The same operation is performed with  $V$  recorded between E4 and E8 to obtain trunk resistance ( $R_T$ ) and

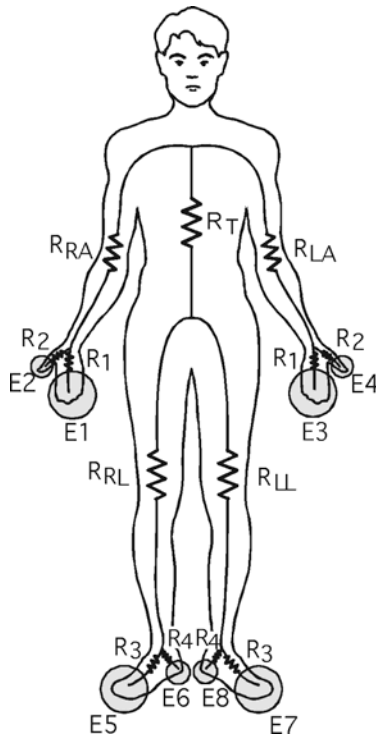


Figure 1. Measurement pathways of InBody 3.0 (graph reproduced with permission of Biospace). The subject stands with her or his soles in contact with the foot electrodes and grabs the hand electrodes. Abbreviations:  $R_{RA}$ , resistance of right arm;  $R_T$ , resistance of trunk;  $R_{LA}$ , resistance of left arm;  $R_{RL}$ , resistance of right leg;  $R_{LL}$ , resistance of left leg. See text for details.

with  $V$  recorded between E6 and E8 to obtain the resistance of right leg ( $R_{RL}$ ). The a.c. is then applied between E3 and E7 and the value of  $V$  measured between E2 and E4 is used to calculate the resistance of left arm ( $R_{LA}$ ). Lastly, the value of  $V$  measured between E6 and E8 is used to calculate the resistance of left leg ( $R_{LL}$ ). No caution was taken to standardize the subject's posture before BIA, as suggested by the manufacturer. Segmental RI were calculated as  $Ht \text{ (cm)}^2/R_x \text{ (}\Omega\text{)}$ , where  $R_x$  is the resistance of arm or leg at frequency  $x$ . Whole-body resistance ( $R_{\text{sum}x}$ ) was calculated as the sum of segmental  $R_x$  (right arm + left arm + trunk + right leg + left leg). The whole-body resistance index ( $RI_{\text{sum}x}$ ) was calculated as  $Ht \text{ (cm)}^2/R_{\text{sum}x} \text{ (}\Omega\text{)}$ . The between-day precision of InBody 3.0, determined by three daily measurements of two subjects for five consecutive days, was  $\leq 2.7\%$  ( $\leq 5 \Omega$ ); within-day precision was always  $\leq 2.0$  ( $\leq 3 \Omega$ ).

#### 2.4. DXA

DXA scans were performed by the same operator using a Lunar DPX-L densitometer and adult software version 3.6 (Lunar Corporation, Madison, WI, USA). The precision of FFM and BMC assessment, as determined by three repeated weekly measurements on three subjects, was 2.5 and 1.0%, respectively. The precision of appendicular LTM assessment was  $\leq 2.5\%$ . The difference between body mass measured by DXA and Wt measured by scale was  $-1 \pm 1$  kg. In spite of its statistical significance ( $p < 0.0001$ , paired  $t$ -test), this difference is of no practical relevance.

#### 2.5. Statistical analysis

Sample size was determined by considering that a sample of 55 subjects has a power of 0.80 to detect a slope of 0.90 at an alpha level of 0.05 when the SD of  $Y$  (FFM) is 11 kg and that of  $X$  ( $RI_{500}$ ) is  $5 \Omega$ . We enrolled 110 ( $55 \times 2$ ) subjects aiming at developing BIA algorithms and cross-validating them on an equal number of subjects. Between-sex comparisons were performed by unpaired  $t$ -tests. The study hypothesis was tested using a general linear model (GLM) with FFM or appendicular LTM as the dependent variable and the corresponding  $RI_x$  as the predictor variable. An interaction term between  $RI_x$  and sex was added to test the influence of sex on this relationship. The adjusted determination coefficient ( $R_{\text{adj}}^2$ ), the root mean square error (RMSE) and the percent root mean square error ( $\text{RMSE}\% = \text{RMSE}/\text{mean value of } Y$ ) obtained from linear regression of FFM or LTM versus  $RI_x$  were used to determine the accuracy of BIA (Guo *et al.* 1996). The same approach was used with Wt, Ht and  $R_x$ . Statistical significance was set to a value of  $p < 0.05$  for all tests. Statistical analysis was performed on a MacOS computer using the Statview 5.1 and SuperANOVA 1.11 software packages (SAS, Cary, NC, USA).

### 3. Results

#### 3.1. Characteristics of the subjects

The measurements of the 110 subjects are given in table 1. The high female:male ratio (1.6) is explained mainly by the higher probability that we had of finding women rather men not using diuretics over 60 years of age. The mean age was 54 years (range: 21–82 years) and there was no difference between sexes ( $p = 0.786$ ). Sixty-one subjects had  $< 50$  years of age and 49 were aged  $\geq 50$  years. Of these latter, 20 were aged  $\geq 70$  years. Wt and Ht were higher in men than women ( $p < 0.0001$ ) but BMI was similar ( $p = 0.537$ ). BMI was between 18.5 and  $33.8 \text{ kg m}^{-2}$  in females and between 19.8 and  $31.2 \text{ kg m}^{-2}$  in males. As expected, FFM and appendicular LTM

Table 1. Anthropometry and body composition of the study subjects. Data are given as means and SD.

	Males	Females
<i>n</i>	42	68
Age (years)	54 ± 15	53 ± 17
Wt (kg)	75.4 ± 9.7*	64.6 ± 10.0
Ht (m)	1.73 ± 0.07*	1.61 ± 0.08
BMI (kg m <sup>-2</sup> )	25.3 ± 3.9	24.9 ± 3.6
FFM (kg)	58.3 ± 7.6*	41.6 ± 4.9
LTM <sub>arm</sub> (kg)†	3.0 ± 0.6*	1.9 ± 0.3
LTM <sub>leg</sub> (kg)†	9.1 ± 1.4*	6.5 ± 1.0

\* $p < 0.0001$  versus females.

† Mean of left and right sides.

Abbreviations: Wt, weight; Ht, height; BMI, body mass index; FFM, fat-free mass; LTM, lean tissue mass.

Table 2. Resistance measurements of the study subjects. Data are given as means and SD.  $R_x$  = resistance at  $x$  kHz.

	Whole body†		Arm‡		Leg‡	
	Males*	Females	Males*	Females	Males*	Females
$R_5$	1193 ± 108	1394 ± 137	328 ± 31	398 ± 44	269 ± 30	299 ± 32
$R_{50}$	1043 ± 95	1236 ± 126	285 ± 27	351 ± 40	236 ± 26	267 ± 29
$R_{250}$	937 ± 92	1119 ± 115	256 ± 26	318 ± 37	212 ± 25	242 ± 27
$R_{500}$	906 ± 90	1084 ± 112	247 ± 25	307 ± 36	206 ± 25	235 ± 26

\* $p < 0.0001$  versus females for all values of  $R$ .

† Sum of segmental resistances (arms, trunk and legs).

‡ Mean of left and right sides.

were higher in men than women ( $p < 0.0001$ ).  $R$  was significantly lower in men than women at all frequencies because of their higher total body water (TBW) (table 2).

### 3.2. Accuracy of eight-polar BIA in the assessment of FFM

The variance of FFM explained by Wt, Ht,  $R_{\text{sum},x}$  and  $\text{RI}_{\text{sum},x}$  is given in table 3.  $\text{RI}_{\text{sum},x}$  was the best predictor of FFM and there was an increase of 2% in the explained variance of FFM from 5 to 500 kHz.  $\text{RI}_{\text{sum}500}$  explained 35% more variance of FFM than Wt and 23% more variance than Ht. The RMSE% associated with the prediction of FFM from  $\text{RI}_{\text{sum}500}$  (6%) was also substantially lower than that associated with the prediction from Wt (14%) and Ht (12%). The Wt × sex ( $p = 0.002$ ), Ht × sex ( $p = 0.0001$ ) and  $R_{\text{sum}500} \times \text{sex}$  ( $p = 0.0001$ ) interactions were significant but  $\text{RI}_{\text{sum}500} \times \text{sex}$  was not ( $p = 0.410$ ). Thus, we modelled the predictive algorithm independently of sex, as we had previously done for TBW (Bedogni *et al.* 2002). Age did not contribute to the unexplained variance of FFM ( $R_{\text{adj}}^2 = 0.003$ ,  $p = 0.257$ ) and the contribution of Wt was low ( $R_{\text{adj}}^2 = 0.06$ ,  $p = 0.004$ ). Adding Wt as predictor with RI did not improve the accuracy of the estimate (RMSE% = 6%).

### 3.3. Accuracy of eight-polar BIA in the assessment of LTM<sub>arm</sub>

The variance of mean LTM<sub>arm</sub> explained by Wt, Ht, mean  $R_{\text{arm},x}$  and mean  $\text{RI}_{\text{arm},x}$  is given in table 3. We used the mean values of LTM<sub>arm</sub> and  $\text{RI}_{\text{arm},x}$  because there was no significant  $\text{RI}_{\text{arm},x} \times \text{hemisphere}$  interaction ( $p = 0.07$ ). Mean  $\text{RI}_{\text{arm},x}$  was the

Table 3. Accuracy of eight-polar BIA in estimating fat-free mass and appendicular lean tissue mass.

	FFM		LTM <sub>arm</sub>		LTM <sub>leg</sub>	
	$R_{adj}^2$ *	RMSE%	$R_{adj}^2$ *	RMSE%	$R_{adj}^2$ *	RMSE%
Wt	0.57	14	0.48	22	0.50	16
Ht	0.69	12	0.62	19	0.73	12
$R_5$	0.52	15	0.56	20	0.36	18
$R_{50}$	0.56	14	0.57	20	0.45	17
$R_{250}$	0.58	14	0.59	19	0.48	16
$R_{500}$	0.59	14	0.60	19	0.49	16
RI <sub>5</sub>	0.90	7	0.91	9	0.79	10
RI <sub>50</sub>	0.92	6	0.92	9	0.84	9
RI <sub>250</sub>	0.92	6	0.91	9	0.86	9
RI <sub>500</sub>	0.92	6	0.93	8	0.86	8

\* $p < 0.0001$  for all values of  $R_{adj}^2$ .

Abbreviations: FFM, fat-free mass; LTM, lean tissue mass;  $R_{adj}^2$ , adjusted coefficient of determination; RMSE%, percent root mean square error; Wt, weight; Ht, height;  $R_x$ , resistance at  $x$  kHz; RI <sub>$x$</sub> , resistance index at  $x$  kHz.

best predictor of mean LTM<sub>arm</sub> and there was an increase of 2% in the explained variance of mean LTM<sub>arm</sub> from 5 to 500 kHz. Mean RI<sub>arm500</sub> explained 45% more variance of mean LTM<sub>arm</sub> than Wt and 31% more variance than Ht. The RMSE% associated with the prediction of mean LTM<sub>arm</sub> from mean RI<sub>arm500</sub> (8%) was also substantially lower than that associated with the prediction from Wt (22%) and Ht (19%). All the  $X \times \text{sex}$  interactions were significant (Ht  $\times$  sex,  $p = 0.0001$ ;  $R_{500} \times \text{sex}$ ,  $p = 0.0001$ ; Wt  $\times$  sex,  $p = 0.034$  and RI<sub>arm500</sub>  $\times$  sex,  $p = 0.004$ ). Adding sex and RI<sub>500</sub>  $\times$  sex as predictors did not, however, improve the accuracy of the RI<sub>arm500</sub> (RMSE% = 8%). Thus, we modelled the predictive algorithm independently of sex. Age explained only a minimal portion of residual LTM<sub>arm</sub> ( $R_{adj}^2 = 0.04$ ,  $p = 0.024$ ) and Wt no portion at all ( $R_{adj}^2 = 0.006$ ,  $p = 0.431$ ). Adding age as predictor with RI did not improve the accuracy of the estimate (RMSE% = 8%).

#### 3.4. Accuracy of BIA in the assessment of LTM<sub>leg</sub>

The variance of LTM<sub>leg</sub> explained by Wt, Ht,  $R_{legx}$  and RI<sub>legx</sub> is given in table 3. We used the mean values of FFM<sub>leg</sub> and RI<sub>legx</sub> because there was no significant RI<sub>legx</sub>  $\times$  hemisphere interaction ( $p = 0.502$ ). Mean RI<sub>legx</sub> was the best predictor of mean FFM<sub>leg</sub> and there was an increase of 7% in the explained variance of FFM<sub>leg</sub> from 5 to 500 kHz. RI<sub>leg500</sub> explained 36% more variance of FFM<sub>leg</sub> than Wt and 13% more variance than Ht. The RMSE% associated with the prediction of mean LTM<sub>leg</sub> from mean RI<sub>leg500</sub> (8%) was also lower than that associated with the prediction from Wt (16%) and Ht (12%). The Wt  $\times$  sex ( $p = 0.020$ ), Ht  $\times$  sex ( $p = 0.0001$ ) and  $R_{500} \times \text{sex}$  ( $p = 0.002$ ) interactions were significant but RI<sub>leg500</sub>  $\times$  sex was not ( $p = 0.408$ ). Thus, we modelled the predictive algorithm independently of sex. Age explained no portion of residual LTM<sub>leg</sub> ( $R_{adj}^2 = 0.002$ ,  $p = 0.263$ ) and Wt explained only a minimal portion of it ( $R_{adj}^2 = 0.03$ ,  $p < 0.388$ ). Adding Wt as predictor with RI did not improve the accuracy of the estimate (RMSE% = 8%).

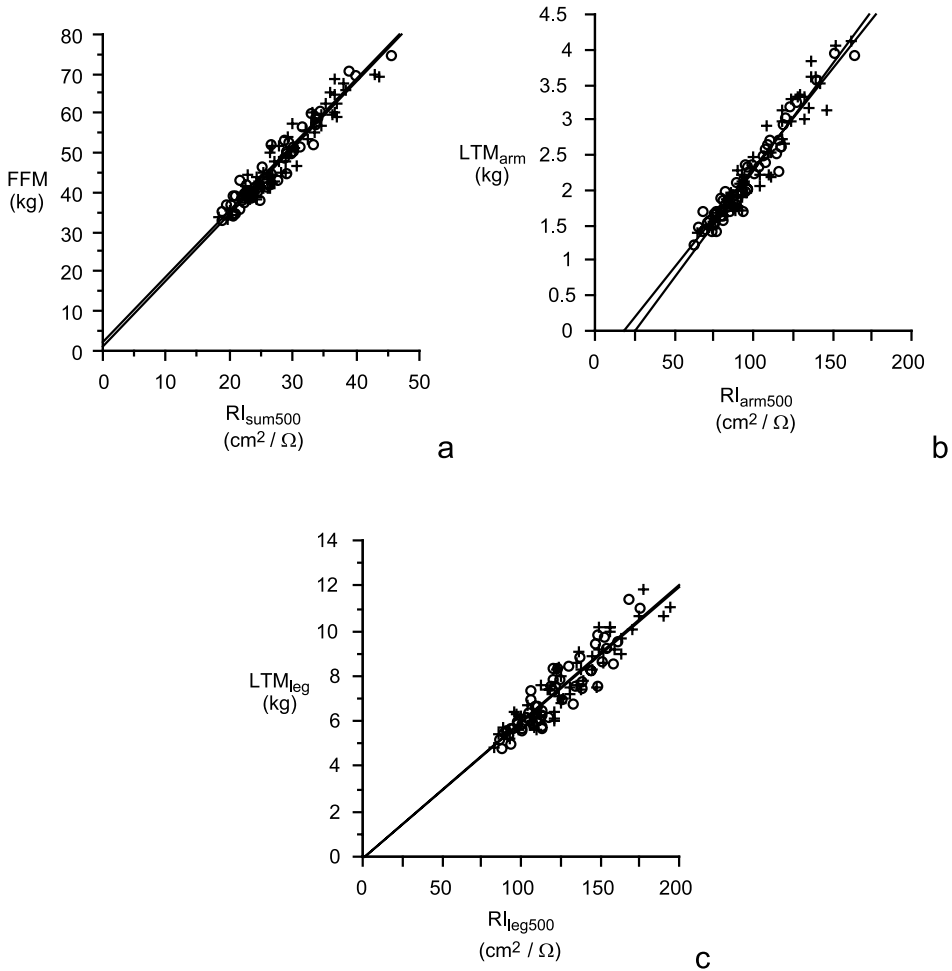


Figure 2. Relationship between fat-free mass (a), arm lean tissue mass (b), leg lean tissue mass (c) and the resistance index at 500 kHz in two random subsamples of 55 subjects each (marked with open circles and plus signs). Slopes and intercepts did not differ between the two samples. Abbreviations: FFM, fat-free mass; LTM, lean tissue mass; RI, resistance index at 500 kHz.

### 3.5. BIA algorithms

To develop BIA algorithms for the prediction of FFM and appendicular LTM, we randomly split the study sample in two halves. The regression lines of the FFM–RI and LTM–RI relationships obtained in the first half ( $n = 55$ ) were compared with those obtained in the second half ( $n = 55$ ) (figure 2).

Because the slopes and intercepts were similar, the two halves were pooled together and common algorithms were developed (table 4). The RMSE% was 6% for FFM and 8% for both  $LTM_{arm}$  and  $LTM_{leg}$ .

## 4. Discussion

In this study, we cross-calibrated eight-polar BIA against DXA for the assessment of FFM and appendicular LTM in healthy subjects.

Table 4. Prediction of fat-free mass and appendicular lean tissue mass from eight-polar BIA.

Y	X	$a_0$	$a_1$	$R_{adj}^2$	RMSE kg (%)	Y by DXA (kg)	Y by BIA (kg)	DY (BIA – DXA) (kg)
FFM	RI <sub>sum500</sub>	2.4	1.6	0.92	2.80 (6)	48.0 ± 10.1	48.0 ± 9.7	0.0 ± 2.8
LTM <sub>arm</sub>	RI <sub>arm500</sub>	-0.6	0.03	0.93	0.18 (8)	2.3 ± 0.7	2.3 ± 0.7	0.0 ± 0.2
LTM <sub>leg</sub>	RI <sub>leg500</sub>	-0.06	0.06	0.86	0.63 (8)	7.5 ± 1.7	7.5 ± 1.6	0.0 ± 0.6

Abbreviations:  $a_0$ , intercept;  $a_1$ , slope;  $R_{adj}^2$ , adjusted coefficient of determination; RMSE, root mean square error; BIA, bioelectrical impedance analysis; DXA, dual-energy X-ray absorptiometry; FFM, fat-free mass; LTM, lean tissue mass; RI<sub>x</sub>, resistance index at x kHz; sum, sum of segmental resistances (arms, trunk and legs).

Eight-polar BIA was consistently superior to Wt in estimating FFM and appendicular LTM. In our studies of four-polar BIA, we have sometimes found Wt to be better than RI in estimating body composition (Bedogni *et al.* 1997, in press, Scalfi *et al.* 1997). Moreover, it is not uncommon for Wt to explain most of the variance of body compartments when employed as a predictor with RI (Bedogni *et al.*, in press). In the present study, however, RI was substantially better than Wt in estimating body composition. Even more important, Wt did not contribute or contributed very little to residual FFM and LTM ( $R_{adj}^2 \leq 0.06$ ). This may be a merit of eight-polar BIA but in order to establish this with certainty a direct comparison with four-polar BIA is needed. Unique characteristics of eight-polar BIA that may contribute to its very low dependency from Wt are: (1) the use of tactile electrodes, avoiding problems connected with adhesive electrodes, (2) the fact that whole-body eight-polar  $R$  is the sum of segmental resistances obtained with a five-cylinder model of the human body (see figure 1), and (3) the insensitivity of eight-polar BIA to subject's posture.

Age did not contribute or contributed very little to the variance of FFM and LTM ( $R_{adj}^2 \leq 0.04$ ). Age is often employed in four-polar BIA algorithms because of an increase in their accuracy (Guo *et al.* 1996). However, this was not observed in this study, performed on subjects aged 21–82 years. Even if a sample including also children and adolescents would be better suited to test the hypothesis of age independence of eight-polar BIA, this evidence is nonetheless interesting and worth of discussion. Age is supposed to enter BIA algorithms as a surrogate marker of bioelectrical properties of the body that change with age (Heymsfield *et al.* 2000). These properties are not well defined but changes in body fat distribution and in the relative proportions of FFM components are likely to play a role. A simple explanation for the apparent age independence of eight-polar BIA may be that with this technique the a.c. transverses both hemisomes as opposed to one hemisome in four-polar BIA. To test this hypothesis more thoroughly, four-polar and eight-polar BIA should be directly compared on a sample of individuals widely differing in age.

The RI<sub>sum500</sub> × sex and RI<sub>leg500</sub> × interactions were not significant and the inclusion of the significant RI<sub>arm500</sub> × sex interaction among predictors did not improve the accuracy of the estimate of LTM<sub>arm</sub> from RI<sub>arm500</sub>. This was observed also in our previous work on TBW (Bedogni *et al.* 2002). Sex is commonly employed in BIA algorithms because it increases the accuracy of the prediction (Guo *et al.* 1996). However, this did not happen in the present study. Sex is supposed to enter BIA predictive algorithms as a surrogate marker of bioelectrical properties of the body that differ with sex. These properties are not well defined but differences in body fat and FFM composition may play a role. Even if it is attractive to speculate



that eight-polar BIA can detect these differences, the limitations of this study should be kept in mind. An acceptable power (i.e. > 80%) for testing the hypothesis of no  $RI \times \text{sex}$  interaction was present only for  $RI_{\text{arm}500} \times \text{sex}$  and a larger sample size is needed to test the hypotheses of no  $RI_{500} \times \text{sex}$  and  $RI_{500\text{leg}} \times \text{sex}$  interaction. However, the decision of including them in a predictive model would depend substantially on the increase in the underlying accuracy.

Higher frequencies were better than lower frequencies in estimating FFM and appendicular LTM from BIA (Pietrobelli *et al.* 1998). As expected by electrical theory, the variance of FFM and appendicular LTM explained by  $R$  increased for increasing frequencies (table 3). This increase was lower when  $R$  was used as the denominator of  $Ht^2$  in the form of  $RI$  because of the already high correlation between  $Ht$ , FFM and appendicular LTM. However, the expected pattern was still present and was especially evident for  $LTM_{\text{leg}}$ .

In conclusion, this study shows that eight-polar BIA is an accurate method for the assessment of FFM and appendicular LTM. The rapidity with which measurements are performed make eight-polar BIA a good candidate for use in epidemiological studies of sarcopenia. The attractive hypothesis that eight-polar BIA is minimally influenced by age and sex should be tested on larger samples including younger individuals.

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**Zusammenfassung.** Ziel: Eichung der Bioelektrischen Impedanzanalyse (BIA) mit 8-Elektroden zur Bestimmung der Körperzusammensetzung des Gesamtkörpers und von Körperabschnitten bei gesunden Erwachsenen mittels Dual-Energy-X-Ray Absorptiometrie (DXA).

*Forschungsdesign:* Querschnittsstudie.

*Probanden:* 68 Frauen und 42 Männer im Alter von 21-82 Jahren.

*Methoden:* Die fettfreie Masse (FFM) des Gesamtkörpers und die Magermasse (LTM) von Körperabschnitten wurden mittels Dual-Energy-X-Ray Absorptiometrie (DXA) bestimmt; die Resistance (R) der Arme, des Rumpfes und der Beine wurde mittels 8-Elektroden BIA bei Frequenzen von 5, 50, 250 und 500 kHz gemessen; zur Bestimmung des Ganzkörperwiderstandes wurden die R-Werte der Arme, des Rumpfes und der Beine summiert.

*Ergebnisse:* der Resistance Index (RI), d.h. die Körperhöhe<sup>2</sup>/Resistance, war der beste Prädiktor der FFM und der LTM von Körperabschnitten. Im Vergleich zum Gewicht (Wt), erklärte der RI bei 500 kHz 35% mehr Varianz bei der FFM ( $R_{\text{adj}}^2 = 0.92$  vs 0.57), 45% mehr Varianz bei der LTM<sub>Arm</sub> ( $R_{\text{adj}}^2 = 0.93$  vs 0.48) und 36% mehr Varianz bei der LTM<sub>Bein</sub> ( $R_{\text{adj}}^2 = 0.86$  vs 0.50) ( $p < 0.0001$  für alle). Das Alters trug nicht oder nur unwesentlich zur unerklärten Varianz der FFM und der LTM der Körperabschnitte bei. Die Interaktionen zwischen RI und Geschlecht waren entweder nicht signifikant oder aus praktischer Sicht unwesentlich. Der prozentuale Mittlere Quadratwurzel Fehler der Schätzung betrug 6% für die FFM und 8% für die LTM<sub>Arm</sub> und die LTM<sub>Bein</sub>.

*Zusammenfassung:* BIA mit 8 Elektroden ermöglicht eine genaue Bestimmung der Körperzusammensetzung des Gesamtkörpers und von Körperabschnitten. Die interessante Hypothese, dass die BIA mit 8 Elektroden minimal durch Alter und Geschlecht beeinflusst wird, sollte durch größere Stichproben, welche jüngere Individuen einschließen, geprüft werden.

**Résumé.** But: Calibrer une analyse d'impédance bioélectrique 8-polaire (AIB) par l'absorptiométrie de rayons X d'énergie double (AXD) afin de rendre compte de la composition corporelle totale et appendiculaire d'adultes en bonne santé.

*Matériel et méthode:* étude transversale sur 68 femmes et 42 hommes âgés de 21 à 82 ans. La masse maigre totale MMT et la masse maigre appendiculaire MMA sont mesurées par AXD, la résistance (R) des bras, du tronc et des jambes sont mesurés par AIB à des fréquences de 5, 20, 250 et 500 kHz; la résistance corporelle totale est calculée comme la somme de R des bras du tronc et des jambes

*Résultats:* l'indice de résistance (IR), soit le rapport stature/résistance, est le meilleur prédicateur de la MMT et de la MMA. L'IR à 500 kHz explique 35% de plus de la variance de la MMT que le poids ( $R_{\text{adj}}^2 = 0.92$  contre 0,57), 45% de plus de la variance de la MMA<sub>bras</sub> ( $R_{\text{adj}}^2 = 0,93$  contre 0,48) et 36% de plus de la variance de la MMA<sub>jambe</sub> ( $R_{\text{adj}}^2 = 0,86$  contre 0,50) ( $p < 0,0001$  pour tous). La contribution de l'âge à la variance inexplicée de la MMT et de la MMA est nulle ou négligeable et les interactions sexe-IR sont soit non significatives ou bien sans importance pratique. Le pourcentage d'erreur d'estimation par la racine du carré moyen est de 6% pour la MMT et 8% pour la MMA<sub>bras</sub> et pour la MMA<sub>jambe</sub>

*Conclusion:* l'AIB 8-polaire produit des estimations précises de la composition corporelle totale et appendiculaire. L'hypothèse séduisante qui veut que l'AIB serait très peu influencée par l'âge et par le sexe, devrait être éprouvée sur de plus amples échantillons incorporant de jeunes individus.

**Resumen.** *Objetivo:* calibrar un análisis de impedancia bioeléctrica (BIA) 8-polar frente a la absorciometría fotónica dual por rayos X (DXA), para estimar la composición corporal total y de las extremidades en adultos sanos.

*Diseño de la investigación:* estudio transversal.

*Sujetos:* 68 mujeres y 42 hombres de 21 a 82 años de edad.

*Métodos:* se midieron la masa libre de grasa de todo el cuerpo (FFM) y la masa tisular magra de las extremidades (LTM) mediante absorciometría fotónica dual por rayos X; se midió la resistencia (R) de los brazos, tronco y piernas mediante BIA 8-polar a las frecuencias de 5, 50, 250 y 500 kHz; se calculó la resistencia corporal total como la suma de R de los brazos, del tronco y de las piernas.

*Resultados:* el índice de resistencia (RI), pe. el cociente estatura<sup>2</sup>/resistencia, fue el mejor predictor de la FFM y de la LTM de las extremidades. Comparado con el peso (Wt), el RI a 500kHz explicaba un 35% más de varianza de la FFM ( $R_{\text{adj}}^2 = 0,92$  vs. 0,57), un 45% más de varianza de la LTM<sub>arm</sub> ( $R_{\text{adj}}^2 = 0,93$  vs. 0,48) y un 36% más de varianza de la LTM<sub>leg</sub> ( $R_{\text{adj}}^2 = 0,86$  vs 0,50) ( $p < 0,0001$  en todos). La contribución de la edad a la varianza no explicada de la FFM y de la LTM de las extremidades fue nula o despreciable y las interacciones RI\*sexo fueron en cualquier caso no significativas o apenas importantes a efectos prácticos. El porcentaje de error de la raíz cuadrada media de la estima fue del 6% para la FFM y del 8% para la LTM<sub>arm</sub> y la LTM<sub>leg</sub>.

*Conclusión:* el BIA 8-polar proporciona estimas precisas de la composición corporal total y de las extremidades. La atractiva hipótesis de que el BIA 8-polar está mínimamente influenciado por la edad y el sexo debería comprobarse sobre muestras más grandes que incluyesen individuos más jóvenes.

**Resumen.** *Antecedentes:* No se han publicado muchos datos sobre composición corporal en Japoneses–Americanos. Los estudios sobre las diferencias en composición corporal entre Japoneses–Americanos y Japoneses nacionales en diversos estadios de la vida, así como en varios momentos de medición, son útiles para comprender el impacto de los cambios en el estilo de vida sobre la composición corporal en las dos sociedades.

*Objetivo:* Observar las diferencias en tamaño y composición corporal entre adultos jóvenes Japoneses–Americanos y Japoneses nacionales.

*Sujetos y Métodos:* El tamaño la composición corporal de 50 Japoneses–Americanos, 28 hombres y 22 mujeres, con edades comprendidas entre los 18 y 23 años, se compararon con las de Japoneses nacionales de la misma edad y estatura. La composición corporal se midió utilizando el método de pesada bajo el agua (pesada hidrostática). El estudio se realizó en los años 80 en Estados Unidos y Japón.

*Resultados:* el porcentaje medio de grasa corporal de los hombres fue de 13,7%, tanto en Japoneses–Americanos como en Japoneses nacionales, y el de las mujeres fue de aproximadamente el 24% en ambos grupos, si bien los hombres y mujeres Japoneses–Americanos tenían un peso corporal, una masa libre de grasa y un índice de masa corporal significativamente mayores que los Japoneses nacionales.

*Conclusión:* Aunque los adultos jóvenes Japoneses–Americanos mostraban un tamaño corporal mayor que los Japoneses nacionales, su porcentaje de grasa no difería en esta etapa de la vida en los años 80.