A comparison of bioelectrical impedance and near infra-red interactance with dual energy x-ray absorptiometry for the determination of body fat

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Abstract

Objective: To compare measurements of percentage body fat obtained using bioelectrical impedance and near infra-red interactance assessments to those obtained using dual energy x-ray absorptiometry, a reference technique.

Design: Cross-sectional, cross-validation study. Percentage body fat was assessed using bioelectrical impedance analysis (Bodystat 1500, Tanita TBF-622 foot-to-foot analysers with proprietary equations and the equation of Kotler and colleagues) and near infra-red interactance (Futrex 1000). Results were compared with a Norland XR-26 dual energy x-ray absorptiometry scanner.

Subjects: Thirteen males (mean age 35 ± 11 years) and 17 females (mean age 33 ± 11 years).

Setting: University of Wollongong, New South Wales, Australia.

Main outcome measures: Assessment of percentage body fat using the different techniques.

Statistical analysis: Bias and limits of agreement using paired t tests and correlation coefficients. Independent samples t test to assess differences between sexes.

Results: Bioelectrical impedance performed well. The foot-to-foot scales (mean 24.44 ± 8.53%), the Bodystat 1500 (mean 26.27 ± 8.57%) and the equation of Kotler et al. (mean 26.33 ± 7.79%) all gave mean values for percentage body fat that were similar to the mean value for dual energy x-ray absorptiometry (mean 24.86 ± 8.01%, $P > 0.05$). Near infra-red interactance gave an estimate of percentage body fat (30.37 ± 5.38%) significantly different from the dual energy x-ray absorptiometry value ($P < 0.001$).

Conclusion: Bioelectrical impedance analysis is an accurate, inexpensive method of assessing body composition. Further research is required before near infra-red interactance could be recommended for use in this subject population. (Nutr Diet 2002;59:120–126)

Key words: Body fat, adult, bioelectrical impedance, near infra-red interactance, dual energy x-ray absorptiometry, nutritional assessment

Introduction

Body composition assessment is a useful clinical tool for dietitians in clinical or research settings to provide feedback to patients or assess the effectiveness of nutritional interventions. Most body composition assessment methods divide the body into two compartments: fat mass and the fat free mass. Relative changes in these components of body composition are of interest in most nutritional interventions and can provide valuable information for outcomes-based research.

Direct analysis of body composition can only be made from sampling of cadavers and few studies have been published (1). Models for indirect measurement of body composition have been developed, however, no research reporting on a comparison between direct and indirect techniques has been published (2). Current methods of indirect body composition analysis can be divided into two types, criterion or reference methods and field methods. A review of currently available techniques can be found elsewhere (3).

The ideal body composition technique would be inexpensive, non-invasive, easily taught, universally applicable and capable of being performed with highly reproducible and accurate results (4). As a technique meeting all these criteria is not yet available, compromises must be made to choose a technique suitable for each situation (5). Criterion techniques are expensive either in the initial outlay for the equipment or the individual assessment and with a couple of exceptions are limited to a setting housing the equipment (usually a major teaching hospital or research centre). Field techniques of body composition have, therefore, been developed to allow cost-effective assessment of body composition in a variety of environments. Combinations of values obtained from field measures of body composition are used in prediction equations developed using the criterion methods for validation. From these analyses, equations can be derived to estimate body composition (6). However, prediction equations developed in one population should not be used in another without cross-validation (5).

Bioelectrical impedance analysis (BIA) and near infra-red interactance (NIR) are two relatively inexpensive field methods of assessing body composition. The aim of this
study was to compare assessments of percentage body fat obtained using these two field methods to the reference method, dual energy x-ray absorptiometry (DXA).

**Methods**

Subjects were healthy adults recruited from the university academic and student community by an email advertisement. Exclusion criteria included in the advertisement included the use of a pace maker (exclusion criteria for BIA) or pregnancy (exclusion criteria for the DXA scan). The study was approved by the University of Wollongong human research ethics committee and all participants signed written informed consent. Height was measured using a two-metre stature measure which was fixed to the wall (Handy height scale, Montone educational, Carnegie, Vic) and weight was measured using the Tanita TBF-622 body fat monitor (Tanita Corporation of Japan, Tokyo). Body fat as a percentage of weight was measured using a Norland XR-26 dual energy x-ray absorptiometry scanner (Norland Company, Fort Atkinson, WI), a Futrex fat analyser (Futrex Company, Gaithersburg, MD), a Bodystat 1500 body composition monitoring unit (Bodystat Ltd, Douglas, Isle of Man) and the Tanita scales. All measures were performed on the same day.

**Bioelectrical impedance analysis**

Impedance is defined as ‘the frequency dependent opposition of a conductor, animate or inanimate, to the flow of an administered alternating electrical current’ (7,8). The impedance of the body can be measured by passing a small alternating electric current (< 1 mA) through the body and measuring the resulting potential difference (voltage drop). The current is administered and detected through electrodes on the right hand and foot or in the case of the Tanita model by foot pads. BIA assesses the amount of total body water. As the fat mass is assumed to be anhydrous the current only passes through the fat free mass which is assumed to be 73% water (9). The current is below the threshold of perception of the subject by a factor of more than 1000 (10). The measure of impedance (or one of its component vectors, resistance and reactance) is used in a regression equation based on comparison with a criterion technique (usually hydrometry or underwater weighing) (5).

In this study three BIA equations were used. The first is the default equation used by the Tanita TBF-622 body fat monitor. This equation is proprietary and requires height, weight, sex, and a factor for adult or athlete. The Tanita model does not present any raw impedance data that could be used to predict body composition by an alternative equation. The second is the default equation utilised by the Bodystat 1500 body fat monitor. This equation requires height, weight, sex, and activity level (low, low to medium, medium to high, very high) to be entered. The Bodystat 1500 reports the impedance on the display. The impedance value can then be used in other equations to predict body composition. In this study the impedance value obtained was used in the Kotler et al. equation (11), a published, validated and highly employed equation in both healthy and diseased subjects.

For males the equation is:

fat-free mass
\[ = 0.50 \times \text{height}^{1.48} \times \text{impedance}^{0.55} \times 1.01(1.21) + 0.42 \times \text{weight} + 0.49. \]

For females the equation is:

fat-free mass
\[ = 0.88 \times \text{height}^{1.39} \times \text{impedance}^{0.49} \times 1.02(2.22) + 0.081 \times \text{weight} + 0.07 \]

where height is in centimetres and weight in kilograms.

**Near infra-red interactance (NIR)**

This technique is based on the principles of light absorption and reflection using near-infra-red spectroscopy. When electromagnetic radiation strikes a material, the energy is reflected, absorbed or transmitted depending on the specific properties of the material sampled (12). The Futrex 1000 emits electromagnetic radiation in the form of infra-red light at a single wavelength of approximately 940 nm into the biceps brachii muscle (personal communication Futrex Inc., 13 February 2001). A silicon-based detector then measures the intensity of the re-emitted light and compares the measure to that obtained from a calibration standard measured before each assessment. The interactance ratio is inverted, log transformed and the second derivative is calculated. The value obtained is expressed as optical density (5). The prediction equation for percentage body fat used by the Futrex 1000 is proprietary and not available from the manufacturers. The variables, other than the optical density, are weight and height and a sex factor is not included. The precision for the Futrex 1000 reported by the manufacturers is 0.41% body fat (pers. comm., Futrex Inc., 8 February 2002).

**Dual energy x-ray absorptiometry (DXA)**

DXA directly measures the total body bone mineral content, the fat mass of soft tissue and the lean mass of soft tissue independently of other variables such as weight and height. The Norland XR-26 scanner used in the present study uses a k-edge filter (samarium) to produce two photon peaks at 44 and 100 keV. This scanner makes a series of transverse scans from head to toe and the total scan takes about 20 minutes to complete. The precision for whole body fat estimates reported by the manufacturer is 2.4%. Bone mass is estimated from the relative attenuation of the two energies through bone-containing pixels. Each of the bone-containing pixels must be corrected for the overlying soft tissue mass. Beam attenuation through soft tissue depends on both the mass and proportion of fat and lean tissue components and constant attenuations have been derived for pure fat and lean tissue that are used in equations to calculate the fat and lean content (13). Studies have shown that the soft tissue attenuation ratio (the ratio of beam attenuation at the lower energy to higher energy) and percentage fat are inversely and linearly related (14). Therefore the percentage fat in soft tissue is estimated directly from the attenuation ratio. Percentage fat in the soft tissue multiplied by the soft tissue mass equals the fat mass. The lean tissue mass can then be calculated by deduction.

**Data analysis**

Data were analysed using the SPSS statistical package (SPSS Inc., Chicago, IL, version 10.0.5, 1999). Pearson
product-moment correlation coefficients were calculated to determine the relationship between DXA and the three field techniques. Paired t tests were used to assess differences between the field techniques and DXA and the technique of Bland and Altman (15) was used to determine the mean bias and limits of agreement (mean ± 2SD). The differences between the two estimates (bias) were plotted against the mean percentage body fat of the two estimates (DXA and the field method) to examine the effect of increasing percentage body fat on the agreement between the two techniques (16). With complete agreement, the mean bias is zero, and the regression slope will be zero (i.e. there is no change in the bias with increases in percentage body fat). Independent sample t tests were used to determine if there were differences in bias between the males and females.

**Results**

Thirty subjects participated in the study. The subject characteristics are shown in Table 1. All participants were Caucasian and 22 participated in regular exercise. Most subjects participated in social team sports or walked for exercise. Two subjects were competitive long distance runners, one participated in competitive kayaking, several subjects participated in regular weight training or aerobic classes and eight participants were sedentary. The sample size is consistent with that reported in the literature for comparison studies of this nature, that is between ten and 77 subjects (17–24).

As shown in Table 2 all the prediction equations for the field methods correlated significantly with the reference method (DXA). The three equations for BIA used in this sample produced an estimate of percentage body fat that was not significantly different from the DXA measure. The NIR estimate significantly overestimated percentage body fat when compared with the DXA measure ($P < 0.001$).

Figures 1 to 4 show the bias plots and limits of agreement (15) for the percentage body fat assessment using the field methods compared with the DXA measures. Figure 1 comparing the results using the Kotler equation with those from DXA results shows that the bias

<table>
<thead>
<tr>
<th>Method of assessing percentage body fat</th>
<th>Mean (%)</th>
<th>SD</th>
<th>Bias (%)</th>
<th>Limits (a)</th>
<th>Paired t test (b)</th>
<th>Correlation coefficient with DXA</th>
<th>Correlation bias vs mean (%)</th>
<th>Slope of the bias vs mean (% body fat)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DXA</td>
<td>24.86</td>
<td>8.01</td>
<td></td>
<td></td>
<td></td>
<td>0.876</td>
<td>0.000</td>
<td>0.138</td>
</tr>
<tr>
<td>BIA Bodystat 1500</td>
<td>26.27</td>
<td>8.57</td>
<td>1.41</td>
<td>8.34</td>
<td>0.075</td>
<td>0.855</td>
<td>0.000</td>
<td>-0.054</td>
</tr>
<tr>
<td>BIA Kotler</td>
<td>26.33</td>
<td>7.79</td>
<td>1.47</td>
<td>8.52</td>
<td>0.068</td>
<td>0.763</td>
<td>0.000</td>
<td>0.097</td>
</tr>
<tr>
<td>BIA Tanita</td>
<td>24.44</td>
<td>8.53</td>
<td>-0.42</td>
<td>11.44</td>
<td>0.692</td>
<td>0.631</td>
<td>0.000</td>
<td>-0.466</td>
</tr>
<tr>
<td>NIR Futrex</td>
<td>30.37</td>
<td>5.38</td>
<td>5.51</td>
<td>12.44</td>
<td>&lt; 0.001</td>
<td>0.631</td>
<td>0.000</td>
<td>0.468</td>
</tr>
</tbody>
</table>

n = 30

BIA, Bioelectrical impedance analysis, Kotler, Kotler et al. equation (11), Tanita, Tanita TBF-622 body fat scales, NIR Futrex, Futrex 1000 near infrared interactance analyzer.

(a) Limits refers to limits of agreement or 2SD from the mean.

(b) Significance of the difference of the mean percentage body fat from the field method with the mean percentage body fat from the DXA scan. This is the $P$ value of the bias.
for this equation is positive (1.47%, see Table 2) and that most of the values fall randomly around this line (the slope is non-significantly negative), only one value falls outside the limits of agreement. Figure 2 shows that the bias is very small (-0.42%, see Table 2), the slope of the bias is non-significantly positive and only one value falls outside the limits of agreement. Figure 3 shows that the bias for the equation for Futrex 1000 is large (5.51%, see Table 2) and the slope is significantly negative, and again a single value falls outside the limits of agreement. Figure 4 shows the comparison of the estimate of body fat from Bodystat 1500 with the values from DXA, the bias is positive but small (1.41%, see Table 2), with a positive non-significant slope, and a single value outside the limits of agreement. The bias using each of the field methods was not significantly different between the sexes (Kotler equation for BIA +1.48 kg female, +1.46 kg male, $P = 0.987$; Futrex 1000 NIR +4.82 kg female, +6.42 kg male, $P = 0.497$; Tanita BIA -0.79 kg female, +0.06 kg male, $P = 0.694$; Bodystat BIA +2.32 kg female, +0.21 kg male, $P = 0.173$).

**Discussion**

This study showed that BIA was accurate in assessing fat mass as a percentage of body weight in this sample population as the bias was small and the mean value obtained was not significantly different from the DXA value. Near infra-red interactance significantly overestimated percentage body fat on average, however, the bias decreased as the percentage body fat increased. These results suggest that BIA is suitable for measuring percentage body fat in our sample population, however further research is required before NIR could be recommended.

All the field methods showed a highly significant correlation with the DXA estimate of percentage body fat. However, it is the bias (average difference of the field methods estimate from the reference measure) and the limits of agreement that allow comparison of different techniques (15). In this study the Tanita scales gave an estimate of percentage body fat with the smallest bias, however, the limits of agreement were large, the Bodystat 1500 and use of the Kotler equation with BIA assessments had a larger bias with smaller limits of agreement. The
Futrex 1000 NIR gave an estimate with both a large bias and limits of agreement. While the assessment provided using the Bodystat 1500, Kotler and Tanita BIA equations are acceptable, the results obtained using the Futrex 1000 NIR have discouraged us from further use of this equipment in our population setting.

To examine the existence of a relationship between the bias and the mean of the two techniques the correlation coefficient is used. If the bias changes across a range of different percentages of body fat this not only implies a change in the bias across body fatness in a cross-sectional analysis such as this one, it also presents doubt over the ability of the technique to measure with a constant bias in longitudinal studies where a change in body composition is anticipated, for example weight loss studies. The correlation coefficient for the bias versus the mean measurement was not significant for the three BIA techniques used in this study. The Futrex 1000 NIR estimate of bias had a negative slope indicating that the bias decreased as percentage body fat increased. This slope was influenced by an outlier (the subject with the greatest body fat), nevertheless the relationship is consistent with a previous study reporting a similar relationship when NIR was compared with densitometry (25,26) and suggests this technique would be inappropriate for use in a longitudinal study.

Previous studies using the Futrex 1000 are limited. Most published research using NIR uses the dual wavelength model (Futrex 5000) as this is the model recommended by the company for research purposes. Smith et al. (26) compared the Futrex 1000 and Futrex 5000 (dual wavelength models) estimates for percentage body fat against those obtained using hydrodensitometry in female high school gymnasts. In this study the F1000 significantly overestimated percentage body fat by 4.5% (n = 89) compared to the estimates obtained using hydrodensitometry, whereas the F5000 model gave a mean estimate not significantly different from the hydrodensitometry result (-0.3%, n = 52). In general however, studies show that NIR using the Futrex 5000 model overestimates percentage body fat in children and underestimates it in adults (17,31,43–47). Further development of the prediction equations for percentage body fat is necessary before this relatively new technique is recommended for routine body composition assessment.

The foot-to-foot method of body composition assessment is also a new technique and validation studies are limited. Jebb et al. (48) found that the Tanita foot-to-foot scales estimated fat mass with a bias of 0.8 kg when compared with a four compartment model (assessed using densitometry, hydrometry and DXA). Bell et al. (49) compared estimates of total body water (which may be extrapolated to obtain fat free mass and hence fat mass) obtained using the Tanita foot-to-foot scales and found a non-significant bias of 0.71 when compared with hydrometry in their group of 57 healthy subjects.

The Tanita analyser has some advantages compared with the standard hand-to-foot Bodystat monitor: assessments can be made with the subject standing rather than fully reclined; it is readily available and approximately one-tenth the cost; and electrocardiographic electrodes are unnecessary.

DXA was used as the reference method in the present study because it was readily available. The equipment is found in most hospital and private radiology practices in Australia. The use of DXA as a gold standard technique is controversial because of software differences between different types of DXA. However, DXA has high subject acceptability, a very low radiation dose and scanning time is only ten to 30 minutes.

Conclusions

Bioelectrical impedance analysis is a simple easy-to-use and relatively inexpensive technique that proved to be accurate for assessing percentage body fat in our adult population when compared with DXA. Further research is necessary before near infra-red intereactance could be recommended for accurate body composition assessment in our population.

References


Future events

35th Annual AIFST Convention
21–24 July 2002, Darling Harbour, Sydney. Contact: tel: (02) 8399 3996. Email: aifst@aifst.asn.au. Web site: www.aifst.asn.au

DAA Symposium, Research and Regulation—Supporting Best Practice
10 August 2002, Perth WA. Contact Conference Solutions. Tel: (02) 6285 300. Fax: (02) 6285 3001. Email: pnapper@consol.com

24th ESPEN Congress—Patients Progress, the Journey from Science to Practice
31 August–4 September 2002, Glasgow, Scotland. Contact Chantal Leverat or Antonio Guadagnoli, 24th ESPEN 2002 c/- MCI Congress.Tel: +41 22 33 99 580. Fax: +41 22 33 99 621. Email: espen@mci-group.com

3rd Asian Congress of Dietetics—Harmonisation of Asian Dietetics
18–21 August 2002, Kuala Lumpur, Malaysia. Contact: 3rd Asian Congress of Dietetics, Department of Nutrition and Dietetics, Faculty of Allied Health Sciences, Universiti Kebangsaan Malaysia, Jalan Raja Muda Abdul Aziz, 50300 Kuala Lumpur, Malaysia. Tel: +60 3 440 5511. Fax: +60 3 294 7621. Email: fatimah@medic.ukm.my, or, winnie@medic.ukm.my

Health Care in Focus, incorporating the 14th Casemix Conference
1–4 September 2002, Hotel Sofitel, 25 Collins Street, Melbourne. Contact: Casemix Conference Secretariat, Commonwealth Department of Health and Aged Care. Tel: (02) 6289 4327.

International Symposium on Stroke Rehabilitation—Diff’rent Strokes
10–11 October 2002, Adelaide, South Australia. Contact: Diff’rent Strokes Symposium Secretariat, PO Box 6129 Halifax Street, Adelaide, SA 5000. Tel: (08) 8227 0252. Fax: (08) 8227 0251. Email: strokes@sapro.com.au. Website: www.sapro.com.au

16th Annual Food Industry Conference
15 October 2002, Adelaide, South Australia. Contact: Jenny Rhodes, CSIRO-HSN, tel: (08) 8303 8870. Fax: (08) 8303 8899

International Federation on Ageing 6th Global Conference
27–30 October 2002, Perth, Western Australia. Contact: Katie Clarke, tel: (08) 9322 6906. Fax: (08) 9322 1734. Email: kclarke@congresswest.com.au

19th International Conference of the International Society for Quality in Health Care
5–8 November 2002, Conference Centre, UNESCO Headquarters, Paris, France. Contact: ISQua 2002, Level 9, Aikenhead Centre, St Vincents Hospital, Fitzroy, Vic 3065. Tel: (03) 9417 6971. Fax: (03) 9417 6851. Email: isqua@isqua.org.zu. Website: www.isqua.org.au

2003 HEIA Biennial Conference, Home Economics—Reflect and Revitalise
16–18 January 2003, Education Development Centre, Hindmarsh, Adelaide. Contact: Christina Tassell, tel: (08) 8362 200. Fax: (08) 8362 8708. Email: ctassell@oac.sa.edu.au

5th National Allied Health Conference
19–21 February 2003, Stamford Grand Hotel, Glenelg, South Australia. Contact: Conference Secretariat, Allied Health 2003, SAPMENA Conventions, 69 Greenhill Road, Wayville, SA 5034. Tel: (08) 8274 6000. Fax: (08) 8274 6000. Email: alliedhealth2003@sapmeca.asn.au. Website: www.sapmeca.asn.au/alliedhealth.htm

IX Asian Congress of Nutrition

XIVth International Congress of Dietetics
28–31 May 2004, Chicago, Illinois, USA. Contact: tel: +1 312 899 4750. Fax: +1 312 899 4772. Email: 2004Congress@eatright.org.

12th International Congress on Nutrition and Metabolism in Renal Disease
19–22 June 2004, Venice/Padua, Italy. Contact: email: info@nutrition.metabolism-2004.it or scientific_info@nutrition.metabolism-2004.it. Website: www.nutrition.metabolism-2004.it