A COMPARISON BETWEEN IMPEDANCE MEASURED BY A COMMERCIAL ANALYZER AND YOUR VALUE ADJUSTED BY A THEORETICAL MODEL IN BODY COMPOSITION EVALUATION

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Abstract - The use of the electrical current on the evaluation of several physiological variables in the human body is not a recent technique but continues awaken a great interest in the research community. One of the greatest applications for such technique is the study of body composition through bioimpedance, where generally a equipment with tetrapolar array set of electrodes is used to realize the bioimpedance measurement. The aim of the present work is to show that the bioimpedance measured is normally sub-estimated and to develop a correction factor to such values. The comparison between the original bioimpedance values, obtained by commercial equipment, and their corrected values, in body composition evaluation, will be shown. Body composition tests were conducted on 10 male subjects. Besides the bioimpedance analysis, anthropometric measures consisting of height, weight and skinfold-thickness were also obtained from the subjects to allow an estimation of the body composition by anthropometric equations established in the literature. The comparison results point to a better a correlation (Pearson coefficient, $r = 0.9735$) between the anthropometric estimated fat-free mass (FFM) and the estimated value by the corrected bioimpedance adjusted, when compared with the original ones Pearson coefficient, $r = 0.9487$).

Keywords: bioimpedance, body composition, tetrapolar electrode array.

I. INTRODUCTION

Bioelectrical impedance analysis (BIA) has been largely used for body composition evaluation, due to their simplicity, low cost and good results when compared to gold standard methods [1]. Researches in this field point out to the utilization of two different methodologies: whole-body, or wrist-to-ankle, and segmental impedance. The first is the most used, it is based on the Hoffer's hypotheses where bioimpedance measures can be extended to obtain total body water (TBW) on the basis of the principle of volume conduction [2].

In both techniques, a tetrapolar electrode array is recommended [3,4]. The use of this electrode array is based on the fact that the input impedance of the preamplifier used to measure the difference of potential (*dop*) between the two sensing electrodes is normally much larger than the electrodes' impedance. Consequently, the electrodes' impedance can be neglected in the analysis that derives the bioimpedance [3,5,6,]. However, if the electrode-tissue impedance is included in electric model of measure, the bipolar electrode array can be used [7].

In a recent study, Neves and Souza [7], evaluated the distribution of the equipotential lines in the neighborhood of the current excitation pair of electrodes and found significant changes in the values of the equipotentials toward the distance from the electrodes. Thus, a corrected factor was theoretically obtained and proposed to adjust the impedance values measured by equipment that uses the tetrapolar electrode array.

The aim of the present study is to compare the impedance values measured by commercial equipment using the tetrapolar array and their corrected values, in body composition evaluation, in order to validate the developed correction factor.

II. METHODOLOGY

Electrically speaking any impedance is defined as the ratio between a voltage and the correspondent current. In fact, bioimpedance should be defined as the ratio between the voltage over the current source that injects the current in the injection pair of electrodes and the value of this injected current. This should imply the measure of the voltage over the current pair of electrodes and not in the sensing pair, in the conventional tetrapolar method. One must remember that the electrode-electrolyte interface is a necessary phenomenon to transform the ionic current, inside the body, into the electronic current supplied by the current source. Therefore it should not be simply neglected in the bioimpedance analysis. Moreover, due to the large nonlinear aspects of the current density pattern in the neighborhood of the current excitation pair of electrodes (in the cases where ordinary surface electrodes are used), the equipotential lines change their values significantly toward the distance from the electrodes. This happen even in a short distance from this pair of electrodes and will not be correct by the fact the preamplifier does not sink a significant amount of current, that is, it presents a great input impedance. Consequently the *ddp* measured by the voltage sensing preamplifier can be significantly smaller than the true *ddp* over the current source. This underestimated voltage will result in an underestimated bioimpedance. It must be mentioned that in electronic phantom (implemented with discrete passive components) normally supplied with commercial bioimpedance equipment, this effect can not be observed,

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since the two pair of electrodes would be coincident during the calibration process.

It must be also mentioned that in some bioimpedance applications, as for example body composition evaluation, a small error in the bioimpedance estimation can generate a considered error in the result of the body composition, due to the estimation equations used.

Under the hypothesis the correct bioimpedance (Z_{theo}) should be the one obtained as the ratio between the voltage over the current-excitation source and the current value itself, and the bioimpedace measured by tetrapolar method (Z_{ab}) is the impedance obtained as the ratio between *dop* between the sensing electrodes and the injected current value Neves and Souza [8] derived an equation to correct the Z_{ab} value. If a and b are the sites of the sensing electrodes and x and y are the sites of the excitation electrodes, and considering r the radius of the electrodes, it can be demonstrated that the ratio α between Z_{ab} and Z_{theo} is given by

$$\alpha = \frac{Z_{ab}}{Z_{theo}} = \frac{\mathrm{Real}\left[\ln\left[\dfrac{(\zeta_a-\zeta_x)\left(\zeta_a-\dfrac{1}{\bar{\zeta}_x}\right)}{(\zeta_a-\zeta_y)\left(\zeta_a-\dfrac{1}{\bar{\zeta}_y}\right)}\cdot\dfrac{(\zeta_b-\zeta_y)\left(\zeta_b-\dfrac{1}{\bar{\zeta}_y}\right)}{(\zeta_b-\zeta_x)\left(\zeta_b-\dfrac{1}{\bar{\zeta}_x}\right)}\right]\right]}{\mathrm{Real}\left[\ln\left[\dfrac{r\left(\zeta_x-\dfrac{1}{\bar{\zeta}_x}\right)}{(\zeta_x-\zeta_y)\left(\zeta_x-\dfrac{1}{\bar{\zeta}_y}\right)}\cdot\dfrac{r\left(\zeta_y-\dfrac{1}{\bar{\zeta}_y}\right)}{(\zeta_y-\zeta_x)\left(\zeta_y-\dfrac{1}{\bar{\zeta}_x}\right)}\right]\right]} \quad (1)$$

Equation (1) was used to correct the Z_{ab}, measured by commercial equipment to Z_{theo} values in order to check the effect of such correction in the Fat-Free Mass (FFM) estimation, using well-established equations in the literature to get FFM values from bioimpedance and from antropometric data.

Ten young healthy males were recruited to supply experimental data. The impedance values were obtained by a single-frequency bioimpedance analyzer - RJL 101 A (RJL Systems, Detroit, MI). The whole-body impedance was measured according to the NIH [4] protocol, where adhesive sensing electrodes Ag/AgCl (3M® – model 4350) were placed at the pisiform prominence of the wrist and between the malleoli lateral and medial at the ankle. The excitation pair of electrodes was place 1.0 cm away. The estimation of Fat-Free Mass from bioimpedance (FFM_{bia}) was calculated using equations according to Gray [9].

$$FFM_{men} = 0.00132Ht^2 - 0.04394R + 0.30520Wt - 0.16760Age + 22.66827 \quad (1)$$

Both, body height and weight were measured in a scale with stadiometer (FILIZOLA®) to the nearest 0.05cm and 0.05 kg, respectively. In all subjects, skinfold-thickness were made twice on the right side of the body with a Cescorf® caliper to the nearest 0.05 mm at the biceps, triceps, subscapular, chest, abdominal, suprailiac, thigh and calf sites, in order to get data to estimate FFM from antropometric parameters. The equations used for body composition estimate from the anthropometric data were those defined by [10,11].

The Pearson's correlation coefficient (r) and the Root Mean Square Error (RMSE) were used to compare the results.

III. RESULTS

The baseline anthropometric, age and fat-free mass estimated from skinfold-thickness (FFM) and from bioimpedance (FFM_{bia}) data of the subjects are summarized in table I.

The measured impedance values (Z_{ab}), the corrected values (Z_{theo}), the ratio d_{ab}/d_{xy} and α values are presented in table II.

TABLE I
BODY COMPOSITION DATA OF THE SUBJECTS

	Mean ± SD	Range
Age (years)	23.7 ± 4.1	19 – 33
Height (cm)	179.3 ± 6.4	172.5 – 190
Weight (kg)	79.4 ± 12.7	54.9 – 100
FFM (kg)	69.7 ± 10.9	46.3 – 86.1
FFM_{bia} (kg)	68.5 ± 7.9	51.7 – 79.0

TABLE II
IMPEDANCE MEASURED AND ADJUSTED, RATIO D_{AB}/D_{XY} AND α VALUES FOR EACH SUBJECT.

Subjects	$Z_{measured}$	d_{ab}/d_{xy}	α	$Z_{adjusted}$
1	484	0.9902	0.8464	571.8
2	481	0.9903	0.8466	569.3
3	421	0.9910	0.8551	492.3
4	633	0.9900	0.8441	749.9
5	365	0.9902	0.8456	431.6
6	392	0.9905	0.8489	461.7
7	415	0.9907	0.8517	487.2
8	362	0.9897	0.8398	431.0
9	456	0.9910	0.8558	532.8
10	545	0.9911	0.8567	636.2

Fig. 1 shows a scatter plot of FFM against FFM_{bia}. This comparison presents a Pearson correlation coefficient (r) equal to 0.9487 and Root Mean Squared Error ($RMSE$) equal to 6.05 kg. Similarly, a scatter plot of the fat-free mass estimated from the new equation using Z_{theo} ($FFM_{bia\text{-}adjusted}$) against our antropometric "gold standard", is shown in Fig. 2. It presents $r = 0.9732$ and $RMSE = 2.5$ kg.

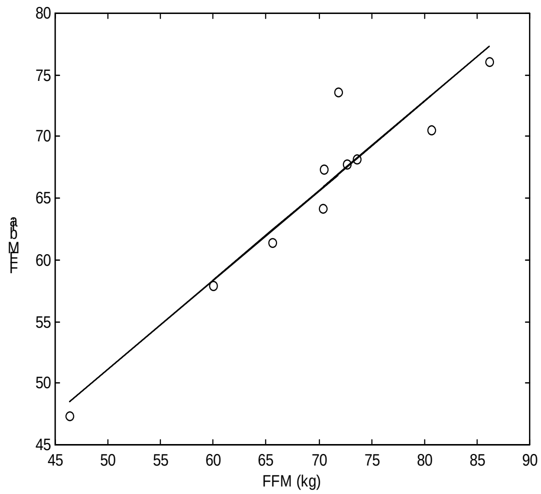

Fig.1. Scatter plot of FFM against FFM_{bia}.

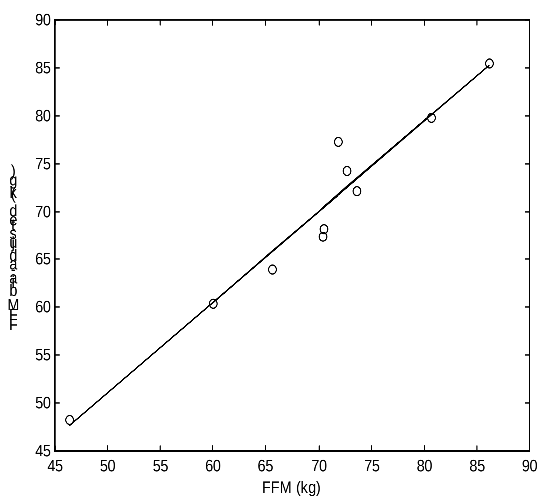

Fig. 2. Scatter plot of FFM against $FFM_{bia\text{-}adjusted}$

IV. DISCUSSION

It may be observed in table2 that for a tetrapolar electrode placing, as recommended in literature [4], the ratio d_{ab}/d_{xy} is 0.99 and produces an underestimation up to 15 %. According to Neves and Souza [8], only to ratio d_{ab}/d_{xy} bigger than 0.996 the $Z_{measured}$ generates underestimation lower than 5 %.

The choice of anthropometric equations for body composition as our "gold standard", to compare with the body composition obtained from bioimpedance, intended to demonstrate the potentiality of the new proposed method of correction, since those anthropometric equations are used broadly and recommended by the American College of Sports Medicine [12].

Once Gray [9] equation was elaborated using the bioimpedance measured by tetrapolar equipment and in the present study these values are adjusted (Z_{theo}), it is reasonable to readjust the constants of their original equation to improve the FFM estimates. From a multiple regression analysis, for the studied sample, a new equation with the same variables as Gray's equation was derived.

The fat-free mass estimated from the new equation using Z_{theo} ($FFM_{bia\text{-}adjusted}$) presents better Pearson's correlation coefficient and root mean square errors ($r = 0.9732$ and $RMSE = 2.5$ kg), when compared to an our "gold standard", than the original Gray's equation (($r = 0.9487$ and $RMSE = 6.05$ kg).

V. CONCLUSIONS

The theory of the method for the correction of the bioimpedance values measured by the commercial bio-electrical impedance analyzers (BIA), that use a tetrapolar electrode array, was describe in a recent paper of the authors. In the present study, we tried to demonstrate that an underestimation in bioimpedance measurements can be corrected and generate more reliable results.

Although a real gold standard method for body composition measurements has not be employed, the FFM estimated from the measured bioimpedance, agree very well with the ones obtained from a very established and recognized anthropometric method. It must be mentioned that after readjust the constants of Gray's equation, our $FFM_{bia\text{-}adjusted}$ estimation seems to be better than those reported by Gray *et al*. (1989). This can be observed by the higher correlation coefficient observed when one compares FFM against $FFM_{bia\text{-}adjusted}$ ($r = 0.9732$). Then, one can concluded on the feasibility and reliability of the proposed correction factor for bioimpedance values.

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