# Bioelectrical Impedance Underestimates Total and Truncal Fatness in Abdominally Obese Women

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**Abstract**

NEOVIUS, MARTIN, ERIK HEMMINGSSON, BO FREYSCHUSS, AND JOANNA UDDÉN. Bioelectrical impedance underestimates total and truncal fatness in abdominally obese women. *Obesity.* 2006;14:1731–1738.

***Objective:*** To compare estimates of total and truncal fatness from eight-electrode bioelectrical impedance analysis equipment ($BIA_8$) with those from DXA in centrally obese women. The secondary aim was to examine BMI and waist circumference (WC) as proxy measures for percentage total body fat (%TBF) and truncal body fat percentage (tr%BF).

***Research Methods and Procedures:*** This was a cross-sectional study of 136 women (age, 48.1 ± 7.7 years; BMI, 30.4 ± 2.9 kg/m$^2$; $\%TBF_{DXA}$, 46.0 ± 3.7%; WC, 104 ± 8 cm). Fatness was measured by DXA and Tanita BC-418 equipment (Tanita Corp., Tokyo, Japan). Agreement among methods was assessed by Bland-Altman plots, and regression analysis was used to evaluate anthropometric measures as proxies for total and abdominal fatness.

***Results:*** The percentage of overweight subjects was 41.9%, whereas 55.9% of the subjects were obese, as defined by BMI, and all subjects had a WC exceeding the World Health Organization cut-off point for abdominal obesity. Compared with DXA, the $BIA_8$ equipment significantly underestimated total %BF (−5.0; −3.6 to −8.5 [mean; 95% confidence interval]), fat mass (−3.6; −3.9 to −3.2), and tr%BF (−8.5; −9.1 to −7.9). The discrepancies between the methods increased with increasing adiposity for both %TBF and tr%BF (both $p < 0.001$). Variation in BMI explained 28% of the variation in $\%TBF_{DXA}$ and 51% of $\%TBF_{BIA8}$. Using WC as a proxy for truncal adiposity, it explained only 18% of $tr\%BF_{DXA}$ variance and 27% of $tr\%BF_{BIA8}$ variance. The corresponding figures for truncal fat mass were 49% and 35%, respectively. No significant age effects were observed in any of the regressions.

***Discussion:*** $BIA_8$ underestimated both total and truncal fatness, compared with DXA, with higher dispersion for tr%BF than %TBF. The discrepancies increased with degree of adiposity, suggesting that the accuracy of BIA is negatively affected by obesity.

**Key words: agreement, bioelectrical impedance analysis, body composition, DXA, women**

## Introduction

The diagnostic criterion for obesity recommended by the World Health Organization is based on BMI, whereas central fatness is commonly assessed by waist circumference (WC)[1] (1). These simple and cheap proxy measures of overall and central fatness do not have optimal accuracy and cannot distinguish fat mass (FM) from fat-free mass. Therefore, other techniques to assess adiposity are needed (2), both to measure current adiposity status and to evaluate interventions in a more exact way than change in weight, BMI, or WC. However, the optimal measurement technique satisfying the criteria of being accurate, precise, accessible, acceptable, inexpensive, and well documented does not exist (3).

Commonly used reference methods, such as computed tomography, magnetic resonance imaging, DXA, and densitometry, may fulfill the accuracy criterion, but they fail other criteria. Price is one problem, training of operators is another, and, for some but not all of the techniques, safety

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[1] Nonstandard abbreviations: WC, waist circumference; FM, fat mass; BIA, bioelectrical impedance; BF, body fat; %BF, percentage body fat; %TBF, percentage total body fat; tr%BF, truncal body fat percentage; trFM, truncal fat mass.

concerns may arise because of radiation exposure. Cheaper and safer methods exist, such as bioelectrical impedance analysis (BIA). Recently, a new model of BIA equipment with eight electrodes (four handheld electrodes added to the four existing footpad electrodes) was introduced (4). It provides total body fatness estimates, as in previous models, and it also provides regional estimates.

One study has investigated the accuracy of $BIA_8$ compared with DXA and found no significant bias (4). The accuracy of four-electrode BIA for estimating body composition has been studied, but findings vary. BIA has been found to agree well with reference methods in several studies (4–8), but it has also been found to provide overestimates (9–11) and underestimates (11–14) in some populations. Recently, the four-electrode BIA was found to have excellent mean agreement for percentage body fat (%BF) in comparison with densitometry measures in a large sample of adolescents (−1.9% BF; 95% confidence interval, −2.4 to −1.5; $n$ = 473; age 16.8 ± 0.4 years; BMI 21.3 ± 3.2 kg/m$^2$) and adult women (−0.5% BF; 95% confidence interval, −0.9 to −0.1; $n$ = 464; age 46.9 ± 4.6 years; BMI 24.6 ± 4.3 kg/m$^2$) (unpublished data, M. Neovius, U. Ekelund, Y. Linné). However, most studies are based on small samples and/or normal-weight subjects. In studies assessing body composition in the obese or assessing the impact on estimates with increasing adiposity, discrepancies have been reported with increasing adiposity between DXA and four-electrode BIA (11,14–17). To the best of our knowledge, this issue has not been investigated pertaining to the new, improved $BIA_8$ equipment.

The $BIA_8$ equipment requires operator input on whether the subject is of athletic or standard body type. Although this may result in more accurate data for some subjects, the approach has at least two limitations. First, the classification is subjective. Secondly, most subjects in obesity treatment programs generally do not fit either the standard or athletic body type.

Therefore, the aim of this study was to compare estimates of total and truncal fatness made by DXA and $BIA_8$ in a sample of centrally obese women, as defined by the WC cut-off point recommended by the World Health Organization (88 cm). The secondary aim was to examine BMI and WC as proxy measures for percentage total BF (%TBF) and truncal BF percentage (tr%BF).

## Research Methods and Procedures

Data were collected from participants in an on-going, randomized intervention study that evaluates methods for increasing lifestyle-oriented physical activity in unfit, abdominally obese women. The subjects were recruited from an advertisement in a free-of-charge newspaper distributed in the Stockholm area. One hundred thirty-nine centrally obese (WC > 88 cm) women were screened before randomization. The analyses presented in this article are based on screening data only. During screening, three women did not complete DXA measurement and were excluded from analyses, resulting in complete data from 136 women. All measurements were carried out in fasting subjects on the same day (<2 hours between BIA and DXA measurements).

### *Fatness Measurements*

Body composition was estimated by use of both DXA and $BIA_8$. DXA measurements were performed using a total body scanner (Lunar Prodigy; Lunar Radiation Corp., Madison, WI). The subjects were measured in underwear without any metal items in their clothing or elsewhere. The same operator performed a whole-body scan on each subject lying in a supine position. Non-bone, fat-free soft tissue (muscle, body water, internal organs), fat soft tissue, and bone mineral densities were measured. %TBF was calculated by dividing fat soft tissue mass by entire body mass using the software supplied by the manufacturer. The Lunar Prodigy software for whole-body composition analysis also provides data on different regions of interest, e.g., trunk, arms, and legs. The equipment was calibrated each day using a standardized phantom.

The BC-418 eight-contact electrode system (Tanita Corp., Tokyo, Japan) was used for BIA measurements. The system consists of four stainless steel rectangular footpad electrodes fastened to a metal platform set on force transducers for weight measurement and two hand grips with an anterior and posterior electrode. The system has eight electrodes: two for each foot and two for each hand. Measurements are carried out at 50 kHz with a 0.8-mA sinus wave constant current, and the impedance across the tissues of the subjects is measured by receiver electrodes after the injector electrodes pass through an electrical signal. Except for whole-body impedance estimates, measured from foot to hand, the equipment provides measurements of the arms, legs, and trunk (including head), producing body composition estimates for five different segments. A research nurse input information on the subjects' age, height, and body types. (All were classified as standard and none as athletic.)

WC was measured with a measuring tape halfway between the iliac crest and the lowest rib in upright subjects after they had exhaled. Two measurements were made 5 minutes apart, and the mean value was used for analysis. Body height in centimeters was measured in subjects in an upright position without shoes using a wall-mounted stadiometer. The Medical Research Ethics Committee (Stockholm, Sweden) approved the study. All participants provided written informed consent.

### *Statistical Analysis*

Statistical analyses were conducted using SPSS software (version 14.0; SPSS, Inc., Chicago, IL) and Microsoft Excel (Microsoft, Redmond, WA), including Analyse-It for plot-

**Table 1.** Subject characteristics ($n = 136$)

| | Mean | Standard deviation | Range |
|---|---|---|---|
| Age (y) | 48 | 8.0 | 27 to 60 |
| Body weight (kg) | 84.6 | 9.5 | 60.4 to 107.6 |
| Height (m) | 1.67 | 0.07 | 1.51 to 1.85 |
| BMI (kg/m$^2$) | 30.4 | 2.9 | 24.8 to 36.7 |
| Waist circumference (cm) | 104 | 8.0 | 89 to 121 |
| Total %BF ($BIA_8$) | 41.0 | 3.3 | 32.8 to 48.3 |
| Total %BF (DXA) | 46.0 | 3.7 | 36.1 to 54.7 |
| Truncal %BF ($BIA_8$) | 39.0 | 4.0 | 27.2 to 47.6 |
| Truncal %BF (DXA) | 47.4 | 3.9 | 36.6 to 56.8 |

%BF, percentage body fat; BIA, bioelectrical impedance.

ting. Summary statistics used for central tendency and dispersion are means and standard deviation. Paired Student's *t* tests were used to compare estimates from the two methods. Methods used to assess agreement were Bland-Altman pair-wise comparisons, Pearson's correlation coefficient, and regression analysis. The 95% limits of agreement for the mean differences in the Bland-Altman plots were also calculated. The association between degree of adiposity, as determined by DXA, and the discrepancy between DXA and $BIA_8$ estimates were investigated both unadjusted and adjusted for age and BMI by use of multiple regression analysis. Statistical significance was defined as a $p$ value of $< 0.05$.

## Results

### *Subject Characteristics*

Subject characteristics are presented in Table 1. The subjects ranged in age from 27 to 60 years. The percentage of overweight subjects (BMI, 25 to 29.9 kg/m$^2$) was 41.9% (57 of 136) and the percentage of obese subjects (BMI $\geq$ 30 kg/m$^2$) was 55.9% (76 of 136), whereas 2.2% (3 of 136) were classified as having normal weight. The mean WC was 16 cm above the recommended cut-off point for adult women of 88 cm, which all subjects exceeded. Adiposity assessed by DXA and $BIA_8$ provided further evidence that the subjects were severely obese, on average, with a minimum $\%TBF_{DXA}$ of 36.1%.

### *Agreement between Methods*

The different fatness measures were all significantly correlated (Table 2), although the body composition assessments differed significantly between the $BIA_8$ and DXA estimates, for both overall %BF and tr%BF (Table 1). Compared with DXA, the $BIA_8$ equipment underestimated fatness for all variables, with greater mean bias for tr%BF than %TBF. The agreement between methods is shown in Figures 1 and 2 by use of Bland-Altman plots and scatterplots. BIA significantly underestimated %TBF by 5.0% units and tr%BF by 8.5% units (Table 3). Indications of magnitude bias were found when investigating the association between degree of adiposity, as assessed by DXA, and the mean difference between the two methods (Figures 3 and 4). In regression analysis, variation in $\%TBF_{DXA}$ explained 23.0% of the variation in differences among methods, while the corresponding $R^2$ for $tr\%BF_{DXA}$ was 17.5%.

**Table 2.** Correlation matrix for body composition variables and anthropometric variables. All correlations are based on the full sample, and all are significant at the $p < 0.001$ level ($N = 136$).

| | Correlations | | | | |
|---|---|---|---|---|---|
| | %BF ($BIA_8$) | BMI | Truncal %BF (DXA) | Truncal %BF ($BIA_8$) | Waist circumference |
| %BF (DXA) | | | | | |
| Pearson correlation | 0.74 | 0.53 | 0.85 | 0.70 | 0.34 |
| %BF ($BIA_8$) | | | | | |
| Pearson correlation | | 0.72 | 0.65 | 0.96 | 0.60 |
| BMI | | | | | |
| Pearson correlation | | | 0.44 | 0.54 | 0.61 |
| Truncal %BF (DXA) | | | | | |
| Pearson correlation | | | | 0.61 | 0.42 |
| Truncal %BF ($BIA_8$) | | | | | |
| Pearson correlation | | | | | 0.52 |

BF, body fat; BIA, bioelectrical impedance.

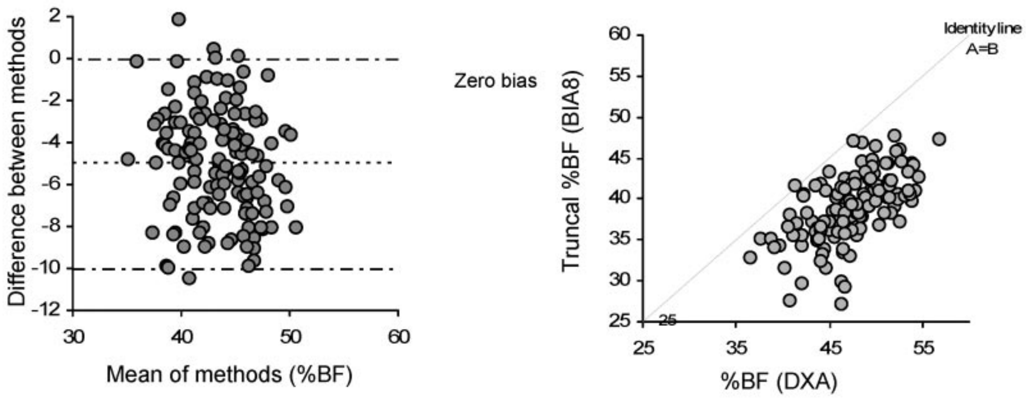


*Figure 1:* Bland-Altman plot (left) with mean bias (central line) and 95% limits of agreement (outer lines) and scatterplot (right) of %TBF estimates by DXA and BIA.

Both variables displayed greater discrepancies with greater adiposity (Table 4). For every additional unit of $\%TBF_{DXA}$, the discrepancy increased by 0.3 percentage units. The association persisted and was further strengthened when adjusting for BMI and age ($\beta_{DXA,\ adjusted} = 0.6$ percentage units) (Table 4).

### *BMI and WC as Proxies for Total and Truncal Fatness*

The point estimate of the correlation coefficient between BMI and $\%TBF_{DXA}$ was weaker than the estimate between BMI and $\%TBF_{BIA8}$ (0.53 vs. 0.72; both $p < 0.001$; Table 1). The strongest correlation coefficient was between the two BIA variables for %TBF and tr%BF (0.96). In regression analyses, 28% of the variance in $\%TBF_{DXA}$ was explained by the variation in BMI, whereas 51% of the variance in $\%TBF_{BIA}$ was explained. When using WC as a proxy for truncal fatness, 18% of the variance of $tr\%BF_{DXA}$ was explained and 27% of $tr\%BF_{BIA8}$. However, when regressing WC on absolute truncal FM (trFM), higher explanatory power was seen, with 49% and 35% for DXA and $BIA_8$, respectively. There were no significant age effects in any of the regressions ($p > 0.05$).

## Discussion

In this study, we investigated eight-electrode BIA equipment, as compared with DXA, with regard to accuracy in estimating both overall and central fatness. Our main finding was that the $BIA_8$ equipment significantly underestimated both total and truncal fatness, compared with DXA, with increasing disagreement among methods with greater adiposity.

BIA is widely used for assessment of body composition in various settings (2,6,18–24). Controversy exists about the accuracy of the technique, with some studies indicating underestimation (12–14), some indicating good agreement (4,6–8), and others showing overestimation (9,10). Recently, Sun et al. (11) showed, in a large healthy cohort, that

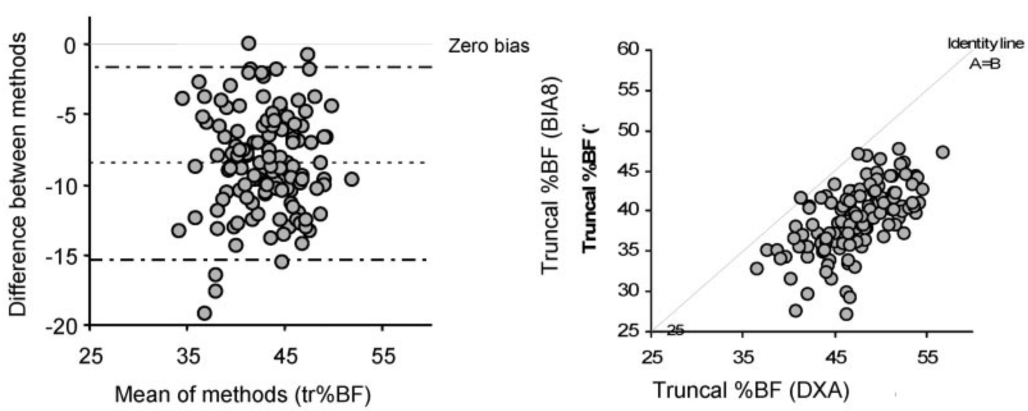


*Figure 2:* Bland-Altman plot (left) with mean bias (central line) and 95% limits of agreement (outer lines) and scatterplot (right) of tr%BF estimates by DXA and BIA.

**Table 3.** Mean differences between methods and 95% limits of agreement

| | Mean difference | 95% CI | 95% Limits of agreement |
|---|---|---|---|
| %TBF | −5.0 | −5.5 to −4.6 | −10.1 to 0 |
| Fat mass (kg) | −3.6 | −3.9 to −3.2 | −7.7 to 0.6 |
| tr%BF | −8.5 | −9.1 to −7.9 | −15.3 to −1.5 |

CI, confidence interval; BF, body fat.; %TBF, percentage total BF; tr%BF, truncal BF percentage.

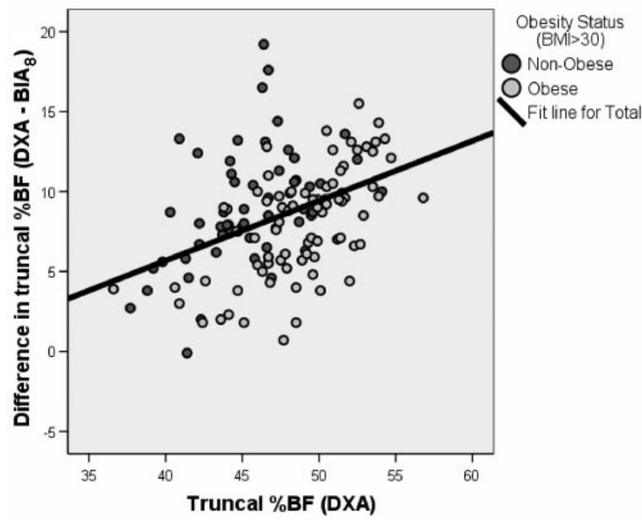


*Figure 4:* Scatterplot displaying the association between increasing degree of truncal adiposity and mean differences between DXA and BIA (tr%$BF_{DXA}$ − tr%$BF_{BIA}$). Obese and non-obese subgroups as judged by BMI are marked ($n$ = 136).

the degree of adiposity influences the accuracy of %BF estimates by four-electrode BIA when compared with DXA. The results of the present study regarding total fatness agree with those reported by Sun et al. (11), but are larger in magnitude (−5.0%TBF vs. −2.71%TBF) compared with the obese percentage, defined as >33%BF, in that study. This may be due to a number of factors, for example, the use of different BIA equipment and differences in degree of total and central adiposity. The characteristics of the obese fraction were not described by Sun et al., making comparisons on these grounds impossible. In addition to the underestimation by $BIA_8$, increasing disagreement with greater adiposity was also seen in this centrally obese sample, as Sun et al. found when comparing discrepancies among lean, normal, and obese subjects.

Few published studies have assessed the agreement between DXA and $BIA_8$. Pietrobelli et al. (4) found no significant bias in their Bland-Altman assessment of %TBF when comparing $BIA_8$ and DXA and also found the new eight-electrode system superior to its four-electrode predecessor in their sample of 20 men and 20 women. Their sample was leaner, on average, than the subjects in the present study, with regard to both mean BMI (24.8 ± 6.1 vs. 30.4 ± 2.9 kg/m$^2$) and %$TBF_{DXA}$ (29.2 ± 10.7%TBF vs. 46.0 ± 3.7%TBF). Similar to Pietrobelli et al., we have previously reported excellent mean agreement between a four-electrode BIA system and densitometry in both adult women and adolescents, although the dispersion was fairly wide (unpublished data, M. Neovius, U. Ekelund, Y. Linné). However, both of these studies examined fairly lean samples, not predominantly overweight or obese subjects. In this study, the prevalence of obesity was 55.9%, with an additional 41.9% overweight, as classified by BMI. Furthermore, all subjects had a WC exceeding 88 cm, and the mean WC was more than 1 m, indicating that the sample was heavily affected by both overall and central obesity. The four-electrode BIA equipment has been shown previously to underestimate %BF in overweight or obese populations or to display larger discrepancies with increasing adiposity, which is in agreement with our results for the eight-electrode equipment in centrally obese women (11,14–17). Our findings provide further support for the hypothesis that body composition estimates by BIA equipment are less accurate in overweight and obese subjects, compared with normal-weight subjects. This study extended the evidence to the new eight-electrode system, whereas previous studies have examined the four-electrode system. The findings warrant attention and should be an impetus for development of adjustments in the prediction equations for the obese.

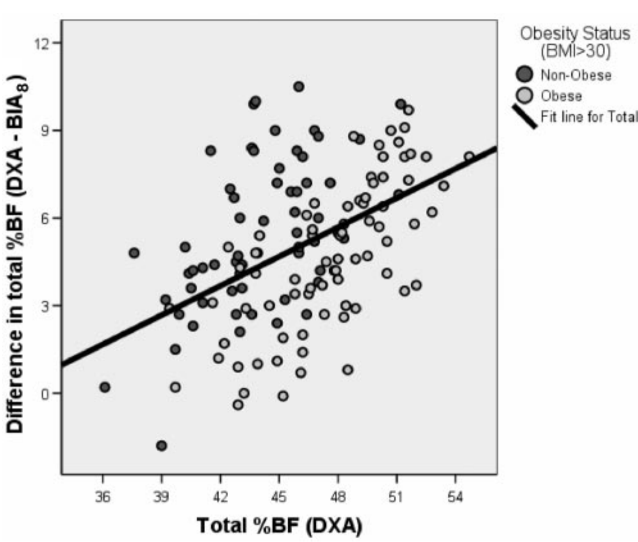


*Figure 3:* Scatterplot displaying the association between increasing degree of total adiposity and mean differences between DXA and BIA (%$TBF_{DXA}$ − %$TBF_{BIA}$). Obese and non-obese subgroups as judged by BMI are marked ($n$ = 136).

**Table 4.** Regression analyses of the difference between DXA and BIA in measurements of total %BF (or truncal %BF) using total $\%BF_{DXA}$ (or truncal $\%BF_{DXA}$), BMI, and age as explanatory variables ($n = 136$)

| Response variable | Explanatory variables | $\beta$ | $p$ value | Adj. $R^2$ |
|---|---|---|---|---|
| ΔTotal %BF (Model 1) | Total $\%BF_{DXA}$ | 0.33 | <0.001 | 23.0% |
| ΔTotal %BF (Model 2) | Total $\%BF_{DXA}$ | 0.55 | <0.001 | 47.1% |
| | BMI ($kg/m^2$) | −0.53 | <0.001 | |
| | Age (y) | −0.02 | 0.395 | |
| ΔTruncal %BF (Model 1) | Truncal $\%BF_{DXA}$ | 0.37 | <0.001 | 17.5% |
| ΔTruncal %BF (Model 2) | Truncal $\%BF_{DXA}$ | 0.52 | <0.001 | 27.9% |
| | BMI ($kg/m^2$) | −0.47 | <0.001 | |
| | Age (y) | 0.02 | 0.578 | |

BIA, bioelectrical impedance; BF, body fat; WC, waist circumference.

The $BIA_8$ equipment used allows the operator to choose between "athletic" and "standard" body type when performing a measurement, but there is no "obese" option. Given the magnitude of the discrepancy, it may be advisable to derive separate prediction equations for this special group of subjects and add a button for "obese." Furthermore, the point estimates of the correlation coefficients for BMI and %BF were higher for BIA than DXA, possibly because of a stronger reliance on BMI as a predictor in the %BF prediction equation, compared with DXA. Similarly, BMI was also more strongly correlated to trFM and tr%BF measured by $BIA_8$ than DXA.

In contrast to previous findings of no systematic bias, we found significant bias that was particularly large for truncal fatness. However, it is premature to conclude that the $BIA_8$ equipment is inaccurate for measuring fatness in obese adult women. First, for use in intervention studies assessing change in adiposity, the absolute values are of less importance for the comparison than the relative change. This possibility could not be assessed in this study because of its cross-sectional nature. Secondly, even though DXA is often used as a reference method for assessment of body composition, it also has documented limitations when the degree of obesity increases. Accuracy problems with increasing tissue depth have been reported in animal studies (25) and also in humans (26). Glickman et al. (26) examined the ability of DXA to determine changes in abdominal fat by placing packages of porcine fat over the abdomen. They showed that DXA accurately accounted for the total mass of the fat package but for only 78% of the total fat of the package that was added.

We also found that WC was more strongly correlated to absolute trFM than to tr%BF, for estimates derived both by DXA and by $BIA_8$. This is contrary to the notion that increasing WC is almost entirely explained by increasing fatness because abdominal fat is assumed to be the most variable component in this body region. In longitudinal studies, this probably holds because intra-individual changes are assessed, but for cross-sectional assessments, inter-individual differences in WC need not imply higher tr%BF, only larger build. That would explain the stronger correlation with absolute trFM. However, it is also possible that problems inherent in the measurement technologies may be responsible for these findings.

The strengths of this study were the relatively large sample size for the design including DXA, the use of the same operators for both DXA and $BIA_8$ measurements, and the short lag time among measurements in the same individual. In addition, we examined a patient group that is likely to be targeted for more detailed measures than BMI and WC for screening and intervention purposes. Therefore, it is of great interest to know how well a fast, simple, and relatively cheap BIA equipment model performs in assessing overall and central fatness, in comparison with a measurement technique considered a reference method. The study also has a number of limitations. First, as already mentioned, we do not know the accuracy of the reference method used for this category of patients, although DXA has been suggested to display little bias according to degree of fatness, age, sex, and physical activity levels (27). A four-compartment model, computed tomography, or magnetic resonance imaging could assist in finding the answer to that question. Second, even though the methods do not agree, they may show the same relative changes when weight status changes during interventions. Because this study describes the subjects at only one period in time, such evaluations cannot be undertaken. Thirdly, the definition of the trunk is not identical for the two machines used, adding interference.

In summary, we found significant differences between the new eight-electrode BIA equipment and DXA when assessing overall and central fatness in centrally obese women. The discrepancies were found to increase with the degree of adiposity. This is unfortunate if it reflects a relatively lower accuracy of BIA in the obese compared with the non-obese female population, because simple, fast, and cheap measures of fatness are highly desirable for more detailed phenotyping in obesity clinics and elsewhere. However, the evidence presented thus far does not suffice for such a conclusion, because the absolute accuracy of DXA in this patient group is uncertain, and agreement among relative changes has not been assessed. Therefore, future studies should address these issues; for example, by using computed tomography or a four-compartment model as a reference method and by analyzing repeated measurements in intervention studies.

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M.N. conceived the hypothesis for the analysis, conducted the statistical analyses, and drafted the manuscript. E.H. is the principal investigator of the study, provided critical input in all phases of the manuscript production, and helped revise the manuscript. B.F. and J.U. were responsible for DXA measurements and medical examinations, respectively, and provided critical input. All authors participated in the interpretation of the results and approved the final version of the manuscript. We thank research nurse Birgitta Spetz and DXA operators Mai Andersson, Ninni Qvist, and Mia Svedin. The data collection phase of this study was funded by Cycleurope Inc., Varberg, Sweden. M.N. was funded by Arbetsmarknadens Forsakrings-och Aktiebolag. No conflicts of interest are declared.

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