Body fat and fatfree mass measured by bioimpedance spectroscopy and dual energy x-ray absorptiometry in obese and non-obese adults

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Abbreviations: BIS, Bioimpedance spectroscopy; BMI, body mass index; DXA, dual energy X-ray absorptiometry; ECW, extracellular water; ΔDXA-BIS, difference between the methods DXA and BIS; FM, fat mass; FMkg, FM measured in kg; FM%, FM measured in %; FFM, fatfree mass; FFMkg, FFM measured in kg; FFM%, FFM measured in %; ICW, intracellular water; LoA, limits of agreement; MUAC, Mid-upper arm circumference; WHR, waist-to-hip ratio

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Abstract

The aim of this study was to compare body fat mass (FM) and fatfree mass (FFM) estimates by bioimpedance spectroscopy (BIS) with respective estimates by dual energy X-ray absorptiometry (DXA) in obese and non-obese subjects. Body composition was measured in 93 obese and non-obese men and women by BIS device BodyScout (Fresenius Kabi) and DXA device Lunar iDXA (GE Healthcare). Mean difference between the methods was analyzed by t-tests, and Bland-Altman plots were generated for further examining differences between the methods. Mean difference between the estimates by DXA and BIS (ΔDXA-BIS) (Bland-Altman 95% limits of agreement) were as follows: FM: 4·1 (-2·9, 11·2) kg, and 4·5 (-2·9 and 11·8) %, FFM: -4·1 (-11·2 and 2·9) kg, and -4·5 (-11·9 and 2·9) %, indicating large inter-individual variation and statistically significant underestimation of FM and overestimation of FFM by BIS as compared to DXA. The underestimation of FMkg and overestimation of FFMkg were more pronounced in men than women, and the underestimation of FM% and overestimation of FFM% were more pronounced in normal weight (body mass index, BMI=20·0-24·9 kg/m²) than overweight and obese (BMI≥25·0 kg/m²) subjects. BIS may be suitable for classification of a population into groups according to FM and FFM. However, the large inter-individual variation suggests that this BIS device with the proprietary software is in-sufficient for estimation of single individual body FM and FFM.
Introduction

Measurement of body composition is frequently used in the assessment of nutritional status. Low body fatfree mass (FFM) may be a better determinant of malnutrition and mortality in patients than low body mass index (BMI). This is becoming more important as prevalence of obesity increases, and malnutrition in different patient groups may be hidden in obesity. Consequently, there is need for a simple, valid bedside body composition assessment method.

Bioelectrical impedance (BI) is a non-invasive, patient-friendly, portable and relatively inexpensive method for body composition assessment. Bioimpedance technology estimates body water compartments, based on variation in electrical conductivity between different body tissues. In bioelectrical spectroscopy (BIS), electric current at a spectre of frequencies is led through the body via electrodes placed on skin. Resistivity of extracellular water (ECW) and intracellular water (ICW) compartments against the current varies for different frequencies. High frequent currents penetrate through cell membranes, whereas low frequent currents pass through the body mainly in ECW without penetration into cells. The measured impedance spectral data are fitted into a physical model, giving estimates for ECW and total body water (TBW) volumes. Using these estimates and measured subject weight and height, ICW and further, body FFM and fat mass (FM) can be calculated. BIS is not limited to constant body geometry and relative hydration degree of FFM, which both vary in obesity. Therefore, as compared to other BI methods, BIS has higher sensitivity to predict water compartments and FFM in obese subjects or subjects with altered fluid balance.

In order to use BIS for FFM estimation in clinical practice on both overweight and normal weight subjects, it has to be validated in a population with a wide spectre of BMIs. Although BIS is supposed to estimate body fluid compartments accurately in normal, healthy subjects, the validity may be reduced in obesity and in patients in a malnourished state. Dual energy X-ray absorptiometry (DXA) is a widely used reference method for body FFM and FM measurements.

A recent study on cardiac patients concluded that the BIS device BodyScout (Fresenius Kabi, Baden, Switzerland) is a simple bedside method to predict FFM in both normal and obese patients.
Homburg, Germany) only slightly overestimated FFM compared to DXA, but that the large inter-individual variation between the methods indicates that the device does not suit in body composition measurement at individual level\(^{(15)}\). It remains unclear whether the validity of FFM and FM estimates by this BIS device differs between obese and non-obese subjects.

The aim of this study was to examine the validity of BodyScout estimates of FM and FFM of the device, compared to DXA estimates in obese and non-obese adults.

**Methods**

**Subjects**

The participants in this study were recruited from The Akershus Sleep Apnea Project, a population-based cross-sectional study in Norway\(^{(16)}\). The aim of the two-phase main study was to assess the prevalence of sleep apnea in Norway. A total of 30,000 subjects aged 30-65 years and living in three different counties in Norway were randomly drawn from the National Population Registry and invited to respond in a questionnaire. A sub-group of 518 responders was further selected for a clinical examination.

We invited 150 randomly drawn participants of the clinical examination to the present sub-study by telephone. Proportion of invited subjects with BMI ≥30.0/<30.0 kg/m\(^2\) was 80/20. One-hundred-eight subjects gave their consent for participation, while 42 refused to participate. Among those who accepted to participate, 11 subjects were unable to meet up at the measurement appointment. A total of 97 subjects were included in this study, which included anthropometric measurements, a DXA analysis and a BIS test at the Akershus University Hospital. Inclusion criteria for the subjects in the clinical sub-study were not to receive treatment for obstructive sleep apnea. Subjects with significant co-morbid conditions such as cancer, heart failure or severe chronic obstructive pulmonary disease were excluded. Further exclusion criteria in our study were pregnancy, lack of safe contraception in fertile women, and Intra-Cardiac-Device, cochlea implant or large metallic implants operated into the body.
This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures were approved by the Regional Ethics Committee, The Norwegian Directorate of Health and Norwegian Social Science Data Services (NSD). Written informed consent was obtained from all subjects. The radiation dose in DXA (0.05-0.15 Gy) was considered very low, less than a standard chest x-ray.

**Measurement procedure**

The data was collected between May-September 2008. After fasting for a minimum of 8 hours and after avoiding hard physical exercise for 24 hrs, participants were met at the orthopaedic outpatient clinic in the morning. Five subjects reported not being in a fasting state. A trained health specialist (a dietician (HU) or a master of science in physical activity and health (GSE)) performed DXA scanning, the BIS test, and did the blood pressure and anthropometric measurements that included height, weight, and waist, hip and arm circumferences. The participants also filled in a lifestyle questionnaire covering questions on physical activity, weight history, recent weight loss and chronic diseases and disabilities limiting physical activity.

**Anthropometric measurements**

All anthropometric measurements were conducted while the participant was without shoes and wearing only underwear. Height was measured to the nearest cm, and body weight was measured to the nearest 0.1 kg with a digital scale (Seca, Seca Deutchland, Hamburg, Germany). Mid-upper arm circumference (MUAC) was measured standardized in the non-dominant arm using a scale band at the mid point of upper arm. Waist- and hip circumferences were measured with a scale band, participant standing. Waist circumference was measured between the lowest ribs and *crista iliaca* after an out-breath. Hip circumference was measured at the level of the thickest point of *nates*.

**Dual-energy X-ray absorptiometry**

The DXA instrument used in this study was Lunar iDXA (GE Healthcare, Madison, WI, USA). Whole-body scans were performed according to manufacturer’s instructions, and body fat, lean tissue mass (LTM) and bone mineral content (BMC) were analysed (software enCore version
The daily quality control procedure of the device was conducted automatically, and included a six-point calibration of three different bone-simulating chambers of known BMC and three different soft tissue-simulating chambers of known fat percent. The program automatically determined total body measurement mode according to participant thickness (thick, >25 cm; standard, 13-25 cm; and thin, <13 cm)\(^{(17)}\). DXA estimate of FFM was calculated as a sum of LTM and BMC estimates. Precision of LTM and BMC estimates of the Lunar iDXA device have been found satisfactory by others (coefficient of variation 0·5% and 0·6%, respectively)\(^{(18)}\).

Nineteen subjects were too large for the DXA instrument. These were scanned one-sided, and the instrument estimated measurement results for the whole body. Agreement in fat and lean mass estimates between whole-body DXA scan and estimates assessed by half-body DXA scan in obese subjects has been reported\(^{(19)}\).

Bioelectric impedance spectroscopy

We conducted the BIS measurement after the participant had taken off all electricity leading items such as belts, watches and jewellery, and rested in a supine position for 5 min. During the measurement, the participant was lying supine with four tactile electrodes placed on the skin, two on the dorsal surface of the dominant hand/wrist and two on the parallel foot/ankle according to the manufacturer’s instructions. The BIS analyser used was BodyScout (Fresenius Kabi, Bad Homburg, Germany). The BodyScout device covers 50 frequencies in a range of 5 kHz to 1 MHz. The proprietary software extrapolates ECW and ICW using the Hanai equation\(^{(20)}\), as described by Moissl et al.\(^{(21)}\). The BodyScout estimates of FM and FFM are not sex specific, and do not expect a fixed ECW/ICW ratio. The body composition model used in the BodyScout software is based on a principal that whole-body mass \(M_{WB}\) is a sum of three compartments: normally hydrated adipose tissue mass \(M_{NH,AT}\), normally hydrated lean tissue mass \(M_{NH,LT}\), and excess fluid (ExF) mass \(M_{ExF}\), as described by Chamney et al.\(^{(22,23)}\):

\[
M_{WB} = M_{NH,AT} + M_{NH,LT} + M_{ExF}
\] (1)
The total water (TW), ICW and ECW components of $M_{\text{NH,LT}}$ and $M_{\text{NH,AT}}$ are defined by equations 2-7.

\begin{align*}
H_{\text{TW,NH,LT}} &= M_{\text{TW,NH,LT}}/M_{\text{NH,LT}} \\
H_{\text{ECW,LT}} &= M_{\text{ECW,NH,LT}}/M_{\text{NH,LT}} \\
H_{\text{ICW,NH,LT}} &= M_{\text{ICW,NH,LT}}/M_{\text{NH,LT}} \\
H_{\text{TW,NH,AT}} &= M_{\text{TW,NH,AT}}/M_{\text{NH,AT}} \\
H_{\text{ECW,AT}} &= M_{\text{ECW,NH,AT}}/M_{\text{NH,AT}} \\
H_{\text{ICW,NH,AT}} &= M_{\text{ICW,NH,AT}}/M_{\text{NH,AT}}
\end{align*}

where $H_{\text{TW,NH,LT}}$, $H_{\text{ECW,LT}}$, $H_{\text{ICW,NH,LT}}$, $H_{\text{TW,NH,AT}}$, $H_{\text{ECW,AT}}$ and $H_{\text{ICW,NH,AT}}$ are fractional mass of TW, ECW and ICW in normally hydrated lean tissue, respectively, and $H_{\text{TW,NH,AT}}$, $H_{\text{ECW,AT}}$ and $H_{\text{ICW,NH,AT}}$ are fractional mass of TW, ECW and ICW in normally hydrated adipose tissue, respectively. In the BodyScout software, total body FM in kg (FMkg) is related to $M_{\text{NH,AT}}$ with equation 8.

\begin{equation}
\text{FMkg} = M_{\text{NH,AT}} \times (1 - H_{\text{TW,NH,AT}} - K_{\text{AR}})
\end{equation}

where $K_{\text{AR}}$ is the ratio of residual adipose components (solids, mainly protein and mineral) to $M_{\text{NH,AT}}$ with a value of typically 0.05\(^{(24,25)}\). FMkg is calculated by the software by extracting FMkg from body weight.

BIS estimate of FFM (FFMkg\(_{\text{TBW/0.73}}\)) was calculated also directly from TBW according to equation 9, based on the assumption of a 73% hydration of the fatfree mass\(^{(26)}\).

\begin{equation}
\text{FFMkg}_{\text{TBW/0.73}} = \text{TBW/0.73}
\end{equation}
Further, FMkg_{TBW/0.73} was calculated as FFMkg_{TBW/0.73} extracted from body weight.

*Lifestyle questionnaire*

In the lifestyle questionnaire, the participants were asked to report how often during the last year they were involved in non-vigorous and vigorous physical activity, choosing between 4 levels for both: Never, less than 1 h/week, 1-2 h/week and 3 h/week or more. They were also asked to report their habitual activity level with four choices: sedate, light activity 4 h/week or more, condition training 4 h/week or more and regular hard physical training. The participants were asked to describe their smoking status by choosing between non-smoker or current smoker, and to give the number of cigarettes smoked daily, years since smoking start and cessation, and how many years totally smoked. The participants were asked to assess their body weight at ages 18, 30, 40, 50 and 60y, 6 and 12 months prior to the study date, and the lowest and highest weight since 18y age. The questionnaire also included a question on whether the participant had one or more chronic diseases or disabilities limiting physical activity, and if answering “Yes”, the participant was asked to write down the disease/disability.

*Pilot study*

We conducted a pilot study on the anthropometric, BIS and DXA measurements in 20 hospital employees and other voluntary subjects recruited by the project team in order to study variability in measurements between the two project team members who conducted the measurements (HU and GSE). There was no statistically significant difference in the measurements of arm, waist and hip circumference or BIS and DXA measurements between the measurers (One-Sample T-test, all P≥0.21). There was a statistically significant slight difference between the measurers in height and weight measurements (mean differences 0.1 cm and 0.1 kg), but this difference was without clinical significance.

*Statistical analysis*

Power calculation. Assuming that the participants have an average weight of 90 kilos and 40% fat, gave estimated total fat mass of around 36 ± 3 kg. Given a α of 5% and statistical power (1-β) of
80%, the minimum number of obese subjects to be included in each group, to detect a difference of
2 kg fat mass, was then $n = 2 \times (3/2)^2 \times 7.9 = 35$ per group. We also invited 20 healthy and normal
weight persons, to make sure to have a control group with optimal measurement conditions and
results.

Data analysis. There is a considerable difference between the BIS and DXA technologies in
estimating FMkg and FFMkg. In DXA, FM is directly estimated in kg, and FFMkg can be
calculated as the sum of LTM and BMC estimates in kg. The percentage estimates of FM and FFM
are calculated using the sum of all body mass compartments in kg as body weight. In BIS, body
weight obtained from an independent measurement (a digital scale in our study) is inserted into the
software prior to the measurements. FMkg and FFMkg estimates are calculated using the
percentage estimates of these and the given body weight in kg. The mean body weight measured by
the digital scale in our study was 0.5 kg (SD 0.8 kg) higher than the mean DXA estimate of body
weight. This did, however, not significantly differ between obese and other subjects, overweight
and normal weight subjects, or half- versus whole- DXA-scanned subjects (data not shown).
Consequently, the FMkg and FFMkg estimates of DXA were converted to values the sum of which
totalled body weight by the digital scale. We calculated physical activity score as a sum of scores
from non-vigorous and vigorous activity, giving score 0-3 for the four choices of non-vigorous
activity and double score for the respective choices of vigorous activity. This resulted in total
physical activity score range from 0 to 9. We further categorized the total physical activity score
into low ($\leq 3$), middle (4-6) and high (7-9) activity groups. We gave score 0-2 for the habitual
physical activity choices, combining the two choices with highest activity. Smoking status was
reported as never-, current and ex-smoker. Weight change during the preceding 12 months was
calculated using the self-reported weight for 12 months earlier and the measured weight. Diseases
and disabilities limiting physical activity were categorized according to type of disease/disability.
Descriptive statistics are reported as distributions and as mean values with SD. Bland-Altman
plots (27), a well-known tool for comparing a new and a referent method, were used to present
differences between FM and FFM estimates by DXA and BIS. The limits of agreement (LoA) between the two methods were defined as mean difference ± 1·96 SD\(^{(27)}\). We tested mean difference between the methods (\(\Delta_{\text{DXA-BIS}}\)) with paired-samples t-test, and used independent-samples t-test (if two subgroups) or one-way ANOVA (if three subgroups) to analyse differences in \(\Delta_{\text{DXA-BIS}}\) between subgroups. We considered two-tailed \(P<0\cdot05\) as statistically significant. We conducted the statistical analysis using software SPSS 17.0.1 for Windows (SPSS Inc., Chicago, IL, USA).

**Results**

Subject characteristics are as described in Table 1. A total of 93 participants (61\% males) with successful measurements were included in the study, with mean age of 51 years. The majority of the participants (59 subjects, 63\%) were obese (BMI\(\geq30\cdot0\, \text{kg/m}^2\)), while 22 subjects (24\%) were overweight (BMI=25·0-29·9 kg/m\(^2\)) and 12 subjects (13\%) had a normal BMI (20·0-24·9 kg/m\(^2\)). Some participants had changed weight between the clinical examination of the main study and the present study measurement date, therefore the intended proportion of subjects with BMI \(\geq30\cdot0/\leq30\cdot0\, \text{kg/m}^2\) (80/20) was some changed. Forty-one percent of the participants reported chronic diseases or disabilities limiting physical activity.

FFM as kg and proportion (FFMkg and FFM\%, respectively) were significantly higher in men than women, whereas FM as proportion (FM\%) was significantly higher in women, estimated with both DXA and BIS (all \(P<0\cdot001\)). There was no significant difference in FM as kg (FMkg) between the sexes (Table 1).

**FM comparison**

BIS significantly underestimated mean FMkg and FM\% as compared to DXA (Table 2 and Fig. 1a and b). Mean differences of the estimates between the methods (\(\Delta_{\text{DXA-BIS}}\)) and Bland-Altman 95\% LoA:s were 4·1 (-2·9 and 11·2) kg and 4·5 (-2·9 and 11·8) \% for FMkg and FM\%, respectively (Table 2 and Fig. 1a and b). The estimates by the two methods were highly correlated (Table 2). There was a statistically significant inverse correlation between the difference and mean values of FM (\(r_{\text{Pearson}}=-0\cdot27\) and -0·54, for FMkg and FM\%, respectively, \(P<0\cdot01\) for both, Fig. 1a and b).
Underestimation of FMkg was significantly more pronounced in men than in women ($\Delta_{\text{DXA-BIS}}$ (SD) 4·8 (3·8) vs. 3·1 (3·0) kg, $P=0·02$) (Table 3). Underestimation of FM% was significantly more pronounced in normal weight subjects than overweight and obese subjects ($\Delta_{\text{DXA-BIS}}$ (SD) 6·9 (2·7) vs. 4·1, (3·8) %, $P=0·005$) (Table 4). Estimation difference for FM% between the two methods was significantly inversely correlated with the FM% estimate by DXA ($r_{\text{Pearson}}=-0·29$, $P=0·005$) (data not shown). The BIS estimates calculated as 73% hydration of FFM ($\text{FMkg}_{\text{TBW/0·73}}$ and $\text{FM\%}_{\text{TBW/0·73}}$) were significantly higher than the respective BIS estimates by the proprietary software. Consequently, the underestimation of these FM values was significantly smaller than for these estimates given by the BIS software. However, the method differences for $\text{FMkg}_{\text{TBW/0·73}}$ and $\text{FM\%}_{\text{TBW/0·73}}$ ($\Delta_{\text{DXA-BIS(TBW/0·73)}}$) were statistically significant (Table 2) and all results for $\text{FM}_{\text{TBW/0·73}}$ estimates close to identical with FM estimates by BIS software (data not shown).

There was neither statistically significant difference in the underestimation of FMkg or FM% by BIS between obese (BMI$\geq$30·0 kg/m$^2$) and other subjects, nor between very obese (BMI$\geq$34·0 kg/m$^2$, 18 subjects) and other subjects, or between subjects with half- and whole-body DXA scan (data not shown). There was no difference in the underestimation through age groups, physical activity scores or recent weight change groups (data not shown).

When grouping subjects into FMkg and FM% quartiles by BIS and DXA estimates, 74 and 73% of the subjects, respectively, were classified into the same quartile by the two methods, whereas 26 and 25%, respectively were classified into same ± 1 quartile (Table 5).

**FFM comparison**

BIS significantly overestimated mean FFMkg and FFM% as compared to DXA (Table 2 and Fig. 1c and 1d). $\Delta_{\text{DXA-BIS}}$ and Bland-Altman LoA:s were -4·1 (-11·2 and 2·9) kg and -4·5 (-11·9 and 2·9) % for FFMkg and FFM%, respectively (Table 2 and Fig. 1c and d). The estimates by the two methods were highly correlated (Table 2). There was a statistically significant inverse correlation between the difference and mean values of FFM ($r_{\text{Pearson}}=-0·36$ and -0·53, for FFMkg and FFM%, respectively $P<0·01$ for both, Fig. 1c and d). Overestimation of the absolute FFMkg was
significantly more pronounced in men than in women ($\Delta_{\text{DXA-BIS}}$ (SD) -4.8 (3.8) vs. -3.1 (3.0) kg, $P=0.03$) (Table 3). Additionally, overestimation of FFM% was significantly more pronounced in normal weight subjects than overweight and obese subjects ($\Delta_{\text{DXA-BIS}}$ (SD) -6.9 (2.8) vs. -4.1 (3.8) %, $P=0.006$) (Table 4). Estimation difference for FFM% between the two methods was significantly inversely correlated with the FFM% estimate by DXA ($r_{\text{Pearson}}=-0.33$, $P=0.001$) (data not shown). The BIS estimates calculated as 73% hydration of FFM (FFMkgTBW/0.73 and FFM%TBW/0.73) were significantly lower than the respective BIS estimates by the proprietary software. Consequently, the overestimation of these FFM values was significantly smaller than for these estimates given by the BIS software. However, the method differences for FFMkgTBW/0.73 and FFM%TBW/0.73 ($\Delta_{\text{DXA-BIS(TBW/0.73)}}$) were statistically significant (Table 2) and all results for FFMTBW/0.73 estimates close to identical with FFM estimates by BIS software (data not shown).

There was neither statistically significant difference in the overestimation of FFMkg or FFM% by BIS between obese (BMI$\geq$30.0 kg/m$^2$) and other subjects, nor between very obese (BMI$\geq$34.0 kg/m$^2$, 18 subjects) and other subjects, or between subjects with half- and whole-body DXA scan (data not shown). There was no difference in the overestimation through age groups, physical activity scores or recent weight change groups (data not shown).

When grouping subjects into FFMkg and FFM% quartiles by BIS and DXA estimates, 74 and 71% of the subjects, respectively, were classified into the same quartile by the two methods, whereas 26 and 26%, respectively were classified into same ± 1 quartile (Table 5).

**Discussion**

In this validation study, we observed large inter-individual variation in FM and FFM estimates between BIS and DXA. We observed a significant underestimation of FM and overestimation of FFM by BIS as compared to DXA. The underestimation of FMMkg and the overestimation of FFMkg were higher in men than to women. The underestimation of FM% and the overestimation of FFM% were both higher at normal compared to high BMI. Further, underestimation of FM% was more pronounced at low FM% and overestimation of FFM% was more pronounced at high FFM%. The
FFM and FM estimates calculated from TBW by BIS were closer to these estimates from DXA. The large inter-individual variation and heterogeneity in validity between subgroups indicate that BIS is not a suitable method for single body fat or fatfree mass assessment at an individual level. The present BIS device BodyScout with the proprietary software was initially designed to estimate body liquid compartments. Our study demonstrates that it may not be equally suitable for estimation of body fat and fatfree mass.

In our population with obese and non-obese subjects, using the present BIS device, the BIS estimates of FM and FFM will be significantly better if these estimates are calculated directly from TBW by BIS, expecting 73% hydration of FFM. Such observation has been done earlier by Ellegård et al. (14). Earlier comparisons in different population groups have, in line with our results, found large inter-individual variation in mean difference between BIS and DXA, accompanied by overestimation of FFM (15,28,29) and underestimation of FM (29) by BIS. Underestimation of FFM by BIS has also been reported, but in incurable cancer patients (14). In contrast to our study, the overestimation of FFM by BIS was in most previous studies in adults not related to BMI, other anthropometric variables, sex (28,29) or magnitude of FFM and FM estimates (29). In one study, overestimation of FFM by BIS compared to DXA was related to overweight (13). In children, BIS has been found to overestimate FM in lean, and underestimate FM in overweight subjects (30). Higher validity of FFM% and FM% estimates in overweight than normal weight subjects is to our knowledge reported only by our study. The number of normal weight subjects in the present study (n 12) probably is too low to draw conclusions on this. However, the significant correlations between the method difference (ΔFM%_{DXA-BIS} and ΔFFM%_{DXA-BIS}) and the FM% and FFM% values, respectively, indicate an inverse dose-response association between validity of these estimates and adiposity of the subject.

BIS validation studies against other than DXA have compared BIS estimates of ECW with dilution methods and ICW with total body potassium. These have found reduced BIS validity in disease state or obesity (12,21). A suggested explanation for reduced validity of BIS measurements in
obesity is the sensitivity of BIS to detect imbalance in body water compartments. BIS estimates of ECW and ICW are altered by changes in these, as found by Moissl in patients with renal failure and healthy subjects\(^{(21)}\). The ECW/ICW ratio is greater in obese due to increased amount of ECW and TBW\(^{(10)}\) as compared to non-obese subjects, leading to overestimation of FFM and underestimation of FM in obesity. Although BIS is sensitive to body water changes in normal, healthy subjects\(^{(9)}\), accuracy of BIS estimates of body water decreases in obesity\(^{(12)}\). The opposite, a larger measurement error by BIS in normal weight subjects in our study, cannot be explained by this reduced BIS sensitivity in an abnormal body fluid balance. However, we observed larger measurement error by BIS in normal weight subjects only in the percentage proportions of FFM and FM. The reduced validity of BIS in altered fluid balance has been associated rather with the absolute estimates of ICW and ECW in litre\(^{(12,21)}\).

Another possible explanation for the large inter-individual variability between BIS and DXA may be a reduced validity of DXA measurements in obese subjects. Although DXA has been found to be an accurate method for body fat and lean tissue measurements\(^{(31)}\), underestimation of FFM in women and reduced validity in FFM estimates by truncal adiposity\(^{(32)}\) and increasing body size\(^{(33)}\) have been reported. DXA has been suspected to underestimate FM in severely obese subjects as a result of increased photon absorption\(^{(34)}\). If the DXA measurements in our study were similarly biased, the observed underestimation of FM by BIS in obese subjects may have been smaller than the real underestimation in these subjects. In that case, the difference in BIS measurement error between normal weight and overweight subjects would in reality be smaller than observed. We did not observe differential method difference between the subjects scanned one-sided by DXA (\(n\) 19) and others. We can therefore not suspect a reduced precision of the DXA device in estimation of total body FM and FFM from the one-sided DXA scan in this study.

It has been suggested that BIS suits for assessment of body composition in groups or individual body composition changes rather than determination of single individual body composition\(^{(35)}\). BIS estimates of individual TBW measurements have not been considered valid in a population with
wide range of BMIs\textsuperscript{(36)}, but BIS has been reported to be a reproducible method within an individual\textsuperscript{(37,38)} and track intra-individual changes in TBW accurately, regardless of BMI\textsuperscript{(36,38)}. Estimating changes in body composition may be the most applicable use of BIS in clinical practice, although a recent study suggested that BIS is inappropriate also for this purpose because of the large inter-individual variability\textsuperscript{(15)}. We found that BIS classifies the population relatively accurately into quartiles according to FM and FFM. This may be satisfactory for epidemiological studies. Body composition assessment is, however, mainly used in clinical studies and accurate individual measurements are necessary. Hence, correct ranging into groups is not sufficient for validity of the device.

Careful participant recruitment and standardized examination procedures are strengths of this study. The pilot study conducted before the data collection showed agreement in measurements between the two measurers. Corrections were made in height and weight measurement procedures in order to minimize the slight measurer difference. The small number of normal weight subjects is a limitation of this study. Use of validated regression equations have been warranted as a condition of clinical bioimpedance technology use in subjects with abnormal body shape\textsuperscript{(6)}. We did not for the purpose of this study develop new predicted equations based on BodyScout estimates of body fluid compartments, resistance and BMI, as our aim was to validate the BodyScout device “as is”. The number of normal weight subjects in our sample would probably have been too low to develop equations useful for clinical practice.

We conclude that we found a large inter-individual agreement in FM and FFM estimates between the present BIS device and DXA. We also observed that this BIS device underestimates FM and overestimates FFM. In agreement with a recent validation study\textsuperscript{(15)}, we conclude that this BIS device using the proprietary software has too low accuracy to be used in estimation of body fat and fatfree mass at individual level. The absolute BIS estimates in kg may be less valid in men than women, and may be less comparable with DXA estimates than the proportional estimates. In epidemiological studies, a population can be satisfactorily classified into groups by the FFM and
Finally, we suggest that future validation studies on BIS among obese subjects include golden standard methods for estimation of body fluids.

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References

### Table 1. Characteristics of study participants (n 93)

<table>
<thead>
<tr>
<th>Variable</th>
<th>All (n 93)</th>
<th>Men (n 57)</th>
<th>Women (n 36)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Age (years)</td>
<td>51·0</td>
<td>11·5</td>
<td>51·7</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>94·6</td>
<td>16·5</td>
<td>100·4</td>
</tr>
<tr>
<td>Body mass index (kg/m^2)</td>
<td>30·9</td>
<td>4·5</td>
<td>31·2</td>
</tr>
<tr>
<td>Waist-hip ratio</td>
<td>0·96</td>
<td>0·10</td>
<td>1·01</td>
</tr>
<tr>
<td>Arm circumference (cm)</td>
<td>33·2</td>
<td>3·2</td>
<td>33·9</td>
</tr>
<tr>
<td><strong>DXA-derived data</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FMkg (kg)</td>
<td>35·2</td>
<td>10·2</td>
<td>34·2</td>
</tr>
<tr>
<td>FM% (%)</td>
<td>36·9</td>
<td>7·2</td>
<td>33·5</td>
</tr>
<tr>
<td>FFMkg (kg)</td>
<td>59·4</td>
<td>10·7</td>
<td>66·1</td>
</tr>
<tr>
<td>FFM% (%)</td>
<td>63·1</td>
<td>7·2</td>
<td>66·5</td>
</tr>
<tr>
<td><strong>BIS-derived data</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECW/ICW ratio</td>
<td>0·80</td>
<td>0·08</td>
<td>0·78</td>
</tr>
<tr>
<td>FMkg (kg)</td>
<td>31·1</td>
<td>11·2</td>
<td>29·5</td>
</tr>
<tr>
<td>FM% (%)</td>
<td>32·5</td>
<td>9·2</td>
<td>28·6</td>
</tr>
<tr>
<td>FFMkg (kg)</td>
<td>63·5</td>
<td>12·0</td>
<td>70·9</td>
</tr>
<tr>
<td>FFM% (%)</td>
<td>67·6</td>
<td>9·2</td>
<td>71·4</td>
</tr>
<tr>
<td>Re (ohm)</td>
<td>549</td>
<td>77</td>
<td>511</td>
</tr>
<tr>
<td>Ri (ohm)</td>
<td>1122</td>
<td>255</td>
<td>992</td>
</tr>
<tr>
<td>Resistance at 50 kHz (ohm)</td>
<td>449</td>
<td>72</td>
<td>410</td>
</tr>
<tr>
<td>Reactance at 50 kHz (ohm)</td>
<td>51·2</td>
<td>7·3</td>
<td>49·6</td>
</tr>
<tr>
<td>Phase angle (°)</td>
<td>6·6</td>
<td>0·8</td>
<td>6·9</td>
</tr>
<tr>
<td><strong>n %</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Abdominal obesity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>waist circum. &gt;102 cm (males), &gt;88cm (females)</td>
<td>65</td>
<td>69·9</td>
<td>39</td>
</tr>
<tr>
<td><strong>High waist-hip ratio</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;1·00 (males), &gt;0·85 (females)</td>
<td>57</td>
<td>61·3</td>
<td>35</td>
</tr>
<tr>
<td><strong>Weight reduction ≥10% during the last 12 months</strong></td>
<td>6</td>
<td>6·5</td>
<td>3</td>
</tr>
<tr>
<td><strong>Weight reduction ≥5% during the last 12 months</strong></td>
<td>18</td>
<td>19·4</td>
<td>9</td>
</tr>
<tr>
<td><strong>Smoking status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoker</td>
<td>40</td>
<td>43·0</td>
<td>27</td>
</tr>
<tr>
<td>Ex-smoker</td>
<td>36</td>
<td>38·7</td>
<td>25</td>
</tr>
<tr>
<td>Daily smoker</td>
<td>17</td>
<td>18·3</td>
<td>5</td>
</tr>
<tr>
<td><strong>Chronic diseases/disabilities limiting physical activity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combined</td>
<td>15</td>
<td>16·1</td>
<td>9</td>
</tr>
<tr>
<td>Knees/Hips</td>
<td>9</td>
<td>9·7</td>
<td>4</td>
</tr>
<tr>
<td>Cardiac</td>
<td>6</td>
<td>6·5</td>
<td>5</td>
</tr>
<tr>
<td>Back/prolaps</td>
<td>3</td>
<td>3·2</td>
<td>3</td>
</tr>
<tr>
<td>Other*</td>
<td>5</td>
<td>5·5</td>
<td>-</td>
</tr>
</tbody>
</table>

3 BIS, Bioelectrical impedance spectroscopy; DXA, Dual-energy X-ray absorptiometry; ECW, extracellular water; FM, fat mass; FFM, fatfree mass; ICW, intracellular water; Re, resistance of extracellular volume; Ri, resistance of intracellular volume.

6 *Rheumatic, pulmonary or psychiatric problems, fibromyalgi or other.
Table 2. Comparison of FM and FFM estimates by DXA, and BIS by the proprietary software (BISsoftware) and by direct calculation from TBW by BIS

All subjects (n 93)

<table>
<thead>
<tr>
<th></th>
<th>DXA</th>
<th>BISsoftware†</th>
<th>Correlation (DXA-BISsoftware)</th>
<th>Difference between the methods, ΔDXA-BISsoftware</th>
<th>BIS_TBW/0.73‡</th>
<th>Correlation (DXA-BIS_TBW/0.73)</th>
<th>Difference between the methods, ΔDXA-BIS_TBW/0.73</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>SD</td>
</tr>
<tr>
<td>FMkg</td>
<td>35·2</td>
<td>10·2</td>
<td>31·1</td>
<td>11·2</td>
<td>0·95</td>
<td>4·1***</td>
<td>3·6</td>
</tr>
<tr>
<td>FM %</td>
<td>36·9</td>
<td>7·2</td>
<td>32·5</td>
<td>9·2</td>
<td>0·92</td>
<td>4·5***</td>
<td>3·8</td>
</tr>
<tr>
<td>FFMkg</td>
<td>59·4</td>
<td>10·7</td>
<td>63·5</td>
<td>12·0</td>
<td>0·96</td>
<td>-4·1***</td>
<td>3·6</td>
</tr>
<tr>
<td>FFM %</td>
<td>63·1</td>
<td>7·2</td>
<td>67·6</td>
<td>9·2</td>
<td>0·92</td>
<td>-4·5***</td>
<td>3·8</td>
</tr>
</tbody>
</table>

BIS, Bioelectrical impedance spectroscopy; DXA, Dual-energy X-ray absorptiometry; FM, fat mass; FFM, fatfree mass; TBW, total body water

Mean difference between the DXA and BIS methods statistically significant: ***P<0·001.

†FM and FFM estimated by BIS software as described by Chamney et al. (22)

‡FM and FFM estimated by direct calculation from TBW by BIS, expecting 73% hydration of FFM (26)

Table 3. Difference between the methods (ΔDEXA-BIS) in FM and FFM estimates in men and women

Mean differences and standard deviations

<table>
<thead>
<tr>
<th></th>
<th>Men (n 57)</th>
<th>Women (n 36)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>ΔFMkgDXA-BIS</td>
<td>4·8</td>
<td>3·8</td>
</tr>
<tr>
<td>ΔFM%DXA-BIS</td>
<td>4·9</td>
<td>3·9</td>
</tr>
<tr>
<td>ΔFFMkgDXA-BIS</td>
<td>-4·8</td>
<td>3·8</td>
</tr>
<tr>
<td>ΔFFM%DXA-BIS</td>
<td>-4·9</td>
<td>3·9</td>
</tr>
</tbody>
</table>

BIS, Bioelectrical impedance spectroscopy; DXA, Dual-energy X-ray absorptiometry; FM, fat mass; FFM, fatfree mass

Mean difference statistically significant from men: *P<0·05.
**Table 4.** Difference between the methods ($\Delta_{\text{DEXA-BIS}}$) in FM and FFM estimates in normal weight (BMI<25 kg/m$^2$) and overweight (BMI$\geq$25 kg/m$^2$) subjects

<table>
<thead>
<tr>
<th></th>
<th>Normal weight subjects (BMI&lt;25 kg/m$^2$) (n = 12)</th>
<th>Overweight subjects (BMI$\geq$25 kg/m$^2$) (n = 81)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>$\Delta$FM$_{\text{kg, DXA-BIS}}$</td>
<td>5·0</td>
<td>2·3</td>
</tr>
<tr>
<td>$\Delta$FM$_{%\text{, DXA-BIS}}$</td>
<td>6·9</td>
<td>2·7</td>
</tr>
<tr>
<td>$\Delta$FFM$_{\text{kg, DXA-BIS}}$</td>
<td>-5·0</td>
<td>2·3</td>
</tr>
<tr>
<td>$\Delta$FFM$_{%\text{, DXA-BIS}}$</td>
<td>-6·9</td>
<td>2·8</td>
</tr>
</tbody>
</table>

BIS, Bioelectrical impedance spectroscopy; DXA, Dual-energy X-ray absorptiometry; FM, fat mass; FFM, fatfree mass

Mean difference statistically significant from normal weight subjects: **$P<0·01$.

**Table 5.** Joint classification of subjects by quartiles of FM and FFM estimated by DXA and BIS (n = 93)

<table>
<thead>
<tr>
<th></th>
<th>Classified into same quartile</th>
<th>Classified into same ± 1 quartile</th>
<th>Classified into opposite quartiles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>FM$_{\text{kg}}$</td>
<td>74</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>FM$_{%}$</td>
<td>73</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>FFM$_{\text{kg}}$</td>
<td>74</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>FFM$_{%}$</td>
<td>71</td>
<td>26</td>
<td>3</td>
</tr>
</tbody>
</table>

BIS, Bioelectrical impedance spectroscopy; DXA, Dual-energy X-ray absorptiometry; FM, fat mass; FFM, fatfree mass
Figure 1. Bland-Altman plots of comparisons of bioelectrical impedance spectroscopy (BIS) with dual-energy X-ray absorptiometry (DXA) estimates for a) body fat mass in kg (FMkg), b) body fat mass as percentage (FM%), c) body fatfree mass in kg (FFMkg), and d) body fatfree mass as percentage (FFM%) with limits of agreement (LoA) (dashed lines) and Pearson correlation coefficient (r) (n 93)
LoA\textsubscript{upper} = 11.2

LoA\textsubscript{lower} = -2.9

\( r = -0.27 \)

LoA\textsubscript{upper} = 11.8

LoA\textsubscript{lower} = -2.9

\( r = -0.54 \)
1c.  

![Graph showing scatter plot with line of agreement (LoA) for Average FFMkg and Difference in FFMkg (DXA-BIS). The LoA upper is 2.9 and the LoA lower is 11.2. The correlation coefficient (r) is -0.36.]

1d.  

![Graph showing scatter plot with line of agreement (LoA) for Average FFM% and Difference in FFM% (DXA-BIS). The LoA upper is 2.9 and the LoA lower is 11.9. The correlation coefficient (r) is -0.53.]

r = -0.36

LoA upper = 2.9

LoA lower = 11.2

r = -0.53

LoA upper = 2.9

LoA lower = 11.9