COMPARISON OF BIPOLAR AND TETRAPOLAR TECHNIQUES IN BIOIMPEDANCE MEASUREMENT

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Abstract: *Currently, the majority of studies about bioimpedance measurement uses the tetrapolar electrode configuration. However, in a multilayered tissue volume the measuring current spreads from the current carrying electrodes resulting in unexpected problems treated as a negative sensitivity problem. This work investigated this problem on the bioimpedance measures of upper and lower limbs comparing the results achieved by a bipolar and a tetrapolar bioimpedance devices. The results showed that for the tetrapolar electrode configuration the bioimpedance magnitude decreases significantly (up to 95% for lower limbs and 87% for upper limbs) as current injection electrodes move away from the signal pickup electrodes. There is no statically significant difference (p = 0.87) between the bioimpedance magnitude achieved by the intrinsically bipolar device and the one obtained by the tetrapolar device when was used in the bipolar electrode configuration. It is concluded that the biompedance measurement made by the bipolar device can be more reliable than those performed by a tetrapolar technique, in the sense the results supplied by the former will never present a decrease in the measured impedance associated to an increase of the biological medium impedivity. Such type of error can lead to serious misdiagnosis in health applications of the bioimpedance technique.*
Keywords: bioimpedance, bipolar and tetrapolar electrode configuration

Introduction

Most of studies concerning bioimpedance measurement use the tetrapolar electrode configuration (four-electrode systems). It is frequently stated that tetrapolar configuration do not suffer the problems associated to electrode impedances and for that reason it is preferable instead of bipolar electrode configuration. This fact has been accepted as an undoubtedly true but few authors [1,2,3] have really investigated the effects associated to these two electrode configurations.

Some recent papers [1,3,4] have shown that when measuring the bioimpedance of a multilayered tissue volume, the current spreads from the current carrying electrodes resulting in problems treated as a consequence of the negative sensitivity field [1]. Grimnes and Martinsen [1] stated clearly that it has been accepted as a common misunderstanding that if the electrodes are placed in a linear fashion, with the voltage pickup electrodes between the current injection electrodes, only the volume between the pickup electrodes is measured. Not only is it wrong, but there will also be zones of negative sensitivity between the pickup electrodes and the current injection electrodes. Such a phenomenon can imply in the fact that if the impedivity increases in these zones, lower total impedance will be measured, what can be considered a counter-intuitive result.

Considering that some year ago our group developed a bipolar spectroscopy method based on the current response to a voltage step excitation (BIS-STEP) [4] and that sometimes the magnitudes of measured bioimpedances are higher than analog results reported by other authors, the present study investigated the negative sensitivity problem in bioimpedance measurement of upper and lower limbs, comparing the results supplied by our bipolar method with the ones produced by a tetrapolar equipment.

Methods

Sample – The study included eight females, aging 24 (mean) ± 2.9 (standard deviation) years old, height of 166.6 ± 6.6 cm and weight of 80.9 ± 33.2 kg. The study was submitted to the Ethics Committee of the Hospital Universitário Clementino Fraga Filho (HUCFF) and approved under the number 312 381. The volunteers were instructed about the study procedures and signed an consent.

Instrumantation – Two devices were used to measure bioimpedance values in upper and lower limbs. A BIS-STEP prototype applies a step of 0.5 V and the current was acquired with a resolution of 16 bits at 1.25 MS/s sampling rate. A Xitron4200 (Xitron Technologies, USA) [6], was used for tetrapolar measurements. This device uses sine sweep method ranging from 1 kHz to 1 MHz geometrically spaced.

Electrodes Ag / AgCl (MediTrace200, Kendall, USA) with 1 cm diameter were used for current injection. Brass electrodes with 12 cm^2 area were used as pickup electrodes for the tetrapolar devices. The bipolar device used the same latter electrodes because their dimensions minimize the effect of electrodes impedance.

Experimental Protocol – The current electrodes (CE) and signal pickup electrodes (SE) were positioned as illustrated in Figures 1 and 2. Figure 1 shows that over the quadriceps the SE electrodes were placed at 10 cm and 16 cm from the upper edge of the patella. For the lower limb measurements, four pairs of CE were positioned as follows: 3 cm apart (above and below) the SE (CE_1); 7 cm apart the SE (CE_2); belly of the tibialis anterior - distal insertion of the biceps (CE_3); wrist-ankle (CE_4). Figure 2 shows that over the biceps the CE electrodes were placed 2 cm above and below the muscle belly. For the upper limb measurements, three pairs of CE electrodes were positioned as follows: 3 cm above and below the SE electrodes (CE_1); middle portion of the forearm - distal insertion of the biceps (CE_2); wrist - ankle (CE_3).

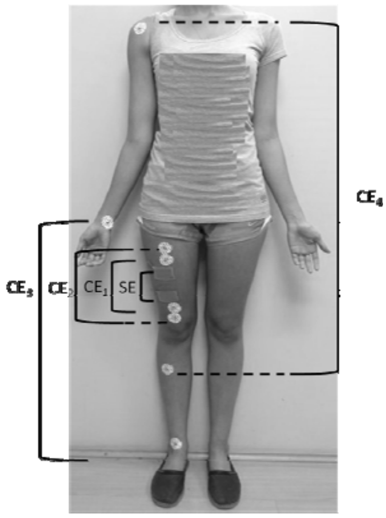

Figure 1: Electrode array for quadriceps measure. CE_1, CE_2, CE_3 and CE_4 are the pairs of current injection electrodes. SE is the signal pickup electrode pair for tetrapolar measurements and the electrode pair for bipolar measurements.

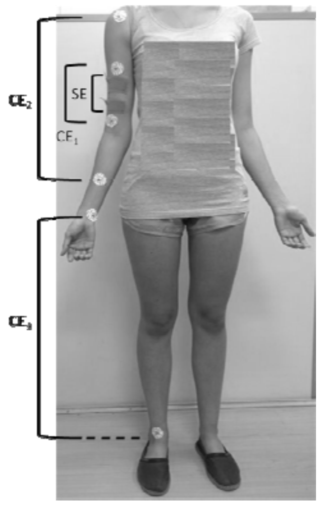

Figure 2: Electrode array for biceps measure. CE_1, CE_2, and CE_3 are the pairs of current injection electrodes. SE is the signal pickup electrode pair for tetrapolar measurements and the electrode pair for bipolar measurements.

During the measurements, the volunteers remained standing and did not perform any kind of activity.

Values of bioimpedance over the quadriceps and biceps brachii muscles were measured with the previously mentioned bipolar and tetrapolar devices. Over the quadriceps site six measures were performed: four measures related to the tetrapolar electrode configuration in which one varies the distance between the pickup pair of electrodes and the pair of electrodes that inject current; and two bipolar measures, one for each measurement equipment. The bipolar measure associated to the tetrapolar device corresponds to the one achieved with the current injection electrodes over the pickup ones. For biceps brachii site five measurements were made: three measures related to tetrapolar electrode configuration in which one varies the distance between the pickup pair of electrodes and the pair of electrodes that inject current; and one bipolar measure for each device. All data were measured randomly.

Analysis and Data Processing – The BIS-STEP provided the parameters of the electrical model assumed by the technique [5]: extracellular resistance (Re), intracellular resistance (Ri), the cell membrane capacitance (Cm) and the electrode capacitance (Ce). Xitron4200 provided as raw bioimpedance data the real and imaginary parts of the bioimpedance (R and X, respectively), and the impedance magnitude and phase (|Z| and θ, respectively).

Both methods were compared by the magnitude of tissue impedance in 50 kHz. The Xitron4200 already provides this data. For BIS-STEP technique this impedance magnitude was estimated by equation 1.

$$Z(\omega) = \frac{1}{\frac{1}{Re} + \frac{1}{Ri + \frac{1}{j\omega Cm}}} \quad \textbf{(1)}$$

where $\omega = 2\pi f$ and $f = 50000$

Box plot were used for exploratory analysis of data supplied by the tetrapolar device XITRON4200. Results obtained for each measurement device through the bipolar electrodes configuration were compared by Mann-Whitney test for difference between means of non-parametric data.

Results

Figures 3 and 4 show the bioimpedance magnitude in 50kHz for both measurement devices considering the bipolar electrode configuration. For both the upper and lower limbs, values of bioimpedance magnitude in 50kHz (|Z|50) achieved by the two measurement systems (BIS-STEP and Xitron4200) represented no statistically significant difference ($p = 0.87$).

Figures 5 and 6 show the behavior of the XITRON4200 as a function of the distance between the pickup pair of electrodes and the pair of electrodes that inject current. It is remarkable the reduction in the values of |Z|50 as the CE pair moves away from the SE pair. The |Z|50 median values decreased up to 95% for lower limbs and 87% for upper limbs.

Part of the dispersion observed in the boxplots that describe the behavior shown in Figures 5 and 6 are associate to the individual bioimpedance basal value variability.

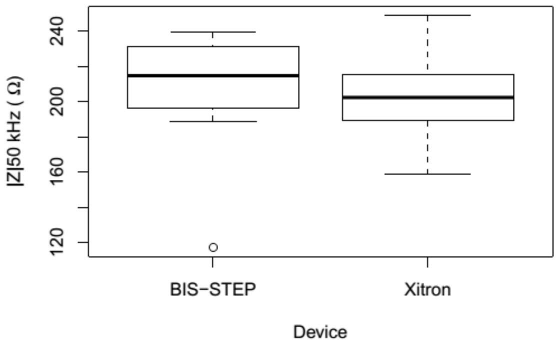

Figure 3: Boxplot of |Z|50 of the lower limbs in both device at bipolar situation.

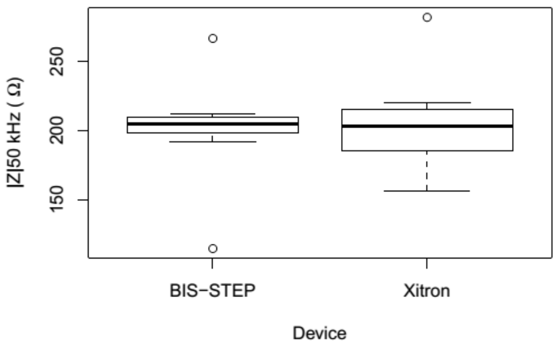

Figure 4: Boxplot of |Z|50 of the upper limbs in both device at bipolar situation.

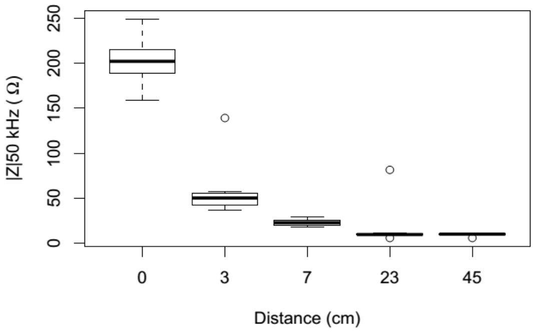

Figure 5: Behavior of |Z|50 for the lower limb as a function of distance between current and signal pickup electrodes, provides by XITRON4200.

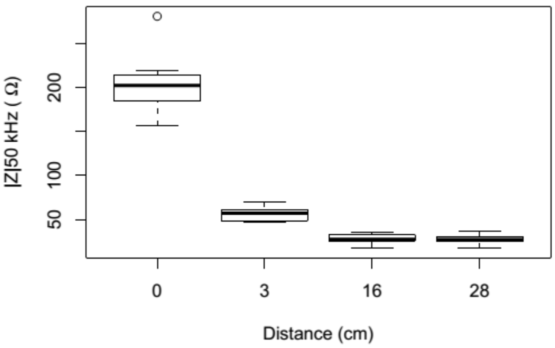

Figure 6: Behavior of |Z|50 for the upper limb as a function of distance between current and signal pickup electrodes, provides by XITRON4200

Figure 7 shows the behavior of |Z|50 for the lower limbs in two different subjects. One can notice that both volunteers presented similar decreasing behavior but different basal bioimpedance values, and both reached similar end values.

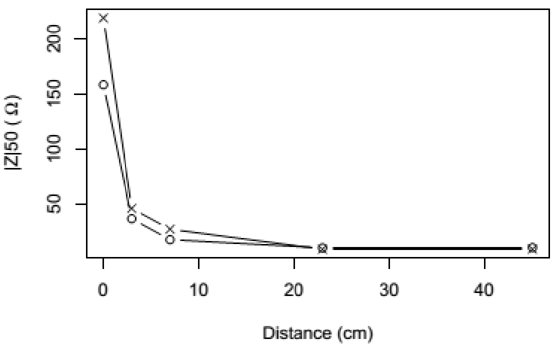

Figure 7: : Behavior of lower limb's |Z|50 at two volunteers as a function of distance between current electrodes and signal pickup electrodes, provides by XITRON4200.

Discussion

Figures 3 and 4 indicate that a bipolar bioimpedance technique (BIS-STEP) could obtain results similar to the ones achieved by bipolar method applied with tetrapolar device. However, due to the influence of electrode impedance, a good estimative of electrode impedance is of paramount importance for the reliability of bipolar measures [5], independently of device or technique used.

If we adopt the classical definition of electrical impedance established by the Theory of Circuit [7] only the setup employed by the bipolar electrode configuration could be really defined as electrical bioimpedance because both the current and the voltage are defined in the same port (pair of terminals). Those measures performed applying the current in one port and acquiring the resultant voltage in a different port must be called transimpedance. Thus, the ordinary measurement associated to the tetrapolar electrode configuration are indeed a bioelectrical transfer impedance.

Despite the result of a tetrapolar measurement be ordinarily called impedance instead of transimpedance, figures 5 and 6 show results where the magnitude of the impedance varies as a function of distance between the pickup pair of electrodes and the pair of electrodes that inject current. This can be considered a counter-intuitive result because if one applies a current in a conductor volume the resultant voltage would just depend on the distance between the pickup electrodes, which were constant during all measures. Then, it is clear that any change in CE placements may imply in measurements errors for the same conductor volume.

The results shown in Figures 5 and 6 corroborate the findings of Grimnes, Martinsen and Johnsen [3], that simulated using Finite Elements Method (FEM) and also observe experimentally, in only one subject, the decrease of bioimpedance magnitude as they increase the distance between the pickup pair of electrodes and the pair of electrodes that inject current. In addition, the results show the same behavior for upper and lower limb and the Figure 7 indicates that this behavior is independent of the analyzed subject. It reinforces the hypothesis that such profile is really an effect of the negative sensitivity problem associated to the tetrapolar electrode configuration when measuring inhomogeneous mediums.

Conclusion

It can be concluded that the biompedance measurement made by the bipolar method BIS-STEP can be more reliable than those performed by a tetrapolar technique. In the sense the results supplied by the former will never present changes in the measured impedance, for the same conductor volume, associated to different current electrodes placements . Such type of error can lead to measurements errors, hindering the bioimpedance technique reproducibility since any modification at current electrodes position may has a sensitive influence at the measure.

Acknowledgments

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