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Comparison of Two Bioimpedance Spectroscopy Techniques in the Assessment of Body Fluid Volumes

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Abstract— **The present study aimed to compare the estimates of body liquid volumes performed by two bioimpedance spectrometry techniques. One based on a step response technique (BIS-PEB) and second one based on multifrequency Xitron Hydra 4200 equipment (Xitron Technologies, San Diego, CA, USA). The convenience sample was initially composed of 422 students from a military parachuting course of the Brazilian Army. From such sample 42 male students were randomly selected to be evaluated during three weeks. The anthropometrical characteristics of the sample can be summarized as: 25.18 ± 4.10 years old; weight equals of 76.77 ± 7.84 kg; height equals to 174.96 ± 5.67 cm; body mass index (BMI) equal to 25.05 ± 2.11 kg m^{-2}. Bland-Altman graphics were used to compare the two methods in what concerns to estimate of extracellular fluid (ECF), intracellular fluid (ICF), and total body water (TBW). One can observe that the estimates of the two techniques present a good correlation, especially in the case of ECF ($r = 0.975$). The present study indicates that BIS-PEB technique associated with De Lorenzo equation can supply noninvasive estimates of body fluid volumes comparable to Xitron Hydra 4200 equipment.**

I. Introduction

Determination of body liquid volumes has diverse applications in assessment and follow-up of health. The ratio between extracellular fluid (ECF) and intracellular fluid (ICF), i.e. ECF/ICF, has been suggested as a unique index of the health state [1]. Such physiological variables have being used, independently or together with other variables, to follow-up body composition in patients with HIV [2], the state of hydration in patients submitted to hemodialysis [3], the state of health of the patients affected for hyperthyroidism [4] and classic dengue [5], as well as the study of hydration during the cellular aging [6].

During last decade, the measurement of ECF and ICF has been no invasively carried out frequent by using bioimpedance spectroscopy (BIS), which is a simple, fast, and low cost technique [7].

Xitron Hydra Bioimpedance Analyzer System (Xitron Technologies, San Diego, CA, USA) uses the classical sinusoidal scan method to achieve bioimpedance parameters and it has been one of most referred device in literature for the measurement of ECF and ICF [8], [9], [10], [11], [12].

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Neves and Souza [13] have developed an alternative BIS technique based on the current response to a voltage step excitation, hereafter called BIS-PEB. The mentioned technique needs just one excitation waveform, in opposition to the classical sinusoidal scan method used by most available commercial multifrequency analyzers, and uses just two electrodes (bipolar technique) because it models the impedances of the electrode-tissue interface. Such alternative BIS technique has been used in bioimpedance applications elsewhere [14], [15], but its estimates of body fluid volumes have never been compared with the ones obtained by using a commercial equipment that implement the classical sinusoidal scan method.

The present study aimed to compare the estimates of body liquid volumes performed by an academic prototype that implemented BIS-PEB technique and ones obtained by Xitron Hydra 4200 equipment.

II. Methods

In order to compare just BIS techniques, both devices used De Lorenzo equations [16] to estimate body fluid volumes from the bioimpedance parameters derived by each technique.

A. *The classical sinusoidal scan technique*

To represent the classical sinusoidal method a Xitron Hydra 4200 equipment was used to acquire bioimpedance parameters in a tetrapolar arrangement of electrodes and using a whole body, i.e., wrist to ankle, protocol [1]. The device uses 50 frequencies between 5 kHz and 1000 kHz, and an excitation sinusoidal current in a range 50 to 700 µA. From 50 data of the complex impedance a software in the equipment estimates values associated to a Cole model [17], composed among other parameters by the resistance at zero frequency (R_0) and the resistance at infinity frequency (R_∞). The extracellular resistance (Re) is associated to R_0 and intracellular resistance (Ri) is computed as:

$$\frac{1}{Ri} = \frac{1}{R_\infty} - \frac{1}{R_0} \tag{1}$$

The value of Re is firstly used to estimate ECF. Then values of Re and Ri determine the value of the total body water (TBW) and, finally, ICF is derived from subtracting ECF from TBW [18].

B. BIS-PEB technique

The BIS-PEB technique imposes the assumption of an electric model to the biological system being studied. In the present work the model depicted in Figure 1 was considered. In such circuit *Re* and *Ri* are associated to resistances of the extra and intracellular fluids, *Cm* is capacitance associated to the cellular membrane, and the resistance *Rb* and capacitance *Ce* represent the simplified model of the electrode-skin interface impedances. The technique can use two electrodes (bipolar technique) because it models the impedances of the electrode-tissue interface. Such technique needs just one interrogating waveform in opposition to the classical sinusoidal scan method used by most available multi-frequency analyzers.

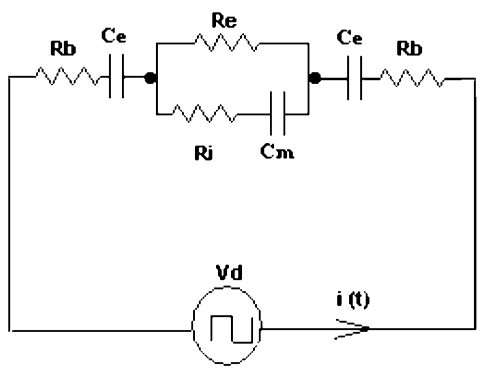

Fig 1 – Electrical model used to interpret the current response to a step voltage excitation (see text for details).

It can be demonstrated that the current response associated to the BIS-PEB technique is expressed as:

$$i(t) = K_1 \cdot e^{(\omega_1 \cdot t)} + K_2 \cdot e^{(\omega_2 \cdot t)} \qquad (2)$$

where, K_1, K_2, ω_1, and ω_2 are constant dependent on the circuit model and also dependent on the step voltage amplitude *Vd*.

From the theoretical expectation of *i(t)* (Equation 2) and its experimental counterpart, it becomes possible to estimate the electric parameters of the bioimpedance model. In the present study, a multiparametric optimization procedure, based on the steepest gradient method, was used to estimate the model parameters that best fit the experimental data in a least-squares sense.

The prototype that implements the BIS-PEB technique applies a 500 mV voltage step in a whole body protocol (Figure 2) and digitizes the current response with 12 bits resolution and using a sample frequency of 500 kHz. The total energy accomplished by the method is in the same order of magnitude of the Xitron equipment.

C. The subjects

A convenience sample was initially composed of 422 students from a military parachuting course of the Brazilian Army. From such sample, 42 male students were randomly selected to be evaluated during the three weeks that composed the first phase of the parachuting course that occurred in the period from January 7th to 25th 2008.

D. Experimental protocol

BIS data were acquired at least 2 hours after food ingestion and at least 30 minutes after micturition. All subjects were also more than 72 hours without any alcohol ingestion. Besides BIS data, height and weight of the volunteers were colleted to the nearest 0.1 cm and 0.1 kg, respectively. During data acquisition the subjects wore light cloths and were in the standing position in an isolated floor.

Electrodes placement (Figure 2) and subject position during the measurement follow the indication of Xitron Hydra 4200 user's manual [1] for a whole body assessment. Stainless steel electrodes 12 cm^2 and electrolyte gel were used instead of the Xitron electrodes. Data acquisition for BIS-PEB technique used only the two distal electrodes.

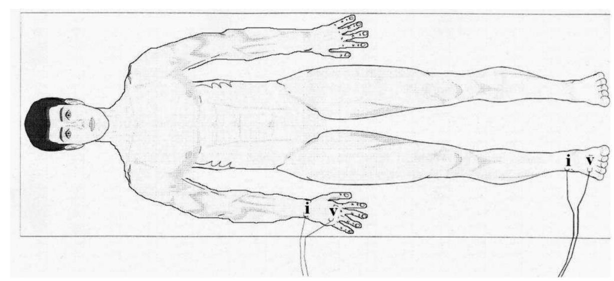

Fig 2 – Electrodes placement according Xitron Hydra 4200 user's manual.

E. Data analysis and statistics

Statistical Package for Social Sciences 13.0 (SPSS 13.0) was used to perform statistical analysis, where a significant level of 0.05 was considered.

III. RESULTS

The anthropometrical characteristics of the sample can be summarized as: 25.18 ± 4.10 years old; weight equals of 76.77 ± 7.84 kg; height equals to 174.96 ± 5.67 cm; body mass index equal to 25.05 ± 2.11 kg m^{-2}.

Table 1 shows the descriptive statistic and Pearson correlation coefficients for comparing the classical sinusoidal scan method implemented by the Xitron Hydra 4200 equipment and the BIS-PEB technique implemented in the academic prototype. Bland-Altman graphics were used to compare the methods in what concerns the estimate of ECF, ICF, and TBW (Figures 3, 4, and 5, respectively). Although Pearson correlation higher than 0.9 for ECF and TBW and 0.79 for ICF estimation, the PEB-BIS technique tend to produce smaller estimations than the ones achieved using

Xitron Hydra 4200. However, such differences were not significant.

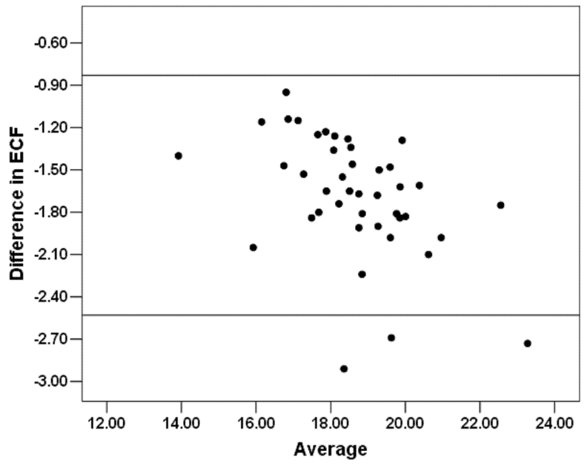

Fig 3 – Bland-Altman plot to ECF with reference lines [mean ± 1.96 standard deviation], where Difference in ECF = [PEB ECF – Xitron ECF] and Average = [PEB ECF + Xitron ECF]/2

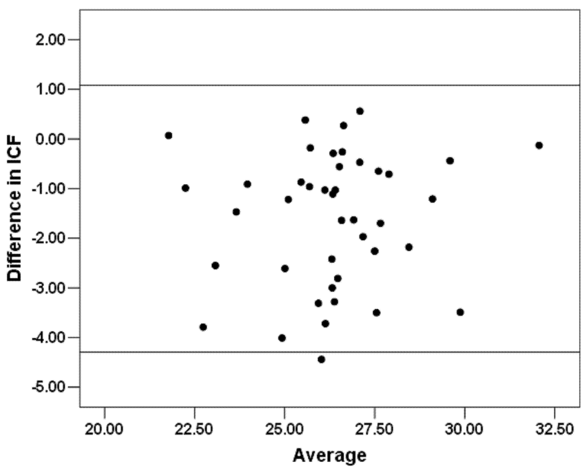

Fig 4 – Bland-Altman plot to ICF with reference lines [mean ± 1.96 standard deviation], where Difference in ICF = [PEB ICF – Xitron ICF] and Average = [PEB ICF + Xitron ICF]/2

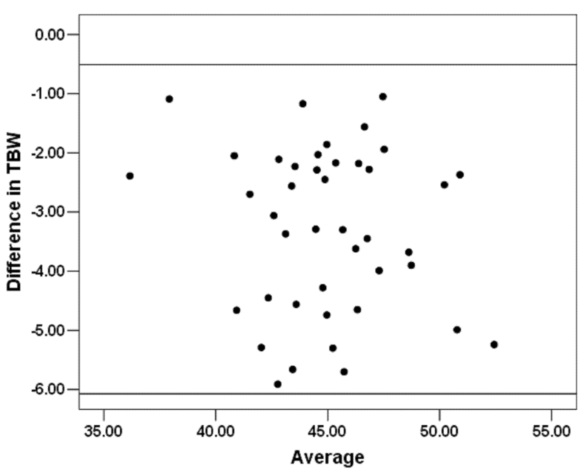

Fig 5 – Bland-Altman plot to TBW with reference lines [mean ± 1.96 standard deviation], where Difference in TBW = [PEB TBW – Xitron TBW] and Average = [PEB TBW + Xitron TBW]/2

TABLE I
DESCRIPTIVE STATISTICS AND CORRELATION BETWEEN STUDIED METHODS

Variable	N	Mean	Std. Deviation	Pearson	*P value*
Xitron ECF	42	19.496	1.795	0.975	0,0001
PEB ECF	42	17.816	1.597		
Xitron ICF	42	27.127	2.036	0.795	0,0001
PEB ICF	42	25.519	2.146		
Xitron TBW	42	46.623	3.401	0.913	0,0001
PEB TBW	42	43.335	3.230		

IV. DISCUSSION

Bioelectrical impedance can be defined as the magnitude of opposition that the biological substrate makes to the flow of an electric current (alternating). Its measurement is influenced by variables such as frequency of electrical signal, electrochemical processes, temperature, potential hydrogen (pH), hidration coefficient and viscosity of the fluid or biological tissue in question. The biological tissues can be interpreted as a complex circuit composed of resistors and capacitors arranged in series and/or in parallel, in which the flow of current follow the path of least opposition.

One can observe that body fluid volumes estimates obtained by the two techniques present good correlation, especially in the case of ECF ($r = 0.975$) and TBW ($r = 0.913$), which depend on *Re* and the parallel association between *Re* and *Ri*, respectively. Results suggest that the major differences between the two methods are associated to the *Ri* estimates, related with ICF, which depend on how each method estimate high frequency behavior of the bioimpedance.

Although the standard deviation calculated for the PEB ICF has been slightly above that the one calculated for the Xitron ICF, the F-test showed no statistical significance between the two parameters. This reinforces the possibility of comparison between these methods.

Some studies have validated the use of BIS to estimate body compartments, comparing the results of such noninvasive technique with those associated to gold standard methods [19], [20]. Despite of this Svantesson *et al.* [21] reported that for subjects presenting good physical training, i.e. athletes, as the subjects investigated in the present study, Xitron Hydra 4200 data can sub-estimate fat mass when compared with dual energy x-ray absorptiometry (DEXA). This indicates that fat free mass compartments, which are highly correlated with TBW, were super-estimated in such population. Considering this fact and the tendency of PEB-BIS technique to supply TBW estimates that are in general lower than ones associated to Xitron Hydra 4200, it is hypothesized that the estimates achieved by BIS-PEB technique could be not wrong, even not agreeing to the ones supplied by the most reported commercial equipment.

V. CONCLUSION

The present study indicates that BIS-PEB technique associated with De Lorenzo equation [16] can supply noninvasive estimates of body fluid volumes comparable to the ones achieved by using the commercial equipment most referred in the literature.

ACKNOWLEDGMENT

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