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ORIGINAL COMMUNICATION

Comparison of bioelectrical impedance analysis and dual-energy X-ray absorptiometry for the assessment of appendicular body composition in anorexic women

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Objective: To establish the accuracy of bioelectrical impedance analysis (BIA) for the assessment of appendicular body composition in anorexic women.
Design: Cross-sectional study.
Setting: Outpatient University Clinic.
Subjects: A total of 39 anorexic and 25 control women with a mean (s.d.) age of 21 (3) y.
Methods: Total, arm and leg fat-free mass (FFM) were measured by dual-energy X-ray absorptiometry and predicted from total and segmental BIA at 50 kHz. The predictor variable was the resistance index (RI), that is, the ratio of height ^{2} to body resistance for the whole body and the ratio of length^2/limb resistance for the arm and leg.
Results: Predictive equations developed on controls overestimated total, arm and leg FFM in anorexics ($P<0.0001$). Population-specific equations gave a satisfactory estimate of total and appendicular FFM in anorexics ($P=$NS) but had higher percent root mean square errors (RMSEs%) as compared to those developed on controls (8% *vs* 5% for whole body, 12% *vs* 10% for arm and 10% *vs* 8% for leg). The accuracy of the estimate of total and leg FFM in anorexics was improved by adding body weight (Wt) as a predictor with RI (RMSE% = 5% *vs* 8% and 7% *vs* 10%, respectively). However, the same accuracy was obtained using Wt alone, suggesting that in anorexics, BIA at 50 kHz is not superior to Wt for assessing total and leg FFM.
Conclusion: BIA shows some potential for the assessment of appendicular body composition in anorexic women. However, Wt is preferable to BIA at 50 kHz on practical grounds. Further studies should consider whether frequencies >50 kHz give better estimates of appendicular composition in anorexics as compared to Wt.
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Introduction

As changes in appendicular fat and fat-free tissues are typical features of malnutrition, anthropometric measurements of limb composition have long been employed as nutritional and prognostic indicators (Heymsfield *et al*, 1982, 1984). Bioelectrical impedance analysis (BIA) is a simple and noninvasive technique with a high potential for the assessment of limb composition (Brown *et al*, 1988; Heymsfield *et al*, 1998; Pietrobelli *et al*, 1998; Fuller *et al*, 1999a; Nunez *et al*, 1999; Elia *et al*, 2000; Lukaski, 2000; Tagliabue *et al*, 2000). BIA has some theoretical advantages over anthropometry because it involves less training and is generally more reproducible (Deurenberg, 1994). The validation of anthropometry and BIA for the assessment of appendicular body composition has been traditionally performed against computed tomography (CT) and mag-

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netic resonance imaging (MRI) (Brown *et al,* 1988; Fuller *et al,* 1999b; Elia *et al,* 2000). Nevertheless, dual-energy X-ray absorptiometry (DXA) gives accurate estimates of appendicular fat-free tissues as compared to CT and MRI (Fuller *et al,* 1999b; Visser *et al,* 1999; Wang *et al,* 1999a; Elia *et al,* 2000; Levine *et al,* 2000; Shih *et al*, 2000). Since DXA is less invasive and/or more readily available than CT or MRI, it has a great potential for the validation of bedside techniques such as BIA. Previous comparisons of BIA with DXA have shown that BIA gives accurate estimates of appendicular fat-free tissues in healthy and overweight subjects (Brown *et al,* 1988; Heymsfield *et al,* 1998; Pietrobelli *et al,* 1998; Fuller *et al,* 1999a; Nunez *et al,* 1999; Elia *et al,* 2000; Lukaski, 2000; Tagliabue *et al,* 2000). However, no data are available as yet for malnourished subjects. Besides offering a more thorough evaluation of the BIA technique, these data may have prognostic implications such as it has been shown for anthropometry (Heymsfield *et al,* 1982, 1984).

The present study aimed therefore at evaluating the accuracy of BIA as compared to DXA for the assessment of appendicular body composition in a sample of anorexic women.

Materials and methods

Subjects

A total of 35 anorexic women followed as outpatients at the Department of Clinical and Experimental Medicine of Federico II University (Napoli, Italy) were consecutively enrolled in the study (DSM-IV, 1994). The median of AN duration was 37 months (range: 7–180 months). All anorexic women had undergone or were undergoing psychological counseling and none of them was taking oral contraceptives at the time of the study. A number of 29 age-matched healthy women recruited among the members of the medical staff served as controls. All subjects had a stable body weight (Wt) during the month prior to the study (± 1 kg). Controls were measured between the 6th and 10th day of the menstrual cycle. The study protocol was approved by the Ethical Committee at Federico II University and all subjects gave informed consent.

Anthropometry

Wt and height (Ht) were measured by the same operator following the Anthropometric Standardization Reference Manual (Lohman *et al,* 1988). The 50th percentile of Wt for age given by the NCHS anthropometric standards was taken as the ideal body weight (Iwt) of the subjects (Frisancho, 1990). Relative weight (RWt) was then calculated as $\{1-[(\mathrm{Wt}-\mathrm{Iwt})/\mathrm{Iwt}]\}$. Body mass index (BMI) was calculated as $\mathrm{Wt\,(kg)/Ht^2\,(m)}$. Arm length was measured as the distance between the lateral tip of the acromion and a line joining the bony prominences of radius and ulna on the dorsum of the wrist (Organ *et al,* 1994). Leg length was obtained by subtracting sitting height from Ht (Lohman *et al,* 1988). $\mathrm{Lt_{arm}}$ and $\mathrm{Lt_{leg}}$ were calculated as the mean of left and right values.

BIA

The resistance of the whole body (R), arms (R_{arm}) and legs (R_{leg}) was measured by the same operator with a 4-polar impedance-meter (BIA 101, Akern, Firenze, Italy) at a frequency of 50 kHz using the method of Cornish *et al* (1999). Each subject was measured in the fasting state (8 h) and after 15 min in the supine position (Deurenberg, 1994). The coefficient of variation (CV) for BIA measurements was $\leq 2.0\%$ at all sites, as determined by repeated daily measurements of one of the subjects. R_{arm} and R_{leg} were calculated as the mean of left and right values. The resistance index (RI) was calculated as $\mathrm{Ht^2\,(cm)}/R\ (\Omega)$ for the whole body and as $\mathrm{Lt^2\,(cm)}/R\ (\Omega)$ for the arm and leg.

DXA

DXA allows the separation of total and segmental body mass (BM) into fat mass (FM), lean tissue mass (LTM) and bone mineral content (BMC). The sum of LTM and BMC gives fat-free mass (FFM), which was the variable of interest in this study. DXA measurements were performed using a Lunar DPX-L densitometer (Lunar Corporation, Madison, WI, USA, software ver. 3.6). $\mathrm{FFM_{arm}}$ and $\mathrm{FFM_{leg}}$ were calculated as the mean of left and right values. DXA measurements were performed by the same operator. The precision of LTM and BMC assessment, as determined by repeated weekly measurements of one of the subjects, was 2.5 and 1.0%, respectively. The precision of segmental LTM and BMC assessment was ≤ 3.0 and $\leq 2.0\%$, respectively. The difference between BM measured by DXA and Wt measured by scale was -0.2 ± 0.6 kg (mean $\pm$ s.d., corresponding to $-0.4 \pm 1.4\%$ of Wt). In spite of its statistical significance ($P<0.05$, paired *t*-test), this difference is of no practical relevance.

Statistical analysis

Statistical analysis was performed on a MacOS computer using the Statview 5.0.1 and SuperANOVA 1.1 software packages (SAS, Cary, NC, USA). Between-group comparisons were performed by unpaired *t*-tests. The adjusted determination coefficient (R^2_{adj}), the root mean square error (RMSE) and the percent root mean square error (RMSE% = RMSE/measured value of Y) obtained from linear regression of FFM *vs* RI were used to determine the accuracy of BIA. Measured and predicted values of FFM were also compared by paired *t*-tests. Statistical significance was set to a value of $P<0.05$ for all tests.

Results

The measurements of the study subjects are given in Table 1.

Anorexics and controls had a similar age and Ht (P = NS) but Wt, RWt and BMI were significantly lower in the former ($P<0.0001$). FFM was lower in anorexics than controls when expressed as an absolute value ($P<0.0001$) but higher when standardized on Wt ($P<0.0001$). A lower BMC ($P=0.001$) contributed to the lower FFM of anorexics. A lower quantity of FFM was observed also in the arms ($P<0.0001$) and legs ($P<0.0005$) of anorexics as compared to those of controls. R ($P<0.0001$) and R_{arm} ($P<0.0005$) were higher in anorexics while R_{leg} was similar to controls (P = ns). Lt_{arm} and Lt_{leg} did not differ between anorexics and controls (P = ns).

The prediction models obtained by regressing FFM *vs* RI in controls and anorexics are given in Table 2.

RI explained 55, 42 and 36% of the variance of FFM, FFM_{arm} and FFM_{leg}, respectively ($P<0.0001$). The corresponding values of RMSE% were 5, 10 and 8%. When the predictive algorithms generated on controls were applied to anorexics, they overestimated FFM (39.7 ± 2.8 *vs* 36.8 ± 3.9 kg, $P<0.0001$), FFM_{arm} (1.9 ± 0.1 *vs* 1.6 ± 0.2 kg, $P<0.0001$) and FFM_{leg} (7.5 ± 0.6 *vs* 6.8 ± 1.0 kg, $P<0.0001$; paired *t*-test). We decided therefore to develop population-specific equations for anorexics (Table 2). These equations gave satisfactory estimates of FFM, FFM_{arm} and FFM_{leg} (P = ns, paired *t*-test) but had higher RMSE% as compared to those developed on controls (8% *vs* 5% for whole body, 12% *vs* 10% for arm and 10% *vs* 8% for leg).

In controls, the residuals of the FFM–RI regression were not correlated with Wt at the whole-body (P = ns) and leg (P = ns) levels. Wt accounted, however, for 11% of the unexplained variance of FFM_{arm} ($P<0.05$). In anorexics, Wt contributed significantly to the residuals of the FFM–RI regression at all levels (FFM: $R^2_{adj}=0.34$, $P<0.0005$; FFM_{arm}: $R^2_{adj}=0.42$, $P<0.0001$; FFM_{leg}: $R^2_{adj}=0.13$, $P<0.005$).

Use of both RI and Wt as predictors of FFM_{arm} was not associated to any relevant improvement of RMSE% in both controls (8% *vs* 8%) and anorexics (12% *vs* 11%). An improvement was however seen when both RI and Wt were used to predict FFM (from 8 to 5%) and FFM_{leg} (from 10 to 7%) in anorexics (Table 3). However, RI contributed only 43% of the variance contributed by Wt (as determined by comparison of standardized regression coefficients) and the RMSE% values were not different from those obtained by regressing FFM *vs* Wt alone (5 and 7%, respectively). Thus, even if the contribution of RI to total FFM and FFM_{leg} was undoubtedly significant ($P \leq 0.009$), Wt alone may be a superior predictor for practical purposes.

Table 1 Measurements of anorexic and control women (mean ± s.d.)

	Anorexics	*Controls*
n	35	29
Age (y)	21 ± 3	21 ± 3
Wt (kg)	$41.6 \pm 4.4^{***}$	52.8 ± 4.7
RWt (%)	$71 \pm 8^{***}$	91 ± 8
Ht (m)	1.61 ± 0.06	1.58 ± 0.05
BMI (kg/m^2)	$16.0 \pm 1.2^{***}$	21.1 ± 1.8
BMC (kg)	$2.1 \pm 0.3^{*}$	2.3 ± 0.3
FFM (kg)	$36.8 \pm 3.9^{***}$	41.4 ± 3.1
FFM:Wt (%)	$89 \pm 5^{***}$	79 ± 5
FFM_{arm} (kg)	$1.6 \pm 0.2^{***}$	2.0 ± 0.2
FFM_{leg} (kg)	$6.8 \pm 1.0^{**}$	7.7 ± 0.6
R (Ω)	$719 \pm 79^{***}$	640 ± 56
R_{arm} (Ω)	$354 \pm 41^{**}$	317 ± 31
R_{leg} (Ω)	298 ± 42	280 ± 30
Lt_{arm} (cm)	50.0 ± 3.0	51.0 ± 3.0
Lt_{leg} (cm)	65.0 ± 5.0	66.0 ± 4.0

*P=0.001, **$P<0.0005$ and ***$P<0.0001$ *vs* controls.
Abbreviations: Wt, weight; RWt, relative weight; Ht, height; BMI, body mass index; BMC, bone mineral content; FFM, fat-free mass; *R*, resistance; Lt, length. FFM, *R* and Lt of limbs are the mean of left and right values.

Discussion

BIA offers accurate estimates of total body composition in anorexics, but its accuracy for the assessment of appendicular body composition in these subjects is not known (Hannan *et al*, 1990; Scalfi *et al*, 1993, 1997; Polito *et al*, 1998). In the present study, population-specific equations were needed to obtain accurate estimates of total and

Table 2 Relation between FFM and RI in controls and anorexics

	a_0	a_1	R^{2*}_{adj}	*RMSE (kg)*	*RMSE (%)*	*DXA (kg)*	*BIA** (kg)*
FFM–CTRL	18.3	0.6	0.55	2.1	5	41.4 ± 3.1	41.4 ± 2.3
FFM_{arm}–CTRL	1.0	0.1	0.42	0.2	10	2.0 ± 0.2	2.0 ± 0.1
FFM_{leg}–CTRL	4.3	0.2	0.36	0.6	8	7.7 ± 0.7	7.7 ± 0.5
FFM–AN	15.6	0.6	0.48	2.8	8	36.8 ± 3.9	36.8 ± 2.7
FFM_{arm}–AN	0.7	0.1	0.34	0.2	12	1.6 ± 0.2	1.6 ± 0.1
FFM_{leg}–AN	3.5	0.2	0.43	0.7	10	6.8 ± 1.0	6.8 ± 0.7

*$P<0.0001$ for all regressions; **P=ns *vs* value measured by DXA.
Abbreviations: FFM, fat-free mass; CTRL, controls; AN, anorexics, a_0, intercept; a_1, slope; RMSE, root mean square error; RMSE%=RMSE/value of FFM measured by dual-energy X-ray absorptiometry (DXA); DXA, value measured by DXA; BIA, value estimated from bioelectrical impedance analysis. FFM_{arm} and FFM_{leg} are the mean of left and right values.

Table 3 Prediction of whole body and leg FFM from RI and weight in anorexics

	Coeff	*Std coeff (β)*	P	R^2_{adj}	*RMSE (kg (%))*	P
FFM						
Intercept	3.3	3.3	ns	0.77	1.9 (5)	<0.0001
Wt (kg)	0.2	0.7	<0.0001			
RI (cm^2/Ω)	0.6	0.3	0.009			
FFM_{leg}						
Intercept	−0.9	−0.9	ns	0.76	0.5 (7)	<0.0001
Wt (kg)	0.1	0.7	<0.0001			
RI (cm^2/Ω)	0.1	0.3	0.002			

Abbreviations: Wt, weight; RI, resistance index; coeff, regression coefficient; Std Coeff, standardized regression coefficient; RMSE, root mean square error; Wt, weight; RI, resistance index. FFM_{leg} is the mean of left and right values.

appendicular FFM from BIA in anorexics. BIA algorithms developed on healthy subjects generally fail when applied to ill subjects, probably because of differences in the underlying body water distribution (Bedogni *et al,* 1996). *R* is highly dependent on the extra- (ECW) to intra-cellular (ICW) water ratio and it is by means of this association that BIA allows an assessment of total body water (TBW) and FFM (Deurenberg, 1994; Heymsfield and Wang, 1994). A greater variability of the ECW:ICW ratio may be responsible for the lower accuracy of BIA and for the greater contribution of Wt to the unexplained variance of total FFM and FFM_{leg} in anorexics. However, this hypothesis needs to be tested by directly measuring TBW and ECW and by establishing their effect on the estimate of FFM obtained with BIA.

The finding that Wt contributed to the unexplained variance of FFM in anorexics but not in controls deserves some comments. In homogeneous samples such as those studied here, Wt is generally a better predictor of TBW and FFM than Rl, while the contrary happens for heterogeneous samples (Kushner *et al,* 1992; Scalfi *et al,* 1997). The reason why Wt did contribute to the unexplained variance of FFM in anorexics but not in controls is unclear but it is possible that a frequency of 50 kHz may not be enough to obtain an accurate estimate of FFM in anorexics because of changes in their ECW: ICW ratio.

Frequencies >50 kHz may be superior for assessing limb composition by BIA because they allow a better evaluation of ICW (Deurenberg, 1994). Since the extremities are made mainly of muscles, and muscles are made by water for about 80% of their weight (Wang *et al,* 1999b), there appears to be a strong physiological reason why future studies of appendicular body composition should consider using frequencies >50 kHz. This may be especially true for ill subjects because subclinical water shifts occur frequently with disease (Bedogni *et al,* 1996, 1997). In a study of healthy subjects performed by Pietrobelli *et al* (1998), frequencies >100 kHz were associated with an increase in the explained variance of FFM_{arm} and FFM_{leg}. However, in a study by Tagliabue *et al* (2000), the opposite was observed, so that there is a clear need for further research on this topic.

This study confirms the potential of BIA for the assessment of appendicular body composition in malnourished subjects. Future studies should consider whether frequencies >50 kHz allow a better assessment of appendicular body composition in anorexics as compared to Wt alone.

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