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BRIEF REPORT

Body composition in subjects with anorexia nervosa: bioelectrical impedance analysis and dual-energy X-ray absorptiometry

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ABSTRACT. OBJECTIVE: *To evaluate the applicability and validity of bioelectrical impedance analysis (BIA) compared with dual-energy X-ray absorptiometry (DXA) in a population of girls with restrictive anorexia nervosa (AN).* **METHODS:** *A total of 30 girls (11-19 years old) with AN were enrolled. DXA and BIA (BIA software and the Deurenberg equations) were used to estimate the body composition. The correlation between the methods was assessed by Pearson's correlation coefficient and the Bland-Altman method.* **RESULTS:** *The mean FFM estimates were 33.2 kg (BIA software), 32.8 kg (BIA, Deurenberg equation) and 33.1 kg (DXA). The mean FM values were 5.6 kg (BIA software), 6.2 kg (BIA, Deurenberg equation) and 6.4 kg (DXA). There was a high correlation between the FFM values estimated with the two methods (BIA software vs DXA r=0.917, p<0.001; Deurenberg equation vs DXA r=0.931, p<0.001). For the FFM, the limits of agreement were equal to ±3.34 kg for the BIA software and ±2.96 kg for the Deurenberg equation. For the FM, the limits of agreement were equal to ±4.60 kg for the BIA software and ±3.82 kg for the Deurenberg equation.* **CONCLUSION:** *The results show a good correlation between DXA and BIA. BIA seems to be a valid alternative for epidemiological and clinical evaluations.*

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INTRODUCTION

Anorexia nervosa (AN) is an eating disorder characterised by a significant weight loss (<85% of expected), fear of gaining weight, distortion of self body image and, in females, amenorrhea. Two subtypes of AN exist: restrictive and binge/purging (reference to DSM IV-TR) (1).

AN is a pathology with a high incidence in adolescence, with a peak of onset between 14.5 and 18 years of age (2) and a fatality rate of 4.27% (3). In Italy, the AN prevalence in women between 12 and 25 years old is estimated to be between 0.3 and 0.5% (4). In AN, an important modification of the body composition has been observed: a reduction in both the lean and fat masses, with differences between the two genders (5). Males have a greater loss of body fat rather than lean mass. The upper limbs tend to lose muscular mass faster than the lower limbs (6). The loss of lean mass occurs not only in the muscle but also in the bowels, including the spleen, liver and kidneys (7). At an advanced stage, there is a loss of up to two-thirds of the fat free mass. Furthermore, in some cases of restrictive AN, the restriction can also significantly affect the fluid intake, leading to a state of dehydration.

In cases of AN, determination of the body composition is used to determine the nutritional rehabilitation requirements, monitor the medical conditions and set the appropriate therapy. Moreover, bringing the clinical data into the psychotherapeutic relationship objectives can help improve the patient's ability to self-evaluate his/her body and body shape.

Currently, the major tool used for the determination of body composition in patients with AN is dual-energy X-ray absorptiometry (DXA), as reported in many scientific articles (3, 5, 8). This method is, however, unavailable to the clinician who works in an outpatient setting. In addition, it is expensive, may limit the patient's compliance because s/he has to be irradiated,

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although at slight levels, and does not provide information on the state of hydration assuming that lean body mass is 73% water (8).

An alternative method, widely used in the general population for body composition assessment, is bioelectrical impedance analysis (BIA). This method has been used only recently for the evaluation of anorexic patients, and its applicability in this area needs further confirmation. The studies designed to validate the use of this method involved limited samples in which there were both adolescents and adults, individuals that have different body composition characteristics (9-11).

The present study aimed to evaluate the applicability and validity of BIA compared with DXA in a population of girls with restrictive AN.

MATERIALS AND METHODS

The sample consisted of 30 girls between 11 and 19 years old consecutively enrolled at the Department of Child and Adolescent Neuropsychiatry, Careggi Hospital in Florence, Italy with a diagnosis of restricting subtype AN according to the DSM IV-TR.

All patients presented severe clinical and mental conditions, were hospitalised as in-patients and received an interdisciplinary (medical, nutritional and psychological) treatment regimen.

The study protocol involved the execution of the DXA and BIA examinations on the same day in patients who had not eaten since the day before, performed in this sequence without fluid intake or meals between the two examinations. After performing the BIA, anthropometric measurements – height and weight – were collected using a SECA stadiometer and balance to the nearest 0.1 cm and 0.1 kg in underwear, respectively. The body mass index (BMI) was calculated and compared with Cacciari's distribution for the Italian population of the same age (12). All measurements were performed according to standard criteria (13) by qualified trained personnel.

The study protocol was discussed with the individual patients and their parents. Additionally, written informed consent was obtained from all study participants.

Dual-energy X-ray absorptiometry (DXA)

The DXA analysis was performed using the General Electric Lunar dpx-IQ machine. DXA uses an X-ray tube that can operate at a constant potential or alternate between two potentials. The effective dose of radiation involved in the body scan is very low (5-7 μSv). The technology used by DXA is the attenuation of the photon in vivo depending on the density of the tissue it has passed through. The use of DXA to measure body composition is based on the assumption that the body is made up of three components, fat mass (FM), bone mass (BM) and lean mass (LM), with different attenuation properties.

To calculate the body distribution, a fundamental assumption is that the soft tissue is considered to be normally hydrated and divided between the fat and lean fractions (assuming 73% constant hydration of the lean mass). The processing software determines the bone mineral density and evaluates the soft tissue in both the entire human body and specific single regions. The DXA scan is accurate for the assessment of body composition with coefficients of variation of approximately 1% for bone mineral content, 2-3% for the total content of body fat (8) and 1.1-1.5% for the content of lean mass (5). The analyses were conducted according to standard conditions (patients supine with arms along their sides, palms down and knees and ankles held together by straps), and the scan time was approximately 10 minutes long.

The fat free mass (FFM) was calculated by the sum of the LM and BM.

Bioelectrical Impedance Analysis (BIA)

The bioelectrical parameters of resistance (R) and reactance (Xc) expressed in ohms were obtained using a single frequency impedance analyser with an operating frequency of 50 kHz at 800 μA (Soft Tissue Analyzer, ®Akern Srl). The accuracy was checked with a calibration circuit of known impedance (R=380 ohm, Xc=47 ohm, 1% error). Whole body impedance measurements were taken using the standard positions of outer and inner electrodes on the right hand and foot (tetrapolar technique). The procedure was performed according to the guidelines of the National Institutes of Health Technology Assessment Conference Statement (14). The values of R and Xc, normalised for height (H) to avoid the conductor length effect, were plotted on a graph (RXc graph) that contains three ellipses of tolerance (50%, 75% and 95%) of the reference population specific by gender and age. The phase angle (PA) was calculated as an arctan (Xc/R).

The bioelectrical parameters also allowed the estimation of the FFM and FM, assuming a constant hydration level of FFM of 73% within and across individuals. The formulas that can be used are numerous, and they have been calculated using populations more or less extensive and sometimes with very different characteristics. The values of FFM and FM in our sample were estimated using two different equations: the one used in the software provided by the manufacturer of the bioelectrical impedance analyser (Akern Bioresearch, Italy; BIA software) and the Deurenberg equation (15), which is the best available BIA equation for patients with AN according to Mattar et al. (16).

The total body water (TBW) was estimated using the software provided by the manufacturer of the bioelectrical impedance analyser.

Statistical methods

The collected data are reported as means, ranges and standard deviations. All the analyses were performed considering the BIA values as the FFM and FM calculated either by the BIA software or the Deurenberg equation. Student's t-test for paired data was used to compare the BIA and DXA measurements.

The means of FFM, FM and TBW by placing the subjects in the RXc graph (within the 50%, 50-75% and 75-95%, or out of the 95%, tolerance ellipses) were compared using an analysis of variance (ANOVA). Student's t-test for paired data was used to compare the BIA and DXA measurements by placing the subjects in the RXc graph.

To determine the best BIA equation compared with the DXA results, the sum of the square of the differences between the estimates of either the FFM or FM was calculated. The smallest sum indicated the equation with the results closest to the DXA results.

The correlation between BIA and DXA in the estimation of the FFM and FM was assessed by calculating Pearson's correlation coefficient and applying the Bland-Altman method (17). With the latter, the difference between the values obtained using the two methods (BIA and DXA) and their mean values are plotted on a graph on the ordinate and abscissa, respectively. A good agreement between two measurements (i.e., interchangeability of measurements) should result in a narrow scatter around zero of the random differences between methods in a direction parallel to the abscissa, representing the mean values of both measurements. As the distribution of the differences between the values obtained using the two methods was parametric, the limits of agreement were identified as the mean differences between the values obtained using the two methods plus or minus two standard deviations of the differences. An alpha level of 0.05 was used. The statistical analyses were performed using the SPSS 19.0 software (SPSS Inc., Chicago, IL).

RESULTS

Table 1 shows the descriptive statistics of the data collected.

The mean age of the subjects was 14.7 years old, and the mean BMI was 15.4 kg/m^2. Comparing the values with the distribution of Cacciari et al. for the same age and gender, 24 individuals (80%) had a BMI below the 3rd percentile.

The mean FFM estimates were 33.2 kg (BIA software), 32.8 kg (BIA, Deurenberg equation) and 33.1 kg (DXA). The mean FMs were 5.6 kg (BIA software), 6.2 kg (BIA, Deurenberg equation) and 6.4 kg (DXA). The mean FFM and FM values estimated by BIA and DXA do not statistically differ using either the BIA software or the Deurenberg equation.

Using BIA vector analysis, the FFM and TBW were shown to decrease significantly while moving away from the average of the reference population, which differs from what was observed for the FM (Table 2). The mean FFM and FM values estimated by BIA and DXA do not statistically differ within each placement level (within the 50%, 50-75% or 75-95%, or out of the 95%, tolerance ellipses).

The phase angle (PA) and BMI also tended to decrease, although not significantly, moving away from the average of the reference population (PA 5.6±0.6 vs 4.5±1.1; BMI 16.6±2.0 vs 14.5±0.8).

TABLE 1
Descriptive statistics of the sample population (N=30 subjects).

	Mean	SD	Minimum	Maximum
Age (years)	14.7	2.0	11	19
BMI (kg/m^2)	15.4	1.6	13.3	19.5
Weight (kg)	39.0	5.1	28.3	50.0
Height (cm)	159.1	6.5	145.0	172.0
Xc	66.0	12.5	37.0	84.0
Xc/h	41.5	7.8	22.0	53.2
Rz	723.4	84.0	545.0	888.0
Rz/h	455.7	57.7	324.4	572.9
PA	5.2	0.9	3.3	6.7
FFM_BIA_Akern (kg)*	33.2	4.1	26.0	42.2
FM_BIA_Akern (kg)#	5.6	2.6	0.9	10.2
TBW_BIA_Akern (l)	25.9	2.6	21.8	32.6
FFM_BIA_Deurenberg (kg)°	32.8	3.7	26.0	40.3
FM_BIA_Deurenberg (kg)^	6.2	2.6	0.6	11.1
FFM_DXA (kg)*°	33.1	4.0	24.9	41.2
FM_DXA (kg) #^	6.4	2.4	2.6	11.1

SD: standard deviation; *°#^Student's t-test for paired data: p>0.05.

TABLE 2
Fat free mass, fat mass, total body water and body mass index. Descriptive parameters by placing the subjects in the RXc graph (within the 50%, 50-75% and 75-95%, or out of the 95%, tolerance ellipses) of the specific reference population.

		Placement in the RXc graph				
		within 50% N=7	50-75% N=5	75-95% N=11	out of 95% N=7	ANOVA univariate (d.f. =3)
FFM_BIA1 (kg)	Mean±SD	37.3±2.9	34.3±2.8	32.0±3.4	30.3±4.1	F=4.409; p=0.004
	Range	33.3-42.2	30.4-36.9	26.0-37.2	26.1-38.7	
FFM_BIA2 (kg)	Mean±SD	36.6±1.4	32.9±2.7	32.1±3.3	30.5±4.5	F=4.284; p=0.014
	Range	34.8-38.9	30.1-36.4	26.0-36.5	27.2-40.3	
FFM_DXA (kg)	Mean±SD	37.1±2.1	33.6±3.2	32.3±3.7	30.0±3.8	F=5.686; p=0.004
	Range	35.1-41.2	30.1-38.5	25.6-37.1	24.9-37.0	
FM_BIA1 (kg)	Mean±SD	7.1±3.2	4.8±2.0	5.1±2.4	5.3±2.6	F=11.250; p=0.363
	Range	0.9-10.2	3.5-8.2	1.3-8.0	2.2-9.5	
FM_BIA2 (kg)	Mean±SD	8.0±3.0	6.3±1.7	5.6±2.2	5.1±2.8	F=1.893; p=0.156
	Range	3.2-11.1	2.0-8.4	2.3-9.9	0.6-8.5	
FM_DXA (kg)	Mean±SD	7.6±3.0	7.0±2.9	5.7±2.3	5.8±1.7	F=1.060; p=0.383
	Range	2.6-11.1	3.6-11.0	2.7-10.0	4.3-8.6	
TBW_BIA1 (kg)	Mean±SD	28.2±1.5	26.4±1.2	25.3±1.9	24.4±3.7	F=13.033; p=0.028
	Range	26.1-30.9	24.9-28.1	22.4-28.6	21.8-32.6	
PA_BIA1 (°)	Mean±SD	5.6±0.6	5.6±0.9	5.1±0.7	4.5±1.1	F=2.586; p=0.075
	Range	4.9-6.3	4.3-6.7	3.3-5.9	3.3-5.9	
BMI (kg/m^2)	Mean±SD	16.6±2.0	16.0±1.1	15.0±1.5	14.5±0.8	F=2.846; p=0.057
	Range	13.7-19.5	14.4-17.1	13.3-17.3	13.7-15.6	

SD: standard deviation; BIA1: BIA software; BIA2: Deurenberg equation. FFM_BIA1 vs FFM_DXA, FFM_BIA2 vs FM_DXA, FM_BIA1 vs FM_DXA, FM_BIA2 vs FM_DXA for each level of placement: p>0.05 (Student's t-test for paired data).

Pearson's correlation analysis and the Bland-Altman method were used to assess the correlation between the values of FFM and FM estimated by BIA vs those estimated by DXA. There was a high correlation between the FFM estimated with the two methods (BIA software vs DXA r=0.917, p<0.001; Deurenberg equation vs DXA r=0.931, p<0.001). A significant correlation also existed for FM, although at a lower value (BIA software vs DXA r=0.587, p=0.001; Deurenberg equation vs DXA r=0.712, p<0.001).

The sum of the square of differences between the estimates of either FFM or FM was smaller for the Deurenberg equation (65.74 and 106.96, respectively) than for the BIA software (81.38 and 172.42, respectively).

The distributions of the differences between the estimates of FFM and FM using the two methods were Gaussian. For the FFM, the limits of agreement (±2 SD) calculated with the Bland-Altman analysis were equal to ±3.34 kg for the BIA software (mean of the difference: 0.1 kg) and ±2.96 kg for the Deurenberg equation (mean of the difference: -0.3 kg). For the FM, the limits of agreement were equal to ±4.60 kg for the BIA software (mean of the difference: -0.8 kg) and ±3.82 kg for the Deurenberg equation (mean of the difference: -0.2 kg) (Fig. 1).

DISCUSSION

The values of FFM, FM and PA recorded in the selected sample were comparable with those of AN patients with a similar BMI and lower than those of girls in the same age group not suffering from AN (7, 18-20). The decrease observed for PA is typical of undernutrition and is attributable to the decrease in cell mass and/or increase in extracellular water (ECW); with respect to the latter (ECW), the subjects with AN also recorded a decrease in the TBW content, mainly dependent on a reduction in the intracellular water content. Significant decreases in the FFM and TBW were also observed, moving away from the 50% confidence ellipse in the BIA vector analysis, suggesting that in subjects with AN, the differences from normal conditions for the bioelectrical parameters are mainly the result of the loss of FFM and TBW.

However, in our sample, there was a mean hydration rate (TBW/FFM) higher than normal (78.0% vs 73%). This condition limits the reliability of the estimation of the FFM and FM with both methods because the formulas assume a normal and constant hydration rate.

The results show a good correlation between the DXA and BIA, at least for the estimation of the FFM.

According to our results, the Deurenberg equation seems to provide better estimates of FFM and FM than the BIA software, given that the sum of the squares of the differences compared with the DXA estimates was smaller and the limits of agreement were closer.

In contrast, the average of the differences in the FFM estimates obtained using the BIA software was, as an absolute value, less than that obtained using the Deurenberg equation, thereby showing a better accuracy for the FFM estimate.

With respect to FM, the situation appeared to be the opposite, with a better accuracy for the FM estimated using the Deurenberg equation.

In fact, although the limits of agreement for the FFM and FM estimates were not very different, the low content of FM in AN patients results in a higher relative error (namely, the absolute error divided by the magnitude of the exact value), which reduces the reliability of the estimation of the FM in these subjects. These results are consistent with the findings in other studies, both in populations of adolescents enrolled in schools and in subjects in the same age range who suffer from eating disorders (AN, obesity) (20-22).

In our sample, however, the limits of agreement identified with the two above-mentioned equations were closer than those reported by other authors (16), underlining a better agreement between the FFM and FM estimates.

Expanding the size of the sample population could be useful to confirm these results and highlight possible predictors of agreement. Once the reliability of BIA for the evaluation of body composition has been established, we would replace DXA with BIA in the clinical setting to exploit the following main characteristics of this tool: reduced expense, increased manageability, increased usability for short-term monitoring, absence of x-rays, and not limited to a hospital environment (20, 23). In addition, because of the cost, DXA cannot be used on a large scale for patients with eating disorders (the guidelines recommend that 8 out of 10 patients benefit from outpatient treatment).

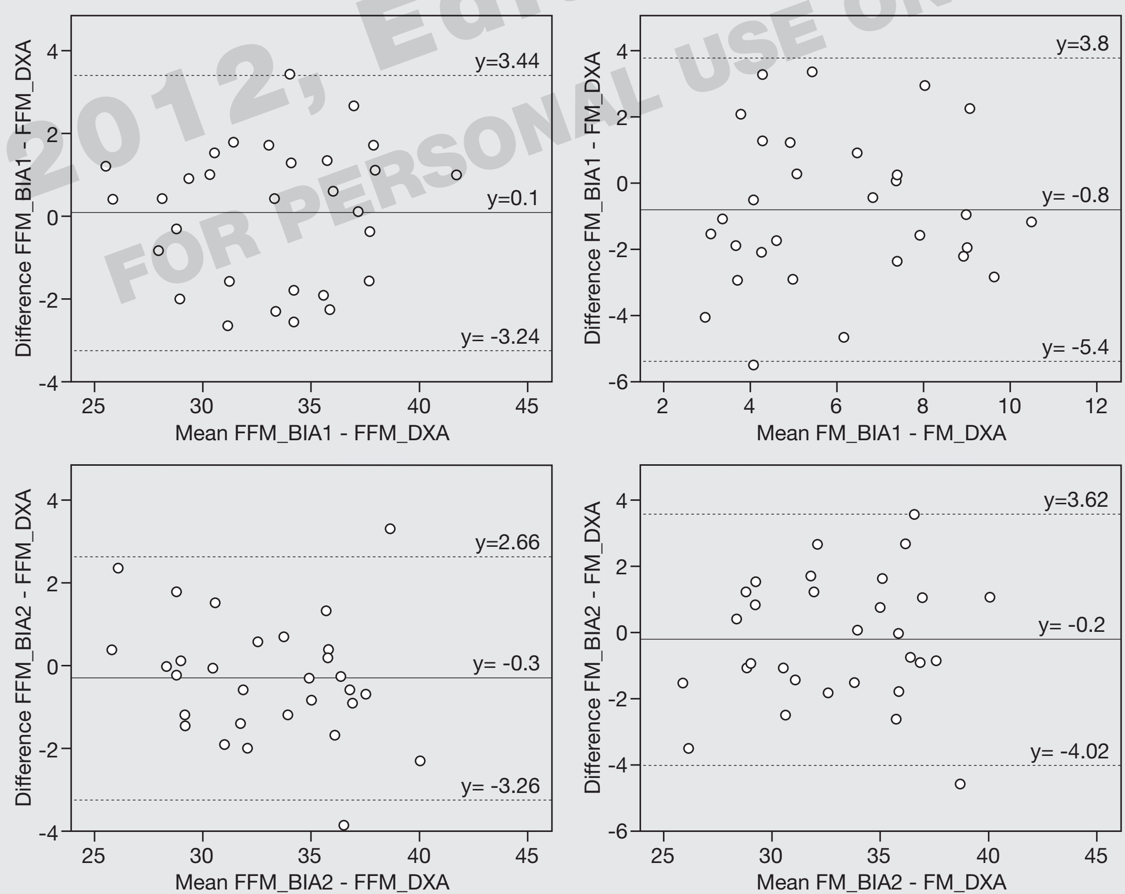

FIGURE 1

FFM (kg) and FM (kg) estimated by BIA (BIA1: BIA software; BIA2: Deurenberg equation) and DXA (Bland-Altman analysis).

In conclusion, the comparison of the two methods for the estimation of body composition in patients with AN seems to confirm the possibility of using bioelectrical impedance analysis as a valid alternative for epidemiological and clinical evaluations, especially in contexts in which the use of and access to DXA is difficult.

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