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TETRAPOLAR BIOELECTRICAL IMPEDANCE ANALYSIS IS INFLUENCED BY TIME-OF-MEASUREMENT

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ABSTRACT

Bio-electrical impedance analysis (BIA) is an attractive method to assess body composition due to its accuracy, time- and cost-effectiveness and simplicity-of-use. Many factors have a confounding influence on the accuracy of the measurement, such as the time-of-measurement once the person assumes a supine position. This occurs due to fluid shifts from a standing to supine position. The purpose of the current study was to determine the effect of assessing body composition at 5-minutes (test) and again at 7-minutes (re-test). Eighty-one college students (21±2 years; 40 men and 41 women) completed the study. Standardised procedures for BIA measurement were followed as outlined in Gonzalez-Correa and Caicedo-Eraso. A paired sample t-test and Bland-Altman analysis were performed between test and re-test. The resistance (R), reactance (Xc) and impedance (Z) increased by 0.8%, 0.6%, and 0.8% from 5 to 7 minutes respectively. Mean values of raw data (R, Xc and Z) and estimated data (total body water, percentage body fat) were significantly different between test and re-test (p<0.01). The Bland- Altman plots revealed systematic bias between measurements. This study emphasises the sensitive nature of time-of-measurement once supine in BIA assessments. The assessment of body composition should occur after 5-minutes once supine.

Keywords: Bio-electrical impedance analysis; Resistance; Reactance; Impedance Body composition.

INTRODUCTION

Bio-electrical impedance analysis (BIA) is an easy, safe, cost-effective and portable method to assess body composition (Mialich *et al*., 2014). It has been reported to have a minor technical error, sound validity against dual-energy X-ray absorptiometry and good test-retest and inter-observer reliability (Thomson *et al*., 2007; Donadio *et al*., 2008; Walter-Kroker *et al*., 2011; Hurst *et al*., 2015). However, numerous studies have identified the confounding influence of patient, equipment, procedural and environmental factors on BIA analysis (Kushner *et al*., 1996; Hansen *et al*., 1997; Khaled *et al*., 1997; Nunez *et al*., 1997; Scharfetter *et al*., 1997; Slinde *et al*., 2003; Caicedo-Eraso *et al*., 2012; Gonzalez-Correa & Caicedo-Eraso, 2012). A few examples of such confounding variables are: breathing during measurement, jewellery, skin preparation, surface on which the participant lies, electrode position, bodily movement, limb position, diseases and medication affecting hydration status, bladder content, menstrual cycle, food and beverage consumption, fat distribution, hydration status, physical exercise, body position, electrode type and analyser type (Gonzalez-Correa & Caicedo-Eraso, 2012).

The confounding effect of standing versus supine position during measurement is one of the factors that have been studied (Roos *et al*., 1992; Shirreffs & Maughan, 1994; Kushner *et al*., 1996; Gonzalez *et al*., 1999), along with the effect of time intervals (5, 10, 15, 30, 45, 60 minutes) between measurements while in a supine position (Roos *et al*., 1992; Shirreffs & Maughan, 1994; Kushner *et al*., 1996). Numerous studies reported large practical differences between time intervals (+3% to +5% increase in impedance or resistance as time increased) (Roos *et al*., 1992; Shirreffs & Maughan, 1994;; Kushner *et al*., 1996). Due to these differences, Gonzalez-Correa and Caicedo-Eraso (2012) recommended that measurements should be standardised and taken at 5-minutes after the correct body position has been assumed.

However, the effect of a smaller deviation from 5-minutes (such as 7-minutes) have not been determined and could have significant effects on the accuracy of raw data (resistance, reactance and impedance), total body water and resultant body composition measurements. Also, the studies that examined the effect of time-interval and the associated effect on impedance values consisted of small sample sizes (10 participants in each study) (Roos *et al*., 1992; Shirreffs & Maughan, 1994; Kushner *et al*., 1996). Consequently, the purpose of this study was to determine the effect of assessing body composition at 5-minutes and again at 7-minutes using a tetrapolar bio-electrical impedance analyser.

METHODS

Participants

Participants were recruited from undergraduate students studying at Stellenbosch University (20.6±1.6yrs; 69.7±15.4kg). Eighty-four (84) Caucasian participants (n=40 men; n=44 women) volunteered to participate in the study (sedentary and physically active students). Participants were excluded if they had a prosthesis, stent, pacemaker, amputation or, in the case of women, were pregnant or in their premenstrual or menstrual phase.

Measures and procedures

Participants visited the Exercise Physiology Laboratory at Stellenbosch University on two occasions (within 2 weeks). During the first visit an information sheet and consent form was handed out. The participants were told exactly what the study entailed. A questionnaire requiring information, such as age, gender, race, menstrual phase, prosthesis, pregnancy, pacemaker, stent, amputation, co-morbidities, treatments and medication was also completed. A checklist of items was also given to the participants as a reminder of certain behavioural modifications in the hours leading up to the test day (Gonzalez-Correa & Caicedo-Eraso, 2012). These actions included an overnight fast (10 hours), avoidance of exercise, coffee, alcohol or any diuretics 24 hours prior to the test. Participants were tested at a later stage if they had diarrhoea or fever.

Upon the second visit and minutes prior to measurements all jewellery had to be removed and the bladder was voided. All measurements occurred in the morning between 07h00 and 09h00. Measurements lasted approximately 30 minutes. The laboratory temperature was controlled at 19 degrees. The participant stripped down to his/her underwear wearing a standard hospital gown.

Firstly, body mass was determined with a calibrated electronic scale (Beurer, Ulm, Germany) and recorded to the nearest 0.1kg. Stature was measured using a sliding steel stadiometer and recorded to the nearest 0.1m (Siber-Hegner GPM, Switzerland).

Anatomical landmarks (dominant side of the body) were then cleaned with alcohol and dried with a piece of paper towel. The participants were asked to lie down on their backs (arms abducted at 30 degrees, not touching the thighs) and legs separated at 45 degrees (with thighs not touching). The plinth on which the participant laid down was constructed of wood and thus non-conductive. BIA was assessed with the Bodystat Quadscan 4000 (Isle of Man; UK). When using the standard, distal, tetrapolar BIA technique, two current electrodes (Bodystat electrodes [Isle of Man; UK]) were placed on the hand and foot and two voltage sensing electrodes were applied to the wrist and ankle. The four land marks included the midline between prominent ends of the radius and ulna of the wrist, the midline of the third metacarpal-phalangeal joint on the dorsal hand surface, the midline between the medial and lateral malleolus of the ankle and the midline of the third metatarsal-phalangeal joint on the anterior surface of the foot. A minimum difference of 5cm was needed between the current and voltage electrodes. A visual demonstration is shown in Caicedo-Eraso *et al.* (2012). The stopwatch was started as soon as the participant laid down.

During the measurement no movement was allowed and the measurements were taken at the end of an exhalation (Gonzalez-Correa & Caicedo-Eraso, 2012). The measurement was taken at exactly 5-minutes. The average of the three measurements was calculated (within a 10-second period). The measurements were repeated at exactly 7-minutes.

Statistical analysis

The mean and standard deviation (SD) were used to evaluate all descriptive statistics. A paired t-test ($p<0.05$) and Bland-Altman (1986) plot were used to assess significant differences between the measurements at 5-minutes and again at 7-minutes (Caicedo-Eraso *et al.*, 2012). The Bodystat Quadscan 4000 (Isle of Man; UK) assesses resistance (R); reactance (Xc); and impedance (Z) at a frequency of 50kHz. The outcome variables assessed were the raw data (R, Xc and Z), total body water (TBW) and percentage of body fat (%BF).

RESULTS

Eighty-one (81) students completed the test and re-test measurements. Three participants with metal implants (lower leg/foot) were excluded from the analysis.

Descriptive statistics for age, stature, body mass, R, Xc, Z, TBW and %BF values are reported in Table 1. A paired t-test demonstrated a significant difference between test and re-test for R, Xc, Z, TBW and %BF ($p<0.01$) (Table 2). A Bland-Altman plot for raw outcome variables are depicted in Figure 1. Resistance, reactance and impedance increased by 0.8%; 0.6%; 0.8% from 5- to 7-minutes respectively. The three Bland-Altman plots (resistance, reactance, impedance) demonstrate systematic bias between measurements (5- vs. 7-minutes). However, the limits of agreement (LOA) are narrow (less than 10% of the mean) and almost all data points are spread within the LOA. Lastly, the spread of the data is without heteroscedasticity (constant variance between test and re-test for lower and higher values).

Table 1. **DESCRIPTIVE STATISTICS EXPRESSED AS MEAN±SD WITH MINIMUM AND MAXIMUM SCORES**

Variable	Mean±SD	Minimum	Maximum
Age (years)	20.6 ± 1.6	18	25
Stature (cm)	173.8 ± 9.8	153	195
Body mass (kg)	69.9 ± 15.3	42	105
BMI (kg/m^2)	22.9 ± 3.2	17	32
Measurements at 5-minutes			
Resistance (Ω)	560.7 ± 98.2	367	786
Reactance (Ω)	67.1 ± 8.4	49	86
Impedance (Ω)	564.8 ± 98.3	371	790
TBW (L)	38.9 ± 9.0	25	65
BF (%)	18.8 ± 7.1	8	36
Measurements at 7-minutes			
Resistance (Ω)	565.2 ± 98.9	371	782
Reactance (Ω)	75.1 ± 8.2	49	8.3
Impedance (Ω)	569.2 ± 98.8	376	786
TBW (L)	38.8 ± 8.9	25	63
BF (%)	19.1 ± 7.1	8	36

BF=Body Fat BMI=Body Mass Index TBW=Total Body Water

Table 2. **COMPARISON BETWEEN TEST AND RE-TEST VALUES**

Variable	Mean difference	t-value	Degrees of freedom	p-value
Impedance (Ω)	-4.49	-6.3	80	0.000
Resistance (Ω)	-4.41	-6.3	80	0.000
Reactance (Ω)	-0.44	-2.7	80	0.007
TBW (L)	0.18	5.6	80	0.000
Body fat (%)	-0.23	-5.6	80	0.000

TBW=Total Body Water

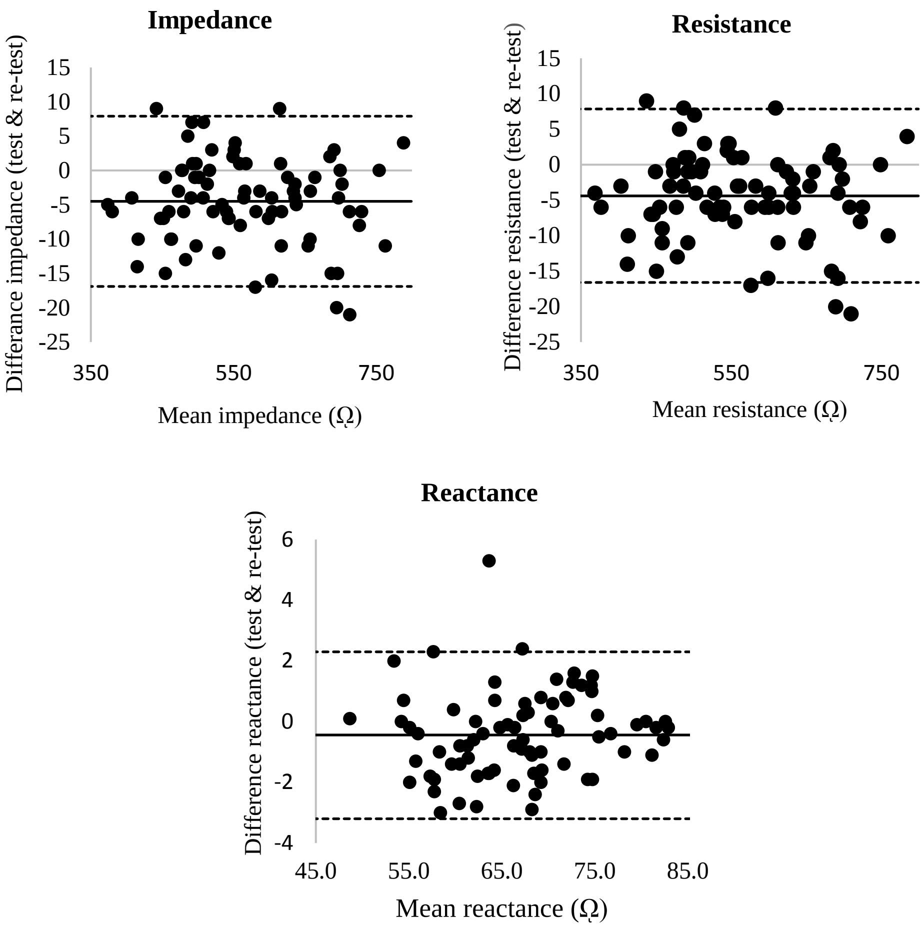

Figure 1. **BLAND-ALTMAN PLOTS FOR AGREEMENT BETWEEN TEST AND RE-TEST OF RESISTANCE, REACTANCE AND IMPEDANCE**

The difference between the first (5-minutes) and second test (7-minutes) was plotted against the participant's two mean scores. The centre line equals the mean difference (bias) between the two tests and the outer lines (limits of agreement) equal ±2SD from the mean.

DISCUSSION

Several procedural and methodological factors influence the validity of BIA measurements. Time of measurement once the participant assumes a supine position is one of these many factors (Gonzalez-Correa & Caicedo-Eraso, 2012). The purpose of the current study was to determine the effect of body composition assessment at 5-minutes and again at 7-minutes (once supine) using a tetrapolar bio-electrical impedance analyser with eighty-one college aged students**.**

The paired sample t-test demonstrated significant differences between test and re-test values for all raw and estimated values ($p<0.01$) (Table 2). This was the case even though all raw values (R, Xc and Z) increased by less than 0.8% from 5-minutes to 7-minutes. The Bland-Altman plots demonstrated systematic bias, although narrow LOA and no heteroscedasticity was reported. The results of the current study re-emphasise the sensitivity of taking BIA measurements and the importance of strict standardisation of BIA procedures as stipulated by Gonzalez-Correa and Caicedo-Eraso (2012).

Previously it was reported that when a participant assumes a supine position from standing, interstitial fluid is absorbed to the intravascular compartment with fluid shifting to the central pool (Maw *et al*., 1995). This fluid shift affects the BIA measurements especially at lower frequencies, as low frequency impedance is conducted largely through the extracellular water (Kushner *et al*., 1996). The tetrapolar BIA device of the current study (Bodystat Quadscan 4000) assesses R, Xc and Z at 50kHz. It was also reported by Kushner *et al*. (1996) that differences in impedance are seen when measurements are made once supine and again at 5 and 10 minutes. The mean change is larger from 5-10 minutes when compared to 0-5 minutes. The change is also larger at 5, 50 and 148kHz when compared to 500-kHz (Kushner *et al*., 1996). Changes in resistance at 50kHz have also been reported by Roos *et al*. (1992) after 15, 30, 45 and 60 minutes. This was confirmed by Shirreffs and Maughan (1994) where impedance increased progressively throughout the 60 minutes of being supine. Blood and plasma (estimated from haemoglobin and haematocrit concentrations) also increased throughout the 60 minutes, demonstrating the confounding effect of fluid shifts on BIA analysis.

LIMITATIONS

A limitation of the current study was that the frequency was measured only at 50kHz. It is known that at lower frequencies (5kHz), raw data are influenced more by a factor such as time-of-measurement compared to high frequency values (500kHz), because low frequency impedance is conducted principally through the extracellular water. Mialich *et al*. (2014), in their critical review of BIA analysis, stipulated that mutli-frequency (5 to 500kHz) impedance does not improve the estimate of body composition compared to a single frequency 50kHz device, but can provide an accurate and precise estimate of extracellular water. The BIA analyser (Bodystat Quadscan 4000) of the current study uses the standard single frequency (50kHz) and this frequency is used for the ultimate prediction of body fat percentage. The purpose of this study was to ascertain the influence of time-of-measurement at this level of measurement.

CONCLUSION

The use of BIA for body composition assessment remains attractive due to its reliability and validity, low cost, easy-to-use, time-effectiveness and portability. However, many factors have a confounding influence when using tetrapolar BIA devices. Gonzalez-Correa & Caicedo-Eraso (2012) provided a checklist of items that should be followed closely due to the sensitivity of BIA tetrapolar techniques. The current study demonstrated that there are significant differences between the raw and estimated values of BIA measurement, when performed after 5 and 7 minutes of laying down. This study demonstrated the added sensitivity that time-of-assessment has on measurement validity.

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