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Original Article

# Body composition: validity of segmental bioelectrical impedance analysis

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Bioelectrical impedance analysis (BIA) measures the impedance associated with passage of an alternating current through the body which is proportional to total body water (TBW) and therefore can provide expedient estimates of body composition. However, little validity information is available for commercially available bathroom scale type devices which perform whole body estimates from segmental (lower limb) measurements. This study therefore compared body composition estimates between a commercially available segmental BIA device (Tanita BC-532) and four compartment criterion values. Body composition of nine males and nine females (mean ± SD: 37.7 ± 18.7 yr; 170.7 ± 5.3 cm; 68.38 ± 9.7 kg) was determined via BIA and a four compartment model incorporating measures of body density, TBW and bone mineral mass. While the mean %BF and fat free mass (FFM) values for both methods were not significantly different, considerable intra-individual differences were observed. BIA values varied from the four compartment values by -3.0 to 4.4 %BF and -3.3 to 1.9 kg FFM. The BIA estimates of TBW were significantly different from the criterion measures and intra-individual differences displayed a large range (-0.6 to 3.6 kg). Significant underestimations of TBW via BIA are concerning given that this is the parameter initially established by this method. Furthermore, the BIA data resulted in a FFM hydration value of 68.5% which was significantly ($p$<0.001) lower than the four compartment value of 72.0%. In conclusion, the BIA device tested displayed poor individual accuracy for the estimation of body composition compared with a four compartment criterion method.

**Key Words: total body water, percent body fat, foot-to-foot BIA, four-compartment body composition model, fat free mass**

## INTRODUCTION

Expedient estimates of body composition are often sought in the areas of medicine, nutrition, sport science and the health and fitness industry. Bioelectrical impedance analysis (BIA), which determines total body water (TBW) from measures of electrical impedance and resistance associated with passage of an alternating current through the body, provides body composition estimates with minimal compliance considerations. Estimates of fat free mass (FFM) may be derived from TBW measures by assuming a fixed FFM hydration value. Fat mass (FM) and percentage body fat (%BF) can then be determined if body mass is measured. Whole body BIA, which requires arm to leg measurements, has been compared recently with values derived using a criterion four compartment densitometric model and prediction equations were developed.[1] However, little information is available regarding the validity of popular commercially available bathroom scale type BIA devices which perform segmental measurements (lower limbs). These devices were developed on the basis that body segments such as the lower limbs account for a large proportion of whole body impedance. Although it would be expected that the accuracy of segmental BIA is less than that for whole body BIA, some work suggests little difference between the two techniques.[2] It was therefore the aim of this study to determine the accuracy of segmental BIA in estimating TBW and %BF by comparing BIA body composition data for a heterogeneous group of males and females with TBW determined via deuterium oxide dilution and four compartment derived %BF.

## METHODS

### *Subjects*

Nine female (26.9 ± 11.2 yr; 167.5 ± 4.2 cm; 64.0 ± 8.9 kg) and nine males (mean ± SD: 48.6 ± 18.8 yr; 173.8 ± 4.5 cm; 72.7 ± 9.0 kg) volunteered for this project which was approved by the Flinders Medical Centre Committee for Clinical Investigations.

### *Protocol*

All measurements on each subject were conducted during

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a 4 hr morning testing session when they were post-absorptive, normally hydrated and had not exercised for 36 hr.

Subjects were requested to void before testing to eliminate any flatus in the gastrointestinal tract. Height was measured to within 1 mm by using a wall-mounted stadiometer and body mass determined to the nearest 20 g with a calibrated electronic scale (model FW-150K, A & D Mercury Pty. Ltd, South Australia, Australia). This was followed by BIA measurements, deuterium dosing, underwater weighing and a whole body dual energy x-ray absorptiometry (DXA) scan.

### *BIA*

All BIA measurements were determined using a Tanita model BC-532 single frequency leg-to-leg impedance analyser. This device combines four foot contact electrodes built into the surface of an electronic platform scale. Subjects stood motionless with bare feet placed on the electrodes while an alternating current (~ 200 µA, 50 kHz) was passed through the lower body. Lower body impedance and body mass were measured simultaneously while the subject stood on the scale. The analyser uses proprietary software to calculate %BF, FM, FFM, bone mineral mass (BMM) and TBW. Subject activity levels were used to determine whether the "athletic mode" was selected as per the manufacturer's guidelines.

### *Four compartment model*

The four compartment body composition model involves the measurement of body density (BD), BMM and TBW by hydrodensitometry, DXA and isotopic dilution, respectively. These procedures have been described previously.[3,4] Briefly, BD was measured by hydrodensitometry (underwater weighing) and corrected for the water density (Dw) and gas volume in the respiratory system. This lung volume (LV) was estimated by oxygen dilution at ~ functional residual capacity. Water temperature was maintained in the range 35.5 ± 1.0 °C. Body mass was determined using an electronic scale and recorded to the nearest 20 g.

BD was then calculated using the formula of Goldman & Buskirk except that no correction was applied for gas in the gastrointestinal tract.[5]

$$BD = \frac{M_A}{\left(\frac{M_A - M_W}{D_W}\right) - LV}$$

Where: BD = Body density
$M_A$ = Mass in air
$M_W$ = Mass in water
$D_W$ = Density of water
LV = Volume of gas in the lungs

DXA measurements were conducted at Flinders Medical Centre's Department of Medical Imaging with a Lunar Prodigy total body scanner. The machine was calibrated daily using the phantom supplied by the manufacturer. The subjects were scanned in minimal amount of clothing e.g. swimming trunks or running shorts. The scan analysis produced values for bone mineral content (BMC), FM, bone free lean tissue and %BF.

A gram of bone mineral yields 0.9582 g of ash because of the loss of labile components during heating at over 500°C.[6] The BMC or bone ash reported by DXA was therefore converted to BMM by multiplying it by 1.0436.[7]

TBW was measured by deuterium dilution (40 mg $^2H_2O$/ kg dose adjusted to ~ 100 ml with distilled $H_2O$). The dose, background and equilibrium $^2H_2O$ concentrations were determined using a Europa Scientific Geo 20-20 isotope ratio mass spectrometer (Europa, Crewe, Cheshire, UK) which was calibrated against Vienna Standard Mean Ocean Water and International Atomic Energy Agency enriched standards 302A and 302B. The isotope dilution space was calculated using a 4% correction factor for the exchange of $^2H_2O$ with non-aqueous hydrogen in accordance with the recommendations of Schoeller et al.[8]

**Table 1.** Descriptive data

| | 4-Compartment Model | Tanita (BC-532) | Mean Difference (4C – Tanita) |
|---|---|---|---|
| Men | | | |
| Age (yr) | 48.6 ± 18.8 | | |
| Height (cm) | 173.8 ± 4.5 | | |
| Mass (kg) | 72.7 ± 9.0 | 72.8 ± 9.0 | -0.1 ± 0.1 |
| %BF | 21.0 ± 6.2 | 20.8 ± 5.5 | 0.2 ± 2.5 |
| FFM (kg) | 57.0 ± 4.2 | 57.4 ± 4.9 | -0.4 ± 1.8 |
| TBW(kg) | 41.1 ± 3.2 | 39.3 ± 3.5 | 1.8 ± 1.2* |
| BMM (kg) | 3.1 ± 0.3 | 2.9 ± 0.2 | 0.2 ± 0.3 |
| $\%FFM_{hyd}$ | 72.0 ± 0.9 | 68.5 ± 1.7 | 3.5 ± 1.8* |
| %BMM/FFM | 5.45 ± 0.6 | 5.02 ± 0.1 | 0.4 ± 0.6 |
| Women | | | |
| Age (yr) | 26.9 ± 11.2 | | |
| Height (cm) | 167.5 ± 4.2 | | |
| Mass (kg) | 64.0 ± 8.9 | 64.1 ± 8.8 | -0.1 ± 0.1 |
| %BF | 26.3 ± 7.3 | 27.4 ± 7.5 | -1.1 ± 2.3 |
| FFM (kg) | 46.8 ± 5.1 | 46.1 ± 4.0 | 0.7 ± 1.5 |
| TBW(kg) | 33.7 ± 3.9 | 32.7 ± 3.0 | 1.0 ± 1.3 |
| BMM (kg) | 2.7 ± 0.4 | 2.3 ± 0.2 | 0.4 ± 0.2* |
| $\%FFM_{hyd}$ | 71.9 ± 1.2 | 70.8 ± 0.7 | 1.1 ± 1.1* |
| %BMM/FFM | 5.77 ± 0.4 | 5.06 ± 0.1 | 0.7 ± 0.4* |
| Combined | | | |
| Age (yr) | 37.7 ± 18.7 | | |
| Height (cm) | 170.7 ± 5.3 | | |
| Mass (kg) | 68.38 ± 9.7 | 68.42 ± 9.7 | -0.05 ± 0.1* |
| %BF | 23.7 ± 7.1 | 24.1 ± 7.2 | -0.5 ± 2.4 |
| FFM (kg) | 51.9 ± 6.9 | 51.8 ± 7.2 | 0.2 ± 1.7 |
| TBW(kg) | 37.4 ± 5.1 | 36.0 ± 4.6 | 1.4 ± 1.3* |
| BMM (kg) | 2.9 ± 0.4 | 2.6 ± 0.4 | 0.3 ± 0.3* |
| $\%FFM_{hyd}$ | 72.0 ± 1.0 | 68.7 ± 1.7 | 2.3 ± 1.9* |
| %BMM/FFM | 5.61 ± 0.5 | 5.04 ± 0.1 | 0.6 ± 0.5* |

%BF = percent body fat; FFM = fat free mass; TBW = total body water; BMM = bone mineral mass; $\%FFM_{hyd}$ = fat free mass hydration; %BMM/FFM = bone mineral proportion of the fat free mass
* $p < 0.05$

The masses and volumes of TBW and BMM (density = 2.982 g.cm$^{-3}$) were subtracted from the mass and volume of the whole body. The remainder was then partitioned into the fat mass and residual mass with assumed respective densities of 0.9007 and 1.404 g.cm$^{-3}$.[9, 10] The formula is:[6]

$$\%BF = \frac{251.3}{BD} - 73.9 \times \left(\frac{TBW}{\text{body mass}}\right) + 94.7 \times \left(\frac{BMM}{\text{body mass}}\right) - 179.0$$

### *Statistical analysis*

Data were analysed using SPSS 12.0.1 for Windows and statistical significance was set at $p \leq 0.05$. Paired t-tests were used to compare the various body composition parameters. The association between %BF, FFM and TBW estimates were evaluated using linear regression analyses.

## RESULTS

The descriptive statistics and body composition variables for our sample are presented in Table 1. The men were significantly older and taller than the women ($p < 0.009$), but there were no gender differences for mass, body mass index (BMI) and %BF (4C). The BIA mass (68.42 ± 9.73 kg) was significantly ($p = 0.014$) higher than the scale mass (68.38 ± 9.74 kg) with individual differences ranging from -0.18 to 0.06 kg. There were no significant differences between the two methods for % BF or FFM values ($p \geq 0.17$) with mean difference of -0.5 ± 2.4 and 0.2 ± 1.7, respectively. However, the intra-individual differences between the two methods were considerable and ranged from -3.2 to 4.4 % BF (Figure 1) and -3.3 to 2.3 kg FFM (Figure 2).

The BIA significantly underestimated both TBW (36.0 ± 4.6 kg vs 37.4 ± 5.1 kg) and hence, $FFM_{hyd}$ (68.7 ± 1.7 % vs 72.0 ± 1.0 %) compared with the criterion deuterium analyses ($p < 0.001$). The mean differences between the four compartment analyses and BIA derived values of TBW and $FFM_{hyd}$ were 1.4 ± 1.3 kg and 2.3 ± 1.9 %, respectively. There was also a large range of intra-individual variation for TBW (-1.2 to 3.6 kg; Figure 3) and $FFM_{hyd}$ (-0.3 to 6.6 %). Furthermore, mean BMM estimates from BIA were significantly ($p < 0.001$) lower than DXA determined values (Table 1), again with relatively large intra-individual differences (-0.3 to 0.6 kg).

## DISCUSSION

The BIA device used in this study measured body mass and lower body impedance simultaneously to estimate %BF, FFM, TBW and BMM. The mean body mass for the group determined via the BIA device was slightly higher (BIA = 68.42 kg, Scale = 68.38 kg; $p = 0.014$) than the scale mass. Individual measures generally varied up to 0.1 kg of each other. One subject displayed a difference between the devices of 0.2 kg. This is an area that could be improved upon even though it can not be expected that the BIA device return the same body mass accuracy (± 20 g) as the more expensive electronic balance. It would be anticipated that the BIA device should measure within ± 50 g and therefore be no more than 70 g different from a more superior scale and certainly not 200 g different. It is anticipated that errors in the measurement of body mass would translate to smaller body composition errors because of an erroneous body mass being portioned into smaller fat and fat free compartments.

The mean %BF and FFM values for the BIA and four compartment model were not significantly different (Table 1) and no bias was apparent (Figure 1 and Figure 2); however, considerable intra-individual differences were observed (Figure 1 and Figure 2). BIA values varied from the four compartment values by -3.2 to 4.4 %BF and -3.3 to 2.3 kg FFM. These values are greater than the propagated error of 0.9 %BF associated with the use of multiple measurements in the four compartment model.[11] The 95% confidence intervals for the prediction of four compartment %BF and FFM values from the BIA measures were large at ± 5 %BF and ± 3.4 kg, respectively. Jebb et al. reported similar confidence interval (± 5.1% BF) for their larger data pool from 104 male and 101 female sub-

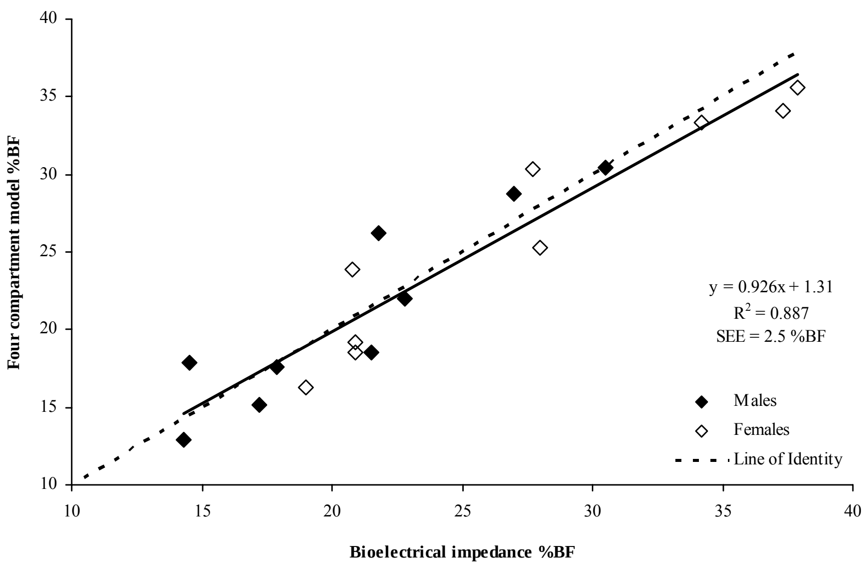


**Figure 1.** Percent body fat (%BF) comparison between the leg-to-leg bioelectrical impedance analyser and the four compartment model (SEE = standard error of estimate)

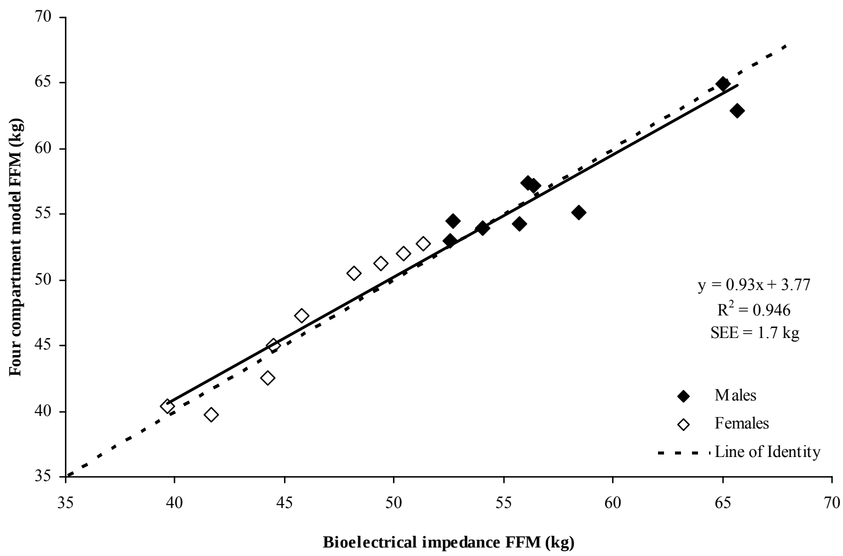


**Figure 2.** Fat free mass (FFM) comparison between the leg-to-leg bioelectrical impedance analyser and the four compartment model (SEE = standard error of estimate)

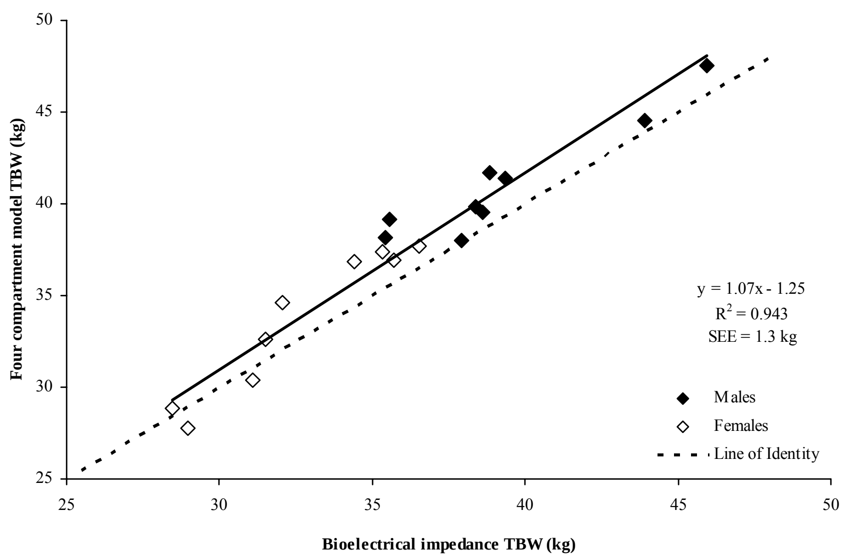


**Figure 3.** Total body water (TBW) comparison between the leg-to-leg bioelectrical impedance analyser and the deuterium dilution method (SEE = standard error of estimate)

jects who displayed a large BMI range (16.1 to 40.5).[2] This magnitude of confidence interval found by Jebb et al. and the current study clearly indicate a limited role for segmental BIA devices to accurately describe individual %BF profiles.[2] However, the small bias apparent with these devices gives them some utility in screening to provide some general body composition descriptions of various cohorts. Furthermore, no data are available to indicate if the accuracy problems with point measurements also extend to the detection of body composition changes, which are often the focus with intervention studies or the individual user.

The BIA estimates of TBW were significantly different from the criterion measures ($p < 0.001$) and intra-individual differences displayed a large range of -1.2 to 3.6 kg (Figure 3). Significant underestimations of TBW via BIA are concerning given that this is the parameter initially established by this method. Furthermore, the BIA data resulted in a FFM hydration value of 68.5 % which was significantly lower than the four compartment value of 72.0 % ($p = 0.002$). Presumably the BIA algorithms use an assumed FFM hydration value to determine body composition. While it may be anticipated that the BIA underestimation of TBW as displayed in Figure 3 should translate to an overestimation for %BF (Figure 1), this was not the case because of inter-individual variability in FFM hydration. The four compartment model does not assume a fixed FFM hydration value when determining %BF. Our 95% confidence interval for the determination of TBW from BIA was 4.4 kg which was similar to that reported by Sun et al., who used whole body BIA, for their large cohort (n = 526) of male subjects (4.2 L).[1] The prediction error for their female cohort (n = 778) was smaller (3.2L) which is in keeping with the significantly smaller mean TBW value for the females. Interestingly their BIA determined TBW was slightly greater than the observed value obtained via deuterium dilution. The use of race combined prediction equations for males and females applied to their mixed black and white cohorts may explain why this finding was different from that of the current study which identified a 1.8 kg mean underestimation of TBW via segmental BIA. An earlier study by Nunez et al. reported larger confidence intervals for the prediction of tritium dilution space via segmental BIA (~5.5 L) in healthy adults ranging in age from 18 yr to 79 yr (n = 231).[12]

BMM differences between DXA and BIA were also compared. While a significant difference between methods was observed intra-individual differences were relatively large (-0.3 to 0.7 kg). However, the determination of BMM is not a primary parameter determined by the BIA device, which presumably bases estimations of BMM from an assumed fixed fraction of the FFM.

In conclusion while the BIA device tested displayed little bias for the prediction of four compartment derived %BF and FFM values, large intra individual differences were detected. This diminishes the utility of such a device for use in describing these parameters for individuals. While a single point measurement using segmental BIA may not be robust, no data are available to determine if these devices are able to track changes in body composition accurately.

## AUTHOR DISCLOSURES

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# Body composition: validity of segmental bioelectrical impedance analysis

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# 體組成：部分生物電阻法的效度

生物電阻法(BIA)是測量交流電通過體內的阻抗，此阻抗與體內含水量成比例，因此可作為簡便的體組成估計。市售的浴室型體組計是利用部分生物電阻法去測量(下肢)而推估個體的體組成，但僅有少數的效度資料。因此本研究是將市售的部分生物電阻法儀器(Tanita BC-532)測量值與四種體組成標準量度值相比較。有 9 名男性及 9 名女性(平均值±標準差: 37.7 ± 18.7 歲; 170.7 ± 5.3 公分; 68.38 ± 9.7 公斤)的體組成各以部分生物電阻法及四種體組成模式法分別評估，體組成模式概括體密度、體內總水分及骨質密度的參數。用兩種方法評估的整體受試者平均體脂肪率及非脂體重都沒有顯著差異，但個體內的差異頗大。BIA 測量值與體組成模式評估值在體脂肪率的相差值為-3.0 至 4.4%，非脂體重的差異為-3.3 至 1.9 公斤。以 BIA 評估體內總水分與標準測量值有顯著的差異，個體內差異範圍很大 (-0.6 至 3.6 公斤)。BIA 顯著地低估體內總水分值得重視，因為這個參數一開始是用這個方法建立的。再者，在非脂組成水合值的 BIA 數據結果為 68.5%，顯著地低於體組成模式估算的 72.0% (*p* <0.001)。總而言之，部分生物電阻法儀器測量體組成，比起以四種體組成標準方法評估，有較差的個體準確性。

**關鍵字：身體總含水量、體脂肪比率、双足生物電阻體組計、四種體組成模式、非脂體重**