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ORIGINAL ARTICLE

Comparison of dual-energy X-ray absorptiometry, air displacement plethysmography and bioelectrical impedance analysis for the assessment of body composition in morbidly obese women

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BACKGROUND/OBJECTIVES: We evaluated the agreement of air displacement plethysmography (ADP) and bioelectrical impedance analysis (BIA) with dual-energy X-ray absorptiometry (DXA) for the assessment of percent fat mass (%FM) in morbidly obese women.

SUBJECTS/METHODS: Fifty-seven women aged 19–55 years and with a body mass index (BMI) ranging from 37.3 to 55.2 kg/m^2 were studied. Values of %FM were obtained directly from ADP and DXA, whereas for BIA we estimated fat-free mass (FFM) from an equation for morbidly obese subjects and calculated %FM as (weight − FFM)/weight.

RESULTS: The mean (s.d.) difference between ADP and DXA for the assessment of %FM was −2.4% (3.3%) with limits of agreement (LOA) from −8.8% to 4.1%. The mean (s.d.) difference between BIA and DXA for the assessment of %FM was 1.7% (3.3%) with LOA from −4.9% to 8.2%.

CONCLUSION: ADP–DXA and BIA–DXA are not interchangeable methods for the assessment of body composition in morbidly obese women.

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INTRODUCTION

Assessing body composition (BC) in obese individuals is challenging because the assumptions made by many direct BC methods, for example, body densitometry, may be violated in the presence of obesity.[1] Partly as a consequence of this violation, otherwise accurate indirect BC methods developed on non-obese individuals, for example, bioelectrical impedance analysis (BIA), fail to work properly in obese individuals.[2–5]

Dual-energy X-ray absorptiometry (DXA) is an increasingly popular method for the assessment of BC.[6,7] Even if DXA cannot replace the four-compartment model as the reference BC method,[8] it is available in many clinical and research centers and provides a reproducible ranking of body fat that is useful for epidemiological studies.[7,9,10]

Air displacement plethysmography (ADP) offers a measure of body density (BD) that is rapidly replacing BD provided by the more invasive underwater weighing (UWW).[11] ADP and UWW offer comparable estimates of BD in obese subjects,[12] however, the assumption of constant fat-free mass (FFM) density made by both the methods may be violated in the presence of obesity.[13]

Both ADP and DXA are being actively employed to study BC in morbidly obese adults,[14–16] but their degree of interchangeability is presently unknown. We have recently shown that DXA and ADP do not agree sufficiently to be considered interchangeable for the assessment of BC in morbidly obese children.[17]

BIA is a low-cost and readily available BC technique that relies on the use of population-specific equations.[18] The need for such equations is especially evident in obese subjects, whose peculiar extra- to intracellular water distribution and body shape violate some basic assumptions made by BIA.[2,3,19] However, just two validation studies of BIA have been performed to date in morbidly obese adults. Horie *et al.*[15] developed a BIA equation to estimate ADP-measured fat mass (FM) and Jiménez *et al.*[16] developed a BIA equation to estimate DXA-measured FFM.

The main aim of the present study was to evaluate the agreement of ADP and DXA for the assessment of percent FM (%FM) in morbidly obese women. The secondary aim was to evaluate the agreement of BIA and DXA for the assessment of %FM using a predictive formula specifically developed for morbidly obese subjects.[16]

SUBJECTS AND METHODS

Subjects

Fifty-seven obese women without overt metabolic or endocrine diseases were consecutively enrolled in the study at the Division of Metabolic

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Diseases of Istituto Auxologico Italiano (Piancavallo, Verbania, Italy). A body weight >130 kg was a reason of exclusion from the study because the employed DXA scanner could not accommodate subjects weighing >130 kg. Anthropometry, DXA, ADP and BIA were performed within 24 h by the same trained operators as described below. The study protocol was approved by the local ethical committee and all subjects gave their written consent to participate.

Anthropometry

Weight and height were measured following international guidelines.[20] Body mass index (BMI) was calculated as weight (kg)/height (m)^2 and obesity was classified using the criteria of the World Health Organization (WHO).[21] Waist circumference was measured at the midpoint between the last rib and the iliac crest.[21]

DXA

DXA was performed using a GE-Lunar Prodigy scanner (GE Medical Systems, Milwaukee, WI, USA). A head-to-toe scan was performed in the default mode with the subject lying supine on the instrument's bed. The three-compartment DXA model separates body mass into FM, lean tissue mass and bone mineral content, with the sum of lean tissue mass and bone mineral content representing FFM.[6] DXA scans were analyzed using GE Encore software version 8.80 (GE Medical Systems, Milwaukee, WI, USA). The scanner was calibrated daily against the calibration block supplied by the manufacturer. %FM was obtained directly from the instrument. In our laboratory, the within-day coefficient of variation (CV) for two repeated DXA measurements of %FM in five obese adults was 2.3%.

ADP

ADP was performed using a BOD POD densitometer (COSMED, Rome, Italy). The subjects wore a tight-fitting bathing suit and a bathing cap during measurements. Lung volume was measured during tidal breathing and during exhalation against a mechanical obstruction. The measure of BD was automatically corrected for lung volume and surface area artifacts. %FM was obtained from BD using Siri's equation.[22] The BOD POD scale was calibrated daily using a 20-kg weight, and a two-point calibration of the measuring chamber was performed before measurement. In our laboratory, the within-day CV for two repeated ADP measurements of %FM in 10 obese adults was 2.7%.

BIA

Whole-body impedance (Z) was measured at a frequency of 50 kHz using a Human IM Plus II impedance meter (DS Medica, Milan, Italy). Measurements were performed after 20 min of supine resting and following international guidelines.[23] The impedance index (ZI) was calculated as height^2/Z. In our laboratory, the within-day CV for two repeated measurements of Z in 10 obese adults was 2.0%. FFM was estimated from the equation developed by Jiménez *et al.*[16] for morbidly obese subjects:

$$\mathrm{FFM\,(kg)} = 18.240 - 4.395 \times \mathrm{gender} + 0.137 \times \mathrm{weight\,(kg)} + 5865.274 \times \mathrm{ZI}\,(\mathrm{m}^2/\Omega)$$

where gender equals 1 for men and 2 for women. $\%FM_{BIA}$ was calculated as (weight $-$ FFM_{BIA})/weight.

Statistical analysis

Descriptive statistics are reported as means (s.d.) and minimum and maximum values. Fractional polynomials were used to test whether the relationship between FFM_{DXA} and FFM_{BIA} was linear.[24] The adjusted coefficient of determination (R^2_{adj}) and the root mean square error of the estimate (RMSE) were calculated using linear regression. Pearson's correlation coefficient was used to evaluate the association between the $FFM_{BIA} - FFM_{DXA}$ difference and ZI, weight and BMI. The Bland–Altman method was used to calculate the limits of agreement (LOA) between FFM_{BIA} and FFM_{DXA}, $\%FM_{ADP}$ and $\%FM_{DXA}$, and $\%FM_{BIA}$ and $\%FM_{DXA}$.[25,26] Fixed bias was calculated as the difference between FFM_{BIA} and FFM_{DXA}, $\%FM_{ADP}$ and $\%FM_{DXA}$, and $\%FM_{BIA}$ and $\%FM_{DXA}$. Pitman's test was used to evaluate proportional bias.[25,26]

RESULTS

Descriptive statistics

The measurements of the 57 study women are given in Table 1.

The women were aged 19–55 years and their BMI ranged from 37.3 to 55.2 kg/m^2. Eleven (19%) of them had class II obesity and 46 (81%) had class III obesity according to WHO.[21] The mean (s.d.) $\%FM_{DXA}$ was 51% (4%) and ranged from 41% to 58%.

Prediction of FFM from BIA

Figure 1a shows the relationship between FFM_{DXA} and FFM_{BIA}. Such relationship was linear and fairly strong with an R^2_{adj} of 0.66 ($P<0.001$) and an RMSE of 3.5 kg. Figures 1b–d show the lack of association between the $FFM_{BIA} - FFM_{DXA}$ difference and the BIA predictors ZI ($P=0.34$) and weight ($P=0.40$), and BMI ($P=0.73$). The mean (s.d.) difference between BIA and DXA for the assessment of FFM was 2.8 kg (3.5). As there was no evidence of proportional bias (Pitman's $r=-0.20$, $P=0.15$), the LOA (–4.0 to 9.8 kg) were used to evaluate interchangeability.

Agreement between ADP and DXA, and BIA and DXA for the assessment of %FM

The agreement between $\%FM_{ADP}$ and $\%FM_{DXA}$ is reported in Figure 2a as Bland–Altman plot. The mean (s.d.) difference was -2.4% (3.3%). There was no proportional bias (Pitman's $r=0.26$, $P=0.07$) and the LOA were -8.8% to 4.1%. The agreement between $\%FM_{BIA}$ and $\%FM_{DXA}$ is reported in Figure 2b as Bland–Altman plot. The mean (s.d.) difference was 1.7% (3.3%). There was no proportional bias (Pitman's $r=0.15$, $P=0.27$) and the LOA were -4.9% to 8.2%.

DISCUSSION

In the present study, we evaluated the agreement of ADP and BIA with DXA in a sample of morbidly obese women. ADP and DXA are increasingly used to assess BC in morbidly obese patients,[14–16] but their degree of interchangeability in such patients is unknown. We believe that our findings are important because a proper evaluation of the interchangeability of BC methods is central to the demonstration of the clinical relevance of BC measurements.[27,28]

The present study has several limitations. First, our women had to weigh <130 kg because the employed DXA scanner could not accommodate heavier individuals. Thus, our conclusions may not apply to heavier women, even if we covered a range of BMI from 37.3 to 55.2 kg/m^2. Second, we studied only Caucasian women so that our findings cannot be extended to men and non-Caucasian groups. For instance, although we reported similar findings for morbidly obese children of both genders,[17] ADP underestimated %FM more in boys than in girls. Third, we measured body

Table 1. Measurements of the 57 women

	Mean	*s.d.*	*Min*	*Max*
Age (years)	37	11	19	55
Weight (kg)	109.7	9.4	85.2	124.9
Height (m)	1.61	0.07	1.42	1.74
BMI (kg/m^2)	42.5	3.5	37.3	55.2
Waist circumference (cm)	120	10	96	145
ZI (cm^2/Ω)	54	8	40	80
FFM_{DXA} (kg)	52.9	6.0	39.0	68.1
FFM_{BIA} (kg)	55.8	5.3	45.3	69.7
FM_{DXA} (kg)	54.4	6.7	41.1	70.1
FM_{DXA} (%)	50.7	3.9	40.9	57.9
FM_{ADP} (%)	53.1	4.7	41.0	62.0
FM_{BIA} (%)	49.0	3.5	41.0	56.9

Abbreviations: ADP, air displacement plethysmography; BIA, bioelectrical impedance analysis; BMI, body mass index; DXA, dual-energy X-ray absorptiometry; FFM, fat-free mass; FM, fat mass; min, minimum; max, maximum; ZI, whole-body impedance index.

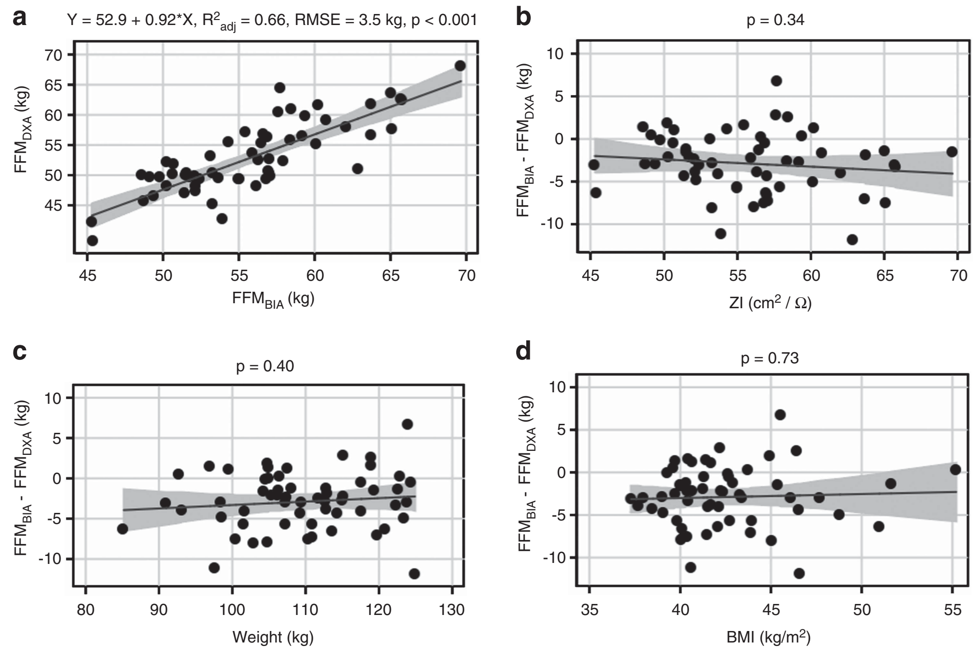

Figure 1. Association between FFM measured by DXA and FFM estimated from BIA using the equation of Jiménez *et al.*[16] Gray bands are 95% confidence intervals.

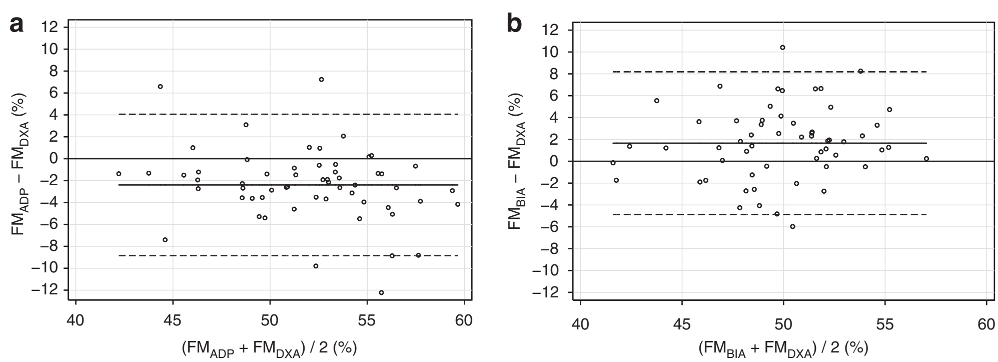

Figure 2. Bland–Altman plots for %FM measured by DXA vs ADP (**a**) and DXA vs BIA (**b**).

impedance at a frequency of 50 kHz. Frequencies >50 kHz may allow a better prediction of FFM but this needs to be investigated by further studies.[3,15]

We chose DXA as our comparator method mainly for practical reasons. DXA is in fact increasingly used to assess BC in clinical and epidemiological research, and is more available than ADP.[7,9] We wish to point out, however, that only a reference four-compartment BC model can establish the true accuracy of ADP and BIA in morbidly obese subjects.[8,29]

With regard to ADP–DXA comparison, the bias of ADP in estimating %FM was nearly the same as that we detected in obese children (−2.4% (3.3%) vs -2.1% (3.4%)).[17] ADP calculates BD as a ratio between body weight and body volume, and estimates %FM assuming constant FFM density.[11,22] The FFM compartment with the greatest influence on the ADP (and UWW) estimate of %FM in obese subjects is total body water (TBW) because TBW is the largest FFM component and FFM hydration is higher in obese individuals.[30,31] Although we cannot prove this in the present study as we did not measure TBW, this is a likely reason for the ADP–DXA discrepancy in the estimate of %FM.[13,17] The fact that ADP and DXA estimate of %FM are not interchangeable in morbidly obese subjects has to be taken into account not only when making inferences about their BC but also when a comparator method is chosen for the validation of an indirect BC method, such as BIA and anthropometry.[14,15]

With regard to BIA–DXA comparison, we obtained %FM from FFM estimated using the equation of Jiménez *et al.*[16] This equation employs ZI, weight and gender as predictors, and was developed and internally cross-validated in a sample of 159 morbidly obese subjects (79% women). The bias of BIA in estimating %FM using this formula was 1.7% (3.3%) with LOA from -4.9% to 8.2%. This suggests that DXA and BIA are not exchangeable at the individual level but a fair evaluation of this BIA–DXA comparison should take at least three methodological issues into account.

First, we used a GE Prodigy densitometer, whereas Jiménez *et al.*[16] used a GE iDXA densitometer. Although these instruments are from the same manufacturer and have been shown to agree very well for the assessment of BC, this does not imply that they provide identical measures of BC.[32] Second, we used a DS Medica Human IM Scan II, whereas Jiménez *et al.*[16] used a Tanita BC 418MA impedance meter. Having not performed any systematic comparison of these instruments, we do not know the degree to which the measures of Z given by them are interchangeable. Third, on both theoretical and practical grounds, a predictive equation is expected to be less accurate in external populations.[33] It is, however, of some interest that we found no evidence of proportional bias for the equation of Jiménez *et al*.,[16] meaning that the bias remained constant across varying levels of FFM and %FM.[34]

In conclusion, ADP–DXA and BIA–DXA are not interchangeable methods for the assessment of BC in morbidly obese women. Because morbid obesity violates many of the assumptions made by direct and indirect BC methods, there is a clear need of more research in this area if the clinical implications of the altered BC of obese individuals have to be fully understood.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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