

Skin-Electrode Contact Area in Electrical Bioimpedance Spectroscopy. Influence in Total Body Composition Assessment.

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Abstract — Electrical Bioimpedance Spectroscopy (EBIS) has been widely used for assessment of total body composition and fluid distribution. (EBIS) measurements are commonly performed with electrolytic electrodes placed on the wrist and the ankle with a rather small skin-electrode contact area. The use of textile garments for EBI requires the integration of textrodes with a larger contact area surrounding the limbs in order to compensate the absence of electrolytic medium commonly present in traditional Ag/AgCl gel electrodes. Recently it has been shown that mismatch between the measurements electrodes might cause alterations on the EBIS measurements. When performing EBIS measurements with textrodes certain differences have been observed, especially at high frequencies, respect the same EBIS measurements using Ag/AgCl electrodes. In this work the influence of increasing the skin-electrode area on the estimation of body composition parameters has been studied performing experimental EBIS measurement. The results indicate that an increment on the area of the skin-electrode interface produced noticeable changes in the bioimpedance spectra as well as in the body composition parameters. Moreover, the area increment showed also an apparent reduction of electrode impedance mismatch effects. This influence must be taken into consideration when designing and testing textile-enable EBIS measurement systems.

I. INTRODUCTION

Electrical Bioimpedance (EBI) has shown to be a useful tool for the supervision of the body hydration and fluid accumulation in several applications like Body Composition Assessment (BCA), detection of lymphedema, [1, 2] and also for assessment of cardiac function via impedance cardiography [2]. Traditionally Electrical Bioimpedance Spectroscopy (EBIS) measurements for BCA are performed with electrolytic electrodes in a tetra-polar configuration. Usually, the electrodes are placed on the foot-ankle and hand-wrist to perform measurements for whole body measurements [3]. The electrode produces a skin-electrode interface with an area defined by its size, around 10 cm^2 .

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Variations in the quality of the skin electrode interface may affect the electrode polarization impedance (Z_{ep}) of one or more electrodes. This unbalance of the Z_{ep} can create an electrode mismatch and as it has been reported by Bogónez-Franco [4] affecting the measurement and producing changes in the impedance spectra, sometimes quite markedly. In addition to this, the relatively small size of the contact area may contribute to an irregular distribution of the current that is injected in the limb. This results in the formation of regions with higher current density near the injecting electrode, known as constriction zone [5]. This constriction zone may influence the potential sensed by the neighboring voltage electrodes and consequently influencing on the EBI measurement.

When performing EBIS measurements with Textrodes (Textile Electrodes), it has been observed that even though the spectral data obtained with electrolytic electrodes and Textrodes are very similar, it is possible to observe certain differences especially at higher frequencies and more evident in the reactance spectrum.

In BCA, these alterations on the impedance spectroscopy measurement might lead to erroneous estimations of the parameters describing the body fluid distribution ICF (Intracellular Fluid), ECF (Extracellular Fluid) and TBW (Total Body Water).

Differences observed in the impedance spectra obtained with Textrodes might be related to the increased area of the skin-electrode around the limbs. Under this hypothesis, this work analyses the influence of increasing the skin-electrode contact area on the acquisition of EBIS measurements and the estimation of the BCA parameters.

II. MATERIAL & METHODS

A. Measurement & Protocol

A Tetra-polar configuration Total Right Side for EBIS measurement was used on three healthy subjects lying in a supine position. The measurements were done using an electrode ring configuration and following the protocol shown in Fig 1.

A set of 30 measurements with each 1-4 electrodes was performed using the Impedimed SFB7 spectrometer in the frequency range of 3 to 1000 kHz.

B. Electrode-Ring Measurements

Electrodes were placed in ring configuration around the limbs as shown in Fig. 2. In this way EBIS measurements were performed with one, two, three and four electrodes

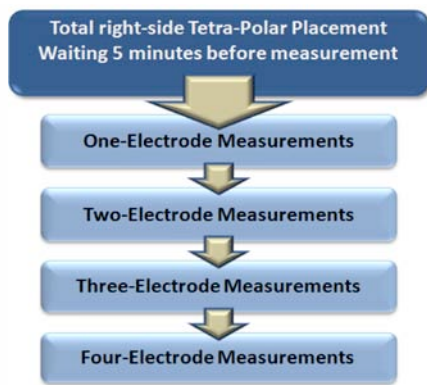


Fig.1. Measurement protocol

placed around the limbs (hand-wrist and foot-ankle) connected with cables for the current injection and voltage sensing points.

The electrodes were placed at opposite and equidistant positions over surface of the limb following a ring pattern. The electrodes used were the traditional Ag/AgCl RedDot 3M repositionable monitoring electrodes with a conductive area of 10.1 cm^2 .

C. Body Composition & Spectral Analysis

The BCA parameters, TBW, ICF and ECF, were estimated with the BioImp software Multi-Frequency Analysis version 5.3.1.1. [6] and then the mean and the standard deviation values were calculated and compared. The 30 EBI measurements performed were also processed and averaged with Matlab to obtain the spectral and impedance plots and to make a spectral comparison.

III. RESULTS

A. Complex EBI Spectrum

In Fig.3A the resistance spectrum shows negligible differences at frequencies under 400 kHz, above that frequency the resistance spectrum obtained with four electrodes continuously decreases with frequency while the

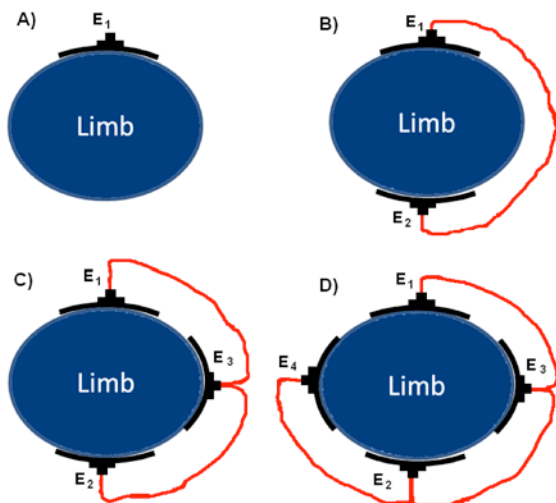


Fig.2. A-D Transversal view of the limb using the electrode-ring configuration with one, two, three and four electrodes (E_1 - E_4).

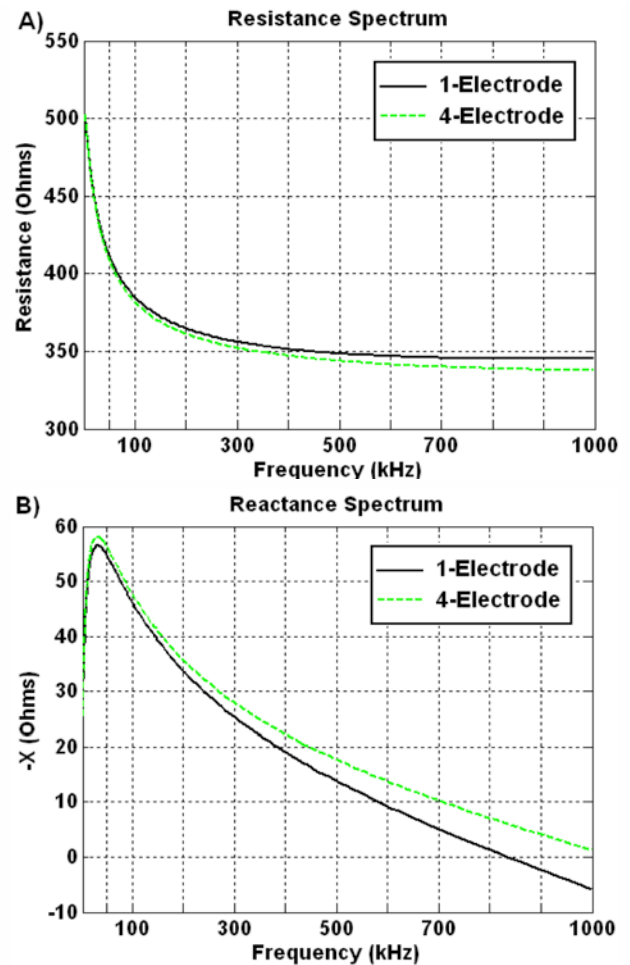


Fig.3. Impedance Spectra of subject 2. A) Resistance and B) Reactance.

spectrum obtained with a single electrode decreases up to 700 kHz but it remains constant above that frequency.

The reactance spectrum shown in Fig. 3B presents noticeable differences above 150 kHz. Note that above 800 kHz the reactance obtained with a single electrode changes from a capacitive value to an inductive.

In the impedance plot in Fig. 4A) the differences between 1 and 4 electrodes measurements are noticeable already from frequencies lower than the characteristic frequency i.e. the frequency of maximum reactance.

The conductance plot shown in Fig.4.B) shows a similar behavior than the resistance spectrum with the difference that in the conductance plot, the spectra deviates from each other from 150 kHz and above.

In Fig.5 the estimation of the BCA parameters performed with the four electrode configurations is depicted. In Fig. 5A and Fig. 5C the TBW and ICF parameters present an increasing trend from the single- to the 4-electrode configuration. The maximum changes observed on the estimation of the TBW and ICF is less than 1.5 liters in TBW and ICF. The ECF parameter did not present any particular trend and the maximal variation obtained was less than 0.19 liters.

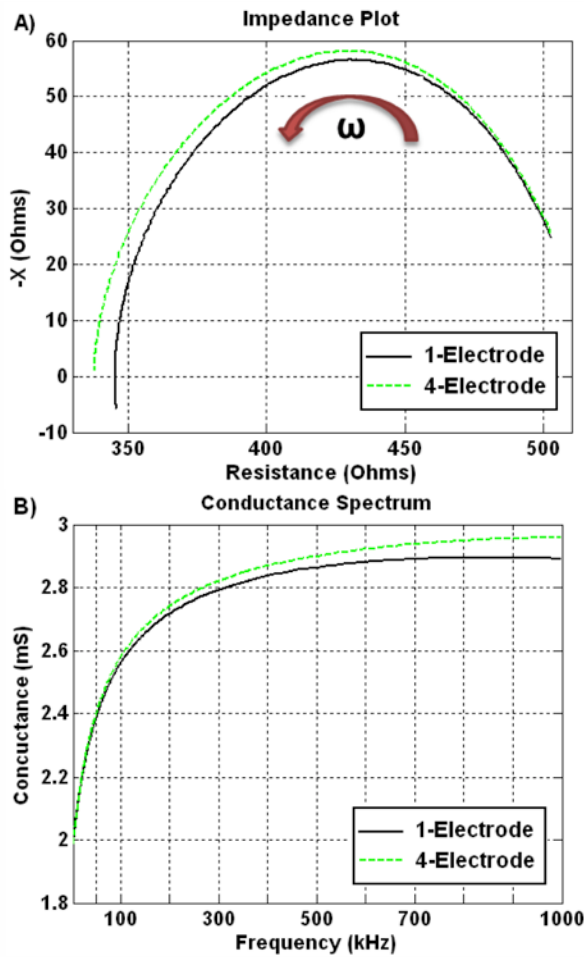


Fig.4. Impedance plot (A) and conductance Spectrum (B) of subject 2

Table I presents the common behavior observed on the measurements, and it also confirms the trend, with increasing number of electrodes, regarding the negligible differences observed in the estimated value of the ECF parameter and the remarkable difference observed on the values of TBW and ICF, especially the later.

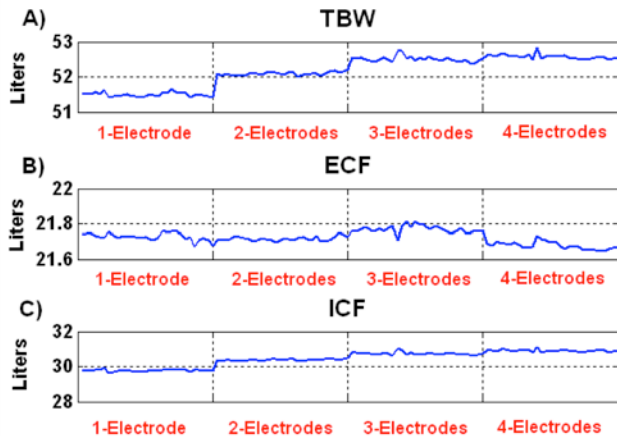


Fig.5. BCA parameters of subject 2 measured with the one, two, three and four electrode configuration.

TABLE I. MEAN RELATIVE PERCENT ERROR

	TBW	ECF	ICF
Subject 1	-2.199	0.236	-4.176
Subject 2	-2.098	0.234	-3.801
Subject 3	-1.017	0.860	-2.613

N.B. The mean relative percent difference shown is between the 1 and 4-electrode configurations.

IV. DISCUSSION

A. Skin-Electrode Impedance Mismatch

In EBI measurements the presence of electrode impedance mismatch can affect the impedance estimation as shown in [4]. In this study the obtained EBI spectra agree with the EBI spectra reported in [4] and obtained with electrode mismatch. The deviation observed at high frequencies indicates a kind-of inductive behavior present in the measurements obtained with a single electrode. Since the same effect was observed in the experiments reported in [4], it is very likely that the inductive effect is related with the presence of skin-electrode impedance mismatch. The inductive character seems to decrease when the area of the skin-electrode interface increases. Increasing the area decreases the probability that a mismatch in the skin-electrode impedance will occur.

B. Constriction Zone Size

The size of the constriction zone is also an element that might affect the impedance value when performing an EBI measurement [7]. In the single-electrode measurement the current density in the constriction zone is high and not uniformly distributed in the area neighboring the injecting electrode. On the other hand, in the 4 electrode the injected current will use more interface area and will spread out easier producing a uniform current distribution closer to the injection electrodes.

C. Influence on BCA Parameters

The presence of electrode mismatch or changes in the size of the electrodes area seems to affect the estimation of the BCA parameters. From the deviations observed on the spectral plots at high frequencies, the increment in the values of TBW and ICF was expected. The reason behind this is that the ICF parameter is estimated from the impedance value at infinite frequency, also known as R_{∞} . Similarly, since the values for the impedance at low frequencies remains practically identical, differences in the ECF estimation are remarkable small.

D. Skin-Electrode increased area

As previously presented in [8], a change on the constriction zone caused by the increased area of the skin-electrode contact interface obtained with textrodes straps, influences on the EBIS measurement Those measurements presented a lower value of the resistance, and consequently estimating lower values for R_0 and R_{∞} .

In a similar manner using the 4-electrodes ring configuration around the limb, which increases the area of the skin-electrode interface showed a very similar behavior than when using textrode straps around the limb. In both cases, as shown in 3.A) and 3.B) respectively, the obtained resistance spectra were slightly smaller and the reactance slightly larger at high frequencies, than the spectra obtained using a single Ag/AgCl electrode. It is remarkable to observe that the slope of the reactance spectrum at high frequencies presented in 3.B) for the 4-electrodes ring configuration is smaller than for the reactance spectrum obtained with a single Ag/AgCl. Such behavior agrees with the reactance spectrum obtained with textrode straps reported in [8].

V. CONCLUSION

Changes in the skin-electrode area size influence the acquired EBI spectra, both on the real and imaginary part. The estimation process used to calculate the BCA parameters is clearly influenced, overestimating the volumes of ICF and consequently TBW. These results should be taken into account when studying and comparing the measurement performance of textrode garments.

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