Changes in body composition during weight loss in obese subjects in the NUGENOB study: Comparison of bioelectrical impedance vs. dual-energy X-ray absorptiometry

C. Verdich, P. Barbe, M. Petersen, K. Grau, L. Ward, I. Macdonald, T.I.A. Sørensen, J.-M. Oppert

Abstract

Aim. – We studied the accuracy of bioelectrical impedance analysis (BIA) to assess changes in body composition during moderate weight loss in obese subjects.

Methods. – Estimates of changes in fat mass (FM) and fat-free mass (FFM) by BIA were compared with those by dual-energy X-ray absorptiometry (DXA) as the reference method during a 10-week standardized weight-loss intervention. In obese women (age: 20–50 years, mean BMI: 33.8 kg/m²) participating in a European multicentre trial (nutrient–gene interactions in human obesity [NUGENOB]), body composition was assessed by BIA (Bodystat QuadScan 4000) and DXA (Lunar DPX-IQ at two centres, Hologic QDR 2000 at another centre) at baseline (n = 131) and at week 10 (n = 105) after a mean weight loss of −5.7 kg.

Results. – At baseline, BIA significantly overestimated FFM and underestimated FM (by 1–3 kg on average) compared with DXA, and the limits of agreement were wide (mean ± 7–8.5 kg). For body-composition changes, although biases were generally non-significant, the limits of agreement were also wide (mean ± 3.7–4.6 kg). An FFM prediction equation for BIA data was developed in subjects scanned with Lunar instruments and cross-validated in an independent sample of 31 obese women undergoing similar weight loss. However, no major improvement in limits of agreement was found.

Conclusion. – During moderate diet-induced weight loss, the use of BIA leads to estimates of changes in body composition at the individual level that can differ substantially from those assessed by DXA, indicating that BIA and DXA cannot be used interchangeably. However, BIA in this context may be used for assessing changes in body composition at group level.

Keywords: Obesity; Body composition; Weight loss; Bioelectrical impedance analysis; Dual-energy X-ray absorptiometry

Résumé

Modifications de la composition corporelle lors de la perte de poids chez les sujets obèses dans l’étude NUGENOB : comparaison de l’impédancemétrie bioélectrique avec l’absorptiométrie bi-énergétique.

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We dedicate this report to the memory of our colleague, Dr Pierre Barbe, who sadly died before this manuscript was completed. Pierre skillfully managed the NUGENOB patients at the Toulouse centre, and will be remembered by the NUGENOB research consortium as being both an expert in clinical nutrition and a good colleague.

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Comparing BIA and DXA in this context have been inconclusive reduction [8,21,22,25,26]. However, results of the few studies changes in body composition in obese subjects following weight loss [6–24]. There is evidence that DXA can accurately assess accurately assess changes in body composition during weight loss[3,4]. There is also evidence on bias in body composition estimates obtained by BIA. Bioelectrical impedance analysis (BIA) is a simple, quick, relatively inexpensive, non-invasive, portable and safe method for estimating body composition [1,2]. The method is widely used in clinical and research settings. It allows derivation of body-composition data from empirically derived statistical relationships between measured body impedance and FFM (or total body water). Predictive equations for estimating FFM (or total body water) depend on the type of BIA device used for recording impedance data (for example, multiple-frequency vs. single-frequency), the reference method used for assessing FFM and the characteristics of the population in which the equation was developed [1–3].

On the basis of data from a number of cross-sectional studies, there is agreement that BIA has sufficient precision for assessing body composition at group level [3,4]. There is also evidence that the degree of adiposity may have a strong influence on bias in body composition estimates obtained by BIA. In a cross-sectional study of 591 healthy adult subjects, Sun et al. [5] found that BIA using a Bodystat QuadScan 4000 device compared with dual-energy X-ray absorptiometry (DXA) underestimated percent body fat (by 2.65%) in overweight and obese subjects (those with percent body fat greater than 30%) while overestimating it (by 3.56%) in the leanest subjects (those with percent body fat less than 20%) [5]. In obese subjects, an important yet still unresolved question is whether or not BIA can accurately assess changes in body composition during weight loss [6–24]. There is evidence that DXA can accurately assess changes in body composition in obese subjects following weight reduction [8,21,22,25,26]. However, results of the few studies comparing BIA and DXA in this context have been inconclusive [25,27–29].

Objectif. – Nous avons étudié la validité de l’impédancémétrie (IMP) pour évaluer les modifications de composition corporelle lors d’une perte de poids modérée par régime chez des patients obèses.

Méthodes. – Nous avons comparé l’estimation du changement de masse grasse (MG) et de masse non grasse (MNG) par IMP avec les données de l’absorptiométrie bi-énergétique (DEXA), comme méthode de référence, lors d’une intervention standardisée (dix semaines) chez des femmes obèses (20–50 ans, IMC moyen = poids/taille2 33,8 kg/m²) incluses dans un essai européen multicentrique (Nutrient-Gene Interactions in Human Obesity [NUGENOB]). Nous avons mesuré la composition corporelle par IMP (Bodystat Quadscan 4000) et par DEXA (Lunar DPX-IQ dans deux centres, Hologic QDR 2000 dans un centre) avant (n = 131) et après dix semaines (n = 105, perte de poids moyenne –5,7 kg).

Résultats. – Avant l’intervention, IMP surestimait MNG et sous-estimait MG de façon significative (1 à 3 kg en moyenne) par comparaison avec DEXA et les limites d’agrément entre méthodes étaient étendues (±7 à 8,5 kg en moyenne). Concernant les modifications de composition corporelle, bien que les biais entre méthodes ne soient pas significatifs, les limites d’agrément étaient également étendues (±3,7 à 4,6 kg en moyenne). Une équation de prédiction de MNG pour les données IMP a été développée chez les sujets mesurés par la DEXA Lunar et validée dans un échantillon indépendant de 31 femmes obèses soumises à une perte de poids similaire. Les limites d’agrément entre méthodes n’étaient pas améliorées.

Conclusion. – IMP et DEXA fournissent des estimations des modifications de composition corporelle lors d’une perte de poids modérée par régime qui diffèrent de façon importante au niveau individuel. Les deux méthodes ne peuvent pas être utilisées de façon interchangeable. IMP peut cependant être utilisée dans cette situation pour donner une estimation au niveau d’un groupe.

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Mots clés : Obésité ; Composition corporelle ; Perte de poids ; Impédancémétrie bioélectrique ; Absorptiométrie bi-énergétique

1. Introduction

Monitoring changes in body composition during weight loss is important for the clinical management of obese patients. A major objective of weight-loss interventions is to decrease fat mass (FM) while preserving fat-free mass (FFM) to maintain the obese subject’s metabolic and physical capacities.

Bioelectrical impedance analysis (BIA) is a simple, quick, relatively inexpensive, non-invasive, portable and safe method for estimating body composition [1,2]. The method is widely used in clinical and research settings. It allows derivation of body-composition data from empirically derived statistical relationships between measured body impedance and FFM (or total body water). Predictive equations for estimating FFM (or total body water) depend on the type of BIA device used for recording impedance data (for example, multiple-frequency vs. single-frequency), the reference method used for assessing FFM and the characteristics of the population in which the equation was developed [1–3].

On the basis of data from a number of cross-sectional studies, there is agreement that BIA has sufficient precision for assessing body composition at group level [3,4]. There is also evidence that the degree of adiposity may have a strong influence on bias in body composition estimates obtained by BIA. In a cross-sectional study of 591 healthy adult subjects, Sun et al. [5] found that BIA using a Bodystat QuadScan 4000 device compared with dual-energy X-ray absorptiometry (DXA) underestimated percent body fat (by 2.65%) in overweight and obese subjects (those with percent body fat greater than 30%) while overestimating it (by 3.56%) in the leanest subjects (those with percent body fat less than 20%) [5]. In obese subjects, an important yet still unresolved question is whether or not BIA can accurately assess changes in body composition during weight loss [6–24]. There is evidence that DXA can accurately assess changes in body composition in obese subjects following weight reduction [8,21,22,25,26]. However, results of the few studies comparing BIA and DXA in this context have been inconclusive [25,27–29].

The issue of the validity of BIA for assessing changes in body composition is of particular concern during moderate weight loss, such as that obtained with moderately low-calorie diets, as changes in the different body compartments in this case may be too small to be accurately assessed by BIA. Therefore, the main aim of the present study was to compare BIA with DXA as the criterion method for assessing changes in body composition associated with moderate weight loss in obese subjects. The comparison was carried out in subjects participating in a European multicentre study. In addition, a new equation for predicting FFM was developed from impedance data, and cross-validated in an independent dataset of obese subjects who were similar to the primary study population in baseline characteristics and weight loss.

2. Methods

2.1. Participants

The present study subjects were part of the nutrient–gene interactions in human obesity (NUGENOB) study, a multicentre obesity research project supported by the European Community (contract #QLK1-CT-2000-00618) [30] (see www.nugenob.org for details of the protocol). A total of 771 obese, but otherwise healthy, Caucasian subjects (580 women), who had been recruited at eight clinical centres in seven European countries (Nottingham, UK; Maastricht, The Netherlands; Paris and Toulouse, France; Pamplona, Spain; Prague, Czech Republic; Stockholm, Sweden; and Copenhagen, Denmark), were enrolled into a randomized two-arm, open-label, 10-week dietary interventional study comparing two different hypo-energetic diets, with either 25 or 40% of their energy from fat. Both diets were designed to provide fewer calories (−2510 kJ/day or −600 kcal/day) than the individually estimated energy requirement, based on the women’s initial measured resting metabolic rate multiplied by 1.3. Inclusion criteria were body mass index (BMI) ≥ 30 kg/m² and age 20–50 years. As reported elsewhere [30], the mean weight loss in the 648 subjects who completed
the trial was 6.76 kg (95% CI: 6.49; 7.02) and did not differ significantly between the two diets. The study protocol was approved by the ethics committee of each participating clinical centre, and all subjects gave their written informed consent before participating in the study.

2.2. Study protocol

All subjects underwent a 1-day standardized clinical investigation protocol at entry into the study and after the 10-week interventional period (completers only). Anthropometric measurement and body-composition assessment using BIA were performed after a 12-h overnight fast, after subjects had voided their bladder, and with the subjects wearing light clothing and no shoes. At each centre, body weight was measured to the nearest 0.1 kg using calibrated scales, and height (Ht) was measured to the nearest cm using a wall-mounted stadiometer. In three of the clinical centres (Copenhagen, Paris and Toulouse), body composition was also assessed by DXA scanning, which was carried out on the same day as the BIA.

2.3. Body composition measurements

The BIA device used was the multi-frequency QuadScan 4000 (Bodystat, Isle of Man, UK; www.bodystat.com). Before taking the measurements, subjects rested in a supine position for 4–5 min, during which time their individual data (gender, age, weight and height) were entered into the device. Following the manufacturer’s instructions, four electrodes were placed on the right hand and the right foot. Although the QuadScan 4000 device records impedance (Z) at four frequencies (5 kHz, 50 kHz, 100 kHz, 200 kHz), the manufacturer’s manual states that only the 50-kHz impedance is used for calculation of total body water, on which estimations for FFM are based using proprietary equations. BIA variables used in the present analyses were FFMBIA, FMIBIA and 50-kHz impedance (Z50).

The DXA scanners used in two clinical centres (Copenhagen and Toulouse) were Lunar DPX-IQ devices (GE Lunar Corp, Madison, WI, USA), with a Hologic QDR-2000 (Hologic, Waltham, MA, USA) used in the third centre (Paris). Procedures for whole-body composition measurements were those previously described for each centre [31–33]. At each centre, the same technicians performed all measurements on all participants. Results were analyzed using the respective manufacturer’s software (Lunar Smart Scan version 4.6c with extended analysis in Copenhagen, and version 3.65 in Toulouse; Hologic version 5.35 in Paris). DXA variables used in the present analyses were FFMDXA, calculated as the sum of lean body mass and bone mass, and FMDXA.

In the present study, body-composition data from both BIA and DXA were available from 140 obese women at baseline and 117 women at the end of the 10-week dietary intervention. Subjects were excluded from the analyses if the sum of FFM and FM, as estimated by either BIA or DXA, deviated by greater than 2% from scale weight. This resulted in the exclusion of eight subjects at baseline and three at week 10. In addition, one subject was excluded from all analyses due to major deviation between changes in body composition as assessed by BIA compared with DXA. The magnitude of the difference in this particular subject was so large (>10 kg) that it appeared to be a true erroneous outlier, making it unreasonable to keep in the dataset for the final analyses.

Only women with data available both at baseline and after the dietary intervention were considered in the analyses on changes in body composition. Analyses were thus performed on 131 subjects (78% of 170 entered) with data available from 140 obese women at baseline and 117 women at the end of the 10-week dietary intervention. In addition, data from two of these subjects were excluded, as the sum of FFM and FM as estimated by DXA deviated by greater than 2% from scale weight at either baseline or after the intervention. In addition, data on body composition were not available for one subject after the intervention. Thus, the analyses were performed on 131 subjects for whom data were available both at baseline and after the intervention.

2.4. Cross-validation sample

In the cross-validation of the FFM prediction equation developed in the NUGENOB study sample, data from an independent set of 34 overweight or obese, but otherwise healthy, women from Nottingham (UK) were used. These subjects were part of the Diet Trials Study, involving five centres in the UK (Nottingham, Surrey, Bristol, Edinburgh and Coleraine) and funded by the British Broadcasting Corporation (BBC). This study compared subjects using one of four commercially available weight-loss systems (WeightWatchers, Slim-Fast, the Atkins diet, and the Rosemary Conley Diet and Exercise Plan) with a non-dieting control group, over 5 to 6 months. Subjects were randomly allocated to one of the weight-loss systems or the control group and, once the study was complete, those in the control group were offered access to whichever weight-loss system they desired. In Nottingham, the subject’s body composition was assessed by both BIA (QuadScan 4000) and DXA (Lunar DPX-L, with version 4.7c software) before the start of the weight-loss period and after 20 weeks of following the weight-loss system (or not, if in the control group). Data from two of these subjects were excluded, as the sum of FFM and FM as estimated by DXA deviated by greater than 2% from scale weight at either baseline or after the intervention. In addition, data on body composition were not available for one subject after the intervention. Thus, the analyses were performed on 31 subjects for whom data were available both at baseline and after the intervention. 2.5. Statistical methods

Descriptive data are presented as means and 95% confidence intervals (CI) or standard deviations (SD). Comparisons between groups were performed using the independent-sample t test or Mann-Whitney U test, and comparisons of changes (difference between values measured after weight loss vs. before) within groups were conducted using the paired-sample t test or Wilcoxon’s test, depending on whether data were normally distributed as determined by the Shapiro-Wilk test.

Agreement between BIA-assessed and DXA-assessed baseline FM, baseline FFM, change in FM and change in FFM was determined using the technique proposed by Bland and Altman [34]. The relationship between the individual differences with
the two methods (BIA minus DXA) and the mean of the two methods were examined graphically and with Pearson’s correlation coefficients. The intermethod bias was estimated by the mean difference between methods and SD of the differences. Limits of agreement were defined as the mean difference ± 2 SD of differences. Analyses were conducted separately by scanner type (Hologic or Lunar). However, as any bias between the two scanner types would be expected to affect only the cross-sectional comparisons and not the within-subject changes in body composition over time, the data for changes in body composition were also analyzed in the sample as a whole.

Regression analysis was used to fit an equation predicting FFM based on impedance data from the 131 obese women at baseline. Using FFM\textsubscript{DXA} as the dependent variable, the following independent variables were entered into a multiple linear stepwise-regression model using Ht\textsuperscript{2} (cm)/Z50 (the impedance quotient), weight and age. Equations were developed separately for the 47 women scanned with Lunar and the 84 scanned with Hologic. The goodness of fit of the equation was assessed as described above.

Table 1A shows the baseline characteristics of the study subjects according to the DXA scanner used. At baseline, age was 20–50 years, BMI was 28.1–45.0 kg/m\textsuperscript{2}, FFM\textsubscript{DXA} was 37.6–68.4 kg and FM\textsubscript{DXA} was 21.4–67.1 kg. Data for changes in body composition after the 10-week dietary intervention are shown in Table 2A. Subjects experienced a mean weight change of −6.2% (95% CI: −5.6; −6.8%) of initial body weight, or −5.65 kg (95% CI: −5.11; −6.19), ranging from −11.50 kg to +4.00 kg. Loss of FM accounted for the majority of weight loss.

At baseline, strong correlations were found between FMB\textsubscript{IA} and FM\textsubscript{DXA}, and between FMB\textsubscript{IA} and FM\textsubscript{DXA}, both within the group scanned with Lunar (r = 0.78, SEE = 3.04 and r = 0.90, SEE = 3.50, respectively; P < 0.001 for both), and within the group scanned with Hologic (r = 0.77, SEE = 4.24 and r = 0.91, SEE = 4.15, respectively; P < 0.001 for both). However, mean between-method differences (biases) for FM and FFM differed significantly from 0 in both the Hologic- and Lunar-scanned groups (Table 1B). Also, compared with either DXA device, the trend was towards underestimation of FM and overestimation of FFM with BIA. Limits of agreement (mean ± 2 SD) for FM (kg) were also wide: (−10.11; 3.77) with Lunar; (−8.96; 7.50) with Lunar.

### Table 1

Baseline anthropometric and body-composition data, according to dual-energy X-ray absorptiometry (DXA) scanner used, in obese women from the NUGENOB project.

<table>
<thead>
<tr>
<th></th>
<th>Lunar scanner (n = 47)</th>
<th>Hologic scanner (n = 84)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>37.2 (34.9; 39.4)</td>
<td>34.3 (32.5; 36.1)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>92.50 (89.28; 95.73)</td>
<td>94.06 (91.50; 96.61)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165.3 (163.3; 167.3)</td>
<td>162.2 (160.8; 163.6)</td>
</tr>
<tr>
<td>BMI (kg/m\textsuperscript{2})</td>
<td>33.8 (32.9; 34.8)</td>
<td>35.7 (34.9; 36.6)</td>
</tr>
<tr>
<td>FFM\textsubscript{DXA} (kg)</td>
<td>50.22 (48.81; 51.62)</td>
<td>49.93 (48.49; 51.38)</td>
</tr>
<tr>
<td>FFM\textsubscript{BIA} (kg)</td>
<td>53.25 (51.60; 54.91)</td>
<td>51.89 (50.77; 53.00)</td>
</tr>
<tr>
<td>FM\textsubscript{DXA} (kg)</td>
<td>42.36 (40.01; 44.71)</td>
<td>43.15 (40.96; 45.34)</td>
</tr>
<tr>
<td>FM\textsubscript{BIA} (kg)</td>
<td>39.19 (37.02; 41.36)</td>
<td>42.17 (40.39; 43.95)</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FFM\textsubscript{BIA-DXA} (kg)</td>
<td>3.04 (3.55)</td>
<td>1.95 (4.22)</td>
</tr>
<tr>
<td>FM\textsubscript{BIA-DXA} (kg)</td>
<td>−3.17 (3.47)</td>
<td>−0.98 (4.24)</td>
</tr>
</tbody>
</table>

Data are presented as means (95% CI) in section A, and as means (SD) for between-method differences in section B; BMI: body mass index; FFM: fat-free mass; FM: fat mass; DXA: dual-energy X-ray absorptiometry (either Hologic or Lunar devices); BIA: bioelectrical impedance analysis (Bodystat).

a P < 0.001, one-sample t test for changes between baseline and week 10.

b P < 0.01, t test or Mann-Whitney U test for differences between groups.

c P < 0.05, t test or Mann-Whitney U test for differences between groups.

d P < 0.05, between-method differences.

### Table 2

Changes in body weight and composition after a 10-week dietary intervention, according to DXA scanner used and pooled data, in obese women from the NUGENOB project.

<table>
<thead>
<tr>
<th></th>
<th>Lunar (n = 33)</th>
<th>Hologic (n = 72)</th>
<th>Total (n = 105)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>−6.73 (−5.95; −7.51)</td>
<td>−5.16 (−4.47; −5.84)</td>
<td>−6.56 (−5.11; −6.19)</td>
</tr>
<tr>
<td>FFM\textsubscript{DXA} (kg)</td>
<td>−1.50 (−1.0; −2.0)</td>
<td>−0.31 (0.09; −0.70)</td>
<td>−0.68 (−0.35; −1.01)</td>
</tr>
<tr>
<td>FFM\textsubscript{BIA} (kg)</td>
<td>−1.86 (−1.21; −2.50)</td>
<td>−0.83 (−0.40; −1.27)</td>
<td>−1.15 (−0.78; −1.12)</td>
</tr>
<tr>
<td>FM\textsubscript{DXA} (kg)</td>
<td>−5.12 (−4.38; −5.85)</td>
<td>−4.75 (−4.11; −5.40)</td>
<td>−4.87 (−4.68; −5.56)</td>
</tr>
<tr>
<td>FM\textsubscript{BIA} (kg)</td>
<td>−4.78 (−3.90; −5.66)</td>
<td>−4.35 (−3.78; −4.93)</td>
<td>−4.49 (−4.96; −4.01)</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FFM\textsubscript{BIA-DXA} (kg)</td>
<td>−0.36 (2.32)</td>
<td>−0.52 (1.94)</td>
<td>−0.47 (2.06)</td>
</tr>
<tr>
<td>FM\textsubscript{BIA-DXA} (kg)</td>
<td>0.33 (2.14)</td>
<td>0.40 (1.87)</td>
<td>0.38 (1.95)</td>
</tr>
</tbody>
</table>

Data are presented as means (95% CI) in section A, and as means (SD) for between-method differences in section B; FFM: fat-free mass; FM: fat mass; DXA: dual-energy X-ray absorptiometry (either Hologic or Lunar devices); BIA: bioelectrical impedance analysis (Bodystat).

a P < 0.001, one-sample t test for changes between baseline and week 10.

b P < 0.01, t test or Mann-Whitney U test for differences between groups.

c P < 0.05, t test or Mann-Whitney U test for differences between groups.

d P < 0.05, between-method differences.
Hologic. (Bland–Altman plots are shown in Fig. S1; see supplementary material associated with this article online) In those scanned with Hologic, there was a significant inverse correlation with FM between the bias and mean of the two methods (r = -0.45; P < 0.001), whereas no such association was seen in those scanned with Lunar.

3.2. Comparison of bioelectrical impedance analysis and dual-energy X-ray absorptiometry during changes in body composition

In the group scanned with Lunar, changes in FM_BIA and FM_DX_A showed a significant correlation (r = 0.57; SEE = 1.73; P < 0.001), whereas changes in FM_BIA and FM_DX_A were not significantly related (r = -0.01; NS). In the group scanned with Hologic, both the changes in FM_BIA and FM_DX_A, and in FM_BIA and FM_DX_A, showed significant correlations (r = 0.40; r = 0.45; r = 1.55 and r = 0.74, SEE = 1.84, respectively; P < 0.001 for both). However, no significant bias was seen between methods in terms of FM changes in either group, whereas BIA overestimated the loss of FF_M compared with DXA in the group scanned with Hologic (Table 2B). In pooled data, changes in FM_BIA and FM_DX_A showed significant correlations (r = 0.70; SEE = 1.83; P < 0.001), as did changes in FM_BIA and FM_DX_A (r = 0.35; SEE = 1.59; P < 0.001). A significant bias was also seen between methods with respect to FF_M, with BIA overestimating the loss of FF_M and slightly underestimating the loss of FM compared with DXA (Table 2B), although the difference in FM loss was not statistically significant. Limits of agreement for change in FM (kg) were again wide: (-3.95; 4.61) with Lunar; (-3.34; 4.14) with Hologic; and (-3.52; 4.28) for the whole sample. (Bland–Altman plots are shown in Fig. S2; see supplementary material associated with this article online)

3.3. Prediction equation and cross-validation

For the FF_M prediction equation in the 47 subjects scanned with Lunar, the impedance quotient (Ht2/Z50) alone explained 53% (R2) of the variation in FF_DX_A (R = 0.73; SEE = 3.33; P < 0.001). When weight and then age were entered into the model, 62% (cumulative R = 0.79; SEE = 3.03) and 67% (cumulative R = 0.82; SEE = 2.85) of the variation in FF_DX_A, respectively, were explained. The regression equation was FF_DX_A = 0.314 (Ht2/Z50) + 0.174 (weight) + 0.143 (age) + 12.1, with FF_DX_A in kg, height in cm, weight in kg and age in years. For the 84 subjects scanned with Hologic, only the impedance quotient was a significant determinant of FF_DX_A, explaining 68% of the variation (R = 0.83; SEE = 3.77). The regression equation for this group was FF_DX_A = 0.813 (Ht2/Z50) + 8.91.

The 31 obese female subjects from the independent dataset used for cross-validation had, at baseline, a mean (95% CI) age of 43.5 (39.7; 47.2) years, weight 84.9 (81.7; 88.1) kg, height 164.3 (161.9; 166.6) cm, BMI 31.5 (30.5; 32.5) kg/m², FM_DX_A 38.5 (36.0; 40.9) kg and FF_DX_A 45.5 (43.9; 47.0) kg. They also had a mean weight change of -5.74 (-3.33; -8.14) kg (P < 0.001), mean FM change of -5.36 (-3.13; -7.58) kg (P < 0.001) and mean FF_M change of -0.07 (0.33; -0.46) kg (NS). When applying the equation developed from the data obtained from the Lunar-scanned group to this sample, significant biases were seen. Mean (SD) of differences between predicted and DXA-assessed body-composition data from the cross-validation sample at baseline were -1.84 (3.05) kg for FM and 2.81 (3.20) kg for FF_M (P < 0.001 and P < 0.005, respectively). Differences in 10-week changes were 1.30 (1.97) kg for FM and -1.61 (1.90) kg for FF_M (P < 0.001 and P < 0.005, respectively). Thus, FM was underestimated and FF_M overestimated at baseline by the equation compared with DXA, while FF_M loss was overestimated and FM loss underestimated by the equation after 10 weeks of dietary intervention.

4. Discussion

The present study compared the ability of BIA (Bodystat) and DXA (Lunar and Hologic devices) to estimate changes in body composition in obese subjects due to moderate weight loss induced by a standardized hypocaloric diet. Irrespective of which DXA device was used, there were no significant mean between-method differences in FM changes in response to the dietary treatment. However, at the individual level, the limits of agreement for changes in FM were wide.

An important feature of the present report is that the study subjects were healthy obese women who followed a diet with a moderate reduction in energy intake to achieve a weight loss of only 5–10% of their initial body weight [35,36]. This suggests that, although the changes in body composition observed in the study were rather modest in magnitude, they may well reflect what may be expected in an everyday setting.

A number of previous, smaller studies have compared BIA with reference methods such as hydrodensitometry, dilution techniques, DXA and multi-compartment models. In assessing changes in body composition brought about by weight loss in adult obese subjects, however, the results are mixed, with some studies showing no bias [6–14,29], as in the present study, whereas others, found that BIA either overestimated [19,20] or underestimated [21–24] loss of FM. These studies, however, are difficult to compare either with each other or with our present one, given the variable degrees of weight loss achieved (ranging from 0.6 kg to greater than 20 kg), and the various BIA devices and reference methods used. Although some of these studies included DXA among their methods [8,10,21,25,27–29], there appear to be only a few studies in which BIA was directly compared with DXA [25,27,28]. In 19 obese women (mean BMI: 36.7 kg/m²) who achieved a mean weight loss of 13.1 kg during a 6-month weight-loss programme, Funkhouser et al. [25] reported no significant bias between BIA (SF-BIA; RJL-100A) and DXA (Lunar) on assessing mean changes in percent body fat. In a study by Hendel et al. [28], changes in FF_M assessed by DXA after an 11.7-kg weight loss in 16 obese women (BMI: 30–43 kg/m²) were correctly predicted by BIA (Ani-meter body-composition analyzer; HTS-Engineering, Odense, Denmark) [28]. In two other studies, mean weight loss was comparable to that of our present study (5.6 kg) [27,29]. In the study by Frisard et al. [27] of 56 participants with a mean BMI
of 33.3 kg/m², discussion of the changes in body composition determined by BIA and DXA was mostly restricted to regression coefficients \(r^2\), which were 0.51 (SF-BIA; Tanita TBF-305 body-fat analyzer foot-to-foot device) and 0.61 (bioimpedance spectroscopy, BIS; XiTRON Technologies) for FM changes with weight loss. In the other, more recent, study by Thomson et al. [29], 24 obese women (mean BMI: 36.4 kg/m²) achieved a mean weight loss of 5.3 kg during a 10-week weight-loss intervention. Mean changes in FM (−3.2 and −3.6 kg) and FFM (−2.1 and −1.7 kg) estimated by leg-to-leg BIA (SF-BIA; Tanita Ultimate Scale model 2000) and the ImpediMed device (model SFB7), respectively, did not differ significantly from DXA (Lunar Prodigy) estimates of changes in FM (−3.6 kg) and FFM (−1.7 kg). Also, the limits of agreement in the Thomson et al. study (mean ± 2.8–4.8) were similar in magnitude to those in our present study (mean ± 3.7–4.8).

As the degree of obesity, geometry of the body and state of hydration can influence estimates of body composition with both DXA and BIA [2,12,32,37], as well as affect the outcomes differently with each of the two methods, the wide limits of agreement for both changes in body composition and cross-sectional baseline data were not unexpected. The precision error has been estimated to be 5% for assessment of FM by BIA [2], and 1–5% for assessment of body composition by DXA, with the highest error being for FM and lowest for bone mass [38]. For a weight loss of 5–10% of initial body weight, as in the present study, changes in the different body compartments may be too small to be accurately assessed by BIA. The measurement of changes in body composition is also likely to produce a larger error term due to propagation of errors [2]. Furthermore, as estimation of FM by BIA is based on the assumption of a constant FFM hydration, changes in total FFM composition with weight loss might bias estimates of change in FFM [20,22,39,40]. This latter phenomenon would, however, be mostly expected with greater weight losses than those observed in the present study, which would result in greater changes in glycogen stores and loss of water bound to glycogen after weight reduction [20].

New equations were developed using FM\(_{\text{DXA}}\) as the dependent variable, and impedance quotient (Ht\(^2\)/Z50 kHz), age and weight as independent variables. However, when applying the equation developed on data obtained in the group scanned with Lunar to the cross-validation sample, a substantial bias was observed in the baseline data as well as in the data on changes in body composition, while the limits of agreement remained wide, despite using Lunar instruments in both studies to avoid inter-DXA instrument differences as a source of variation. These findings highlight how population-specific BIA prediction equations can be [41], and how matching the degree of obesity, gender, weight loss and intervention may still not eliminate the phenomenon. It may be speculated that there is an even higher degree of population specificity for equations developed in obese subjects compared with normal-weight populations.

There are some limitations of the present study that need to be mentioned. One is related to the structure of our study sample. Indeed, the underestimation of FM by BIA compared with DXA is in agreement with a previous report by Sun et al. [5], who found an adiposity-dependent bias of BIA-assessed body composition compared with DXA-assessed body composition: FM was overestimated in lean subjects and underestimated in obese subjects. It should be noted that this finding might be, in part, a statistical consequence of having a less-than-perfect correlation \(r < 1.0\) between measures obtained by BIA and DXA. In fact, even when there is no bias, \(r < 1.0\) will result in a slope of regression of DXA-assessed FM on BIA-assessed FM < 1.0—in other words, the so-called ‘flat slope syndrome’.

Another important limitation of the present study is the use of DXA as the reference method, which is increasingly being challenged [12,42] in favour of more sophisticated criteria-based methods, such as the four-compartment model based on the simultaneous assessment of body weight, density, water and mineral content. A few studies have examined the bias between DXA and a four-compartment model in assessing changes in FM with weight loss [8,12,21,43]. However, in contrast to earlier reports [21], the most recent of such studies [12] have shown DXA to significantly overestimate changes in FM with a mean bias of 1.2 kg for a modest weight loss of 3.3 kg on average. In addition, increasing body size and increasing tissue depth appears to be associated with a greater bias with DXA [42], leading to concerns over the use of this technique in obese subjects. Another limitation is that two of the centres in the present study used a Lunar DXA scanner as the reference method, whereas the third centre used a Hologic DXA device. It should be acknowledged that neither of these two types of DXA device have high accuracy in measuring body composition in obese people [12,42]. Interestingly, there were no major differences when comparing BIA with either Lunar or Hologic in the assessment of mean FM changes. Mean between-method differences at baseline, however, appeared to be substantially greater between BIA and Lunar compared with BIA and Hologic, although these differences might be ascribed to differences in the study populations or in the DXA scanners used. It is well recognized that different scanner devices, and different software (based on different reference methods) for a given device, can lead to different DXA results [44].

It should also be noted that, in the present study, the use of a BIA device providing impedance data only limited the ability to test other BIA equations, such as Heitmann’s and Segal’s equations based on resistance and reactance [45,46], or measurements taken at frequencies other than 50 kHz [47]. Finally, our study sample comprised only obese women.

In conclusion, during moderate diet-induced weight loss, the use of BIA will lead to estimates of changes in body composition at the individual level that may differ from those assessed by DXA, indicating that BIA and DXA cannot be used interchangeably. However, BIA—a low-cost, easy-to-use and portable method—may still be used for assessing changes in FM at group level in this context.

**Conflicts of interest statement**

No potential conflict of interest relevant to this article was reported.
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Appendix A. Supplementary material

Supplementary material (Fig. S1, S2) associated with this article can be found at http://www.sciencedirect.com, at Appendix A. Supplementary material

References


