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Electrical Bioimpedance Cerebral Monitoring. Preliminary Results from Measurements on Stroke Patients

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***Abstract*— Electrical Bioimpedance Spectroscopy (EBIS) is currently used in different tissue characterization applications. In this work we aim to use EBIS to study changes in electrical properties of the cerebral tissues after an incident of hemorrhage/ischemic stroke. To do so a case-control study was conducted using six controls and three stroke cases. The preliminary results of this study show that by using Cole-based analysis on EBIS measurements and analyzing the Cole parameters R_0 and R_∞, it is possible to detect changes on electrical properties of cerebral tissue after stroke.**

I. Introduction

Electrical bioimpedance (EBI) is currently used as a non-invasive diagnosis and monitoring tool in several different applications. The development of Electrical bioimpedance spectroscopy (EBIS) measurement and analysis techniques has supported applications of tissue characterization like skin cancer detection [1, 2], lymphedema [3] and total body water estimation [4] providing information about tissue composition and its condition.

The noninvasive and safety properties of EBI makes it an ideal diagnostic and monitoring tool where other options like X-ray or MRI examinations are not available, for instance bedside and/or for continuous monitoring. An emerging and potential application of EBIS that is not yet widely spread in clinical routine is studies and monitoring of cerebral related injuries.

Stroke or *"brain attack"* is currently ranked as the third cause of death in developed countries by the World Health Organization [5]. Stroke can be categorized into two main types: ischemic or hemorrhagic. Ischemic stroke is due to lack of blood supply to one part of the brain, infarct, followed by edema; and hemorrhage is caused by a ruptured blood vessel leading to an accumulation of blood in a portion of the brain followed by hematoma. Both edema and hematoma will impose a change in the composition and structure of the cerebral tissue and consequently the electrical properties of the brain will change [6-9].

In this work an ongoing case-control study and some preliminary results are presented. The results indicated that transcephalic EBIS measurements might contain information about the brain tissue that could be useful for discriminating between healthy subjects and patients that have suffered a brain stroke.

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II. Methods and Materials

A. Tetrapolar EBIS Measurements and Subjects

Two EBIS measurements targeting two different regions of the brain in each hemisphere have been performed. The measurements targeting the central areas are label as Ma_L or Ma_R depending on the side of which they were taken, left or right. Similarly, the measurements targeting the lateral areas are label as Mb_L or Mb_R, see Fig. 1 and Table I. The electrodes used in this study were standard EEG silver electrodes dipped in electro-conductive paste Elefix. The Electrodes were placed according to the 10-20 system as listed in Table I and the skin surface was prepared in the same way as for regular EEG recordings i.e. cleaning the skin with alcohol and scrubbing gently with mild abrasive conductive cream.

TABLE I. Electrode Allocation for EBIS Measurements

	Mb_L	Ma_L	Ma_R	Mb_R
I^+	Fp_1	Fp_1	Fp_2	Fp_2
V^+	F_7	F_3	F_4	F_8
V^-	T_5	P_3	P_4	T_6
I^-	O_1	O_1	O_2	O_2

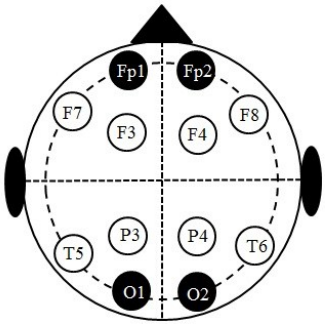

Fig. 1. Different electrode placement for performing the Cerebral EBIS measurements. Note the electrodes are located according to the 10-20 system.

B. Measurement Subjects

This study includes a total of six volunteers and 3 patients who suffer unilateral stroke. i.e. only one brain-hemisphere was damaged by the stroke. Consequently a total of 30 EBIS measurements from healthy brain hemispheres and 6 from stroke damage hemispheres were collected. The healthy volunteers were all males with ages 29-54 while the ages of the patients ranged 40-55, 2 were females and 1 was male. In two patients the stroke was present in the left hemisphere and in the other patient in the right hemisphere. The patients were in the initial phase of rehabilitation, 6-8 weeks after the stroke episode. This study has been done with an ethical approval from the regional ethical review board of Gothenburg.

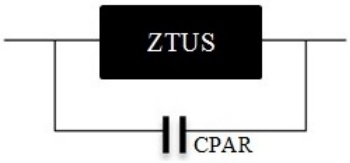

Fig. 2. Measurements model

B. EBI Spectrometer SFB7

EBIS measurements were recorded by the four-electrode technique using the SFB7 spectrometer manufactured by Impedimed. Sinusoidal current with constant RMS amplitude of 200 μA was used to perform complex EBIS measurements in the frequency range 3.096-1000 kHz by sweeping the measurement frequency over 255 logarithmically-spaced frequencies.

C. Measurement Model and Artifacts

One the most common artifacts present in EBI measurements is the capacitive leakage artifact produce by stray capacitances in parallel with tissue under study i.e. *ZTUS*. Such artifacts appear as deviations in the measured EBI spectra and is most noticeable at high frequencies. In [10] a simplified model of the tissue under study and these parasitic capacitances CPAR is presented. See Fig. 2.

D. Cole function

The Cole function is a mathematical expression introduced by K.S. Cole in 1940 (1) that experimentally fits measurements of complex EBI [11]. The Cole function consists of four parameters R_0, resistance at *DC*, R_∞, resistance at frequency infinity, α and τ *i.e. inverse of the characteristic frequency* ω_C.

$$Z_{\text{Cole}}(\omega) = R_\infty + \frac{R_0\text{-}R_\infty}{1+(j\omega\tau)^\alpha} \approx Z_{Meas}(\omega) \qquad (1)$$

For estimation of the Cole parameters from an EBIS measurement, curve fitting iterative methods are often used. In this work following [12] the Non-Linear Least Square method has been applied fitting the conductance spectra from the EBIS measurement to the conductance version of the Cole function $G_{COLE}(\omega)$, see (2).

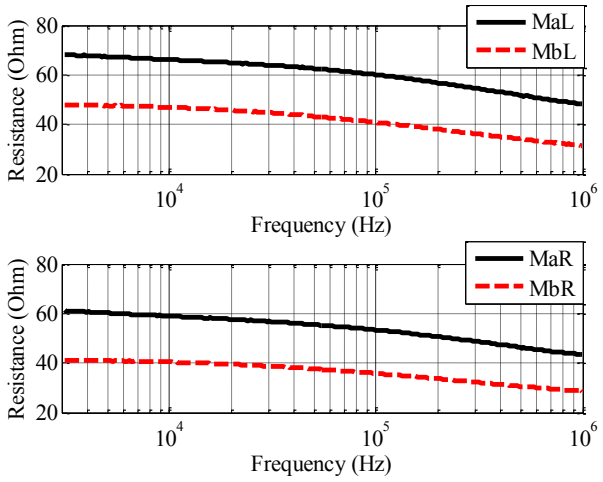

Fig. 3. Comparision of the resistance spectra obtained from a healthy volunteer. Legend produced in accordance with the notation introduced in II.A

$$G_{COLE}(\omega) = Y_0 + \frac{(Y_\infty - Y_0)\left(1 + \frac{Y_\infty}{Y_0}(\omega\tau)^{-\alpha}\cos(\alpha\pi/2)\right)}{1 + \frac{Y_\infty^2}{Y_0^2}(\omega\tau)^{-2\alpha} + 2\frac{Y_\infty^2}{Y_0^2}(\omega\tau)^{-\alpha}\cos(\alpha\pi/2)} \qquad (2)$$

In [13],it was shown that in EBIS measurement according to model from Fig. 2, fitting the conductance of EBIS measurement to (2) would produce an estimation of the Cole parameters free from the influence of capacitive leakage.

E. Rule based Analysis

Cole parameters R_0 and R_∞ have been obtained from the two lateral $Mb_{L/R}$ and central $Ma_{L/R}$ cerebral areas of each hemisphere. Since Ma on each hemisphere covers a larger volume in of the brain, it is expected that the magnitude of such a measurement will be larger than the magnitude from Mb measurements. Thus the values for R_0 and R_∞ parameters obtained from Ma measurements should be larger than the values obtained from Mb measurements; at least in a healthy brain. This has been used as the main rule to compare damaged hemispheres with undamaged ones and find out about changes in electrical properties of the cerebral tissue after a case of stroke.

III. Results

An example of resistance spectra for both Ma and Mb of each hemisphere obtained from a healthy volunteer is shown in Fig 3. It is observed that for the whole frequency range the resistance spectrum from the Ma measurement, plotted continuous trace, is larger than resistance values obtained from Mb, dashed trace, in both hemispheres, left hemisphere is represented in the upper plot and the right hemisphere in the lower plot. In all the healthy volunteers the resistance spectra from Ma is larger than from Mb in both hemispheres, as shown in the plots on Fig. 3.

In Fig. 4 the resistance spectra obtained from the stroked hemisphere in each patient is plotted. It is easy to see that in two of the three cases, b) and c) plots, the resistance spectrum obtained from Ma measurement and plotted with continuous trace present the smallest values along the frequency range.

The remaining plot shows the resistance spectrum obtained from the Mb measurements, dashed trace, an it exhibits smaller values at low frequencies and larger at high frequencies than the resistance from the Ma measurements.

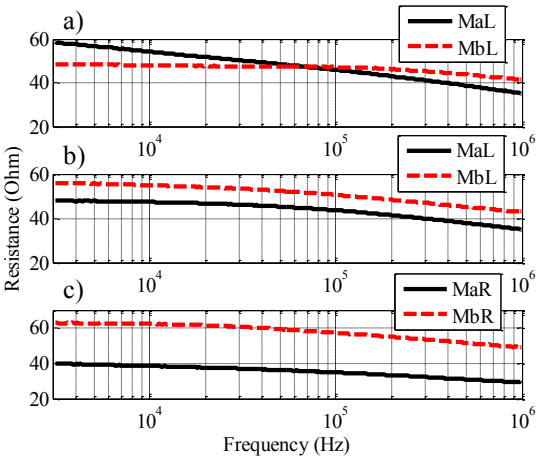

Fig. 4. Resistance spectra from the damage brain hemisphere in all three patients.

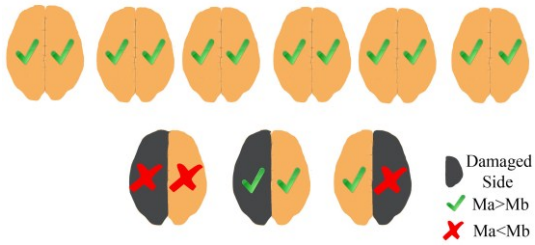

Fig. 5. Comparision of R_0 values between Ma and Mb measurements in both volunteers and stroked patients.

In Fig. 5 the results from the R_0 comparison are shown for the healthy volunteers and the 3 patients, lower row. The damage hemisphere is indicated by the dark color. From the figure it is easy to see that in 2 out 3 patients the expected rule is not fulfilled as it is fulfilled in all the healthy volunteers for both hemispheres.

In Fig. 5 among the stroked cases, there is one case that fulfills the R_0 rule; this case corresponds to the EBIS measurement in fig. 4.a), that presents a resistance spectrum that is completely different to any of the spectra presented in this section.

In Fig. 6 similarly to Fig. 5 the results from the R_∞ comparison are shown for the healthy volunteers, upper row, and the 3 patients lower row. In this case none of the measurements from the damage brain hemispheres fulfill the rule while the rule is fulfilled in all the healthy volunteers for both hemispheres.

Fig. 7 shows how the expected rules for R_0 and R_∞ are fulfilled in healthy hemispheres of controls and damage hemispheres of cases when referred to. It is observed that for controls 100% of hemispheres comply with R_0 and R_∞ rule while only one (33%) of stroked hemispheres complies with the expected R_0 rule and none complies with the expected rule for R_∞.

IV. Discussion

When comparing between the measurements form central and lateral cerebral regions, the results show that the EBIS data obtained from brain hemispheres with stroke differs remarkably from EBIS data obtained from healthy subjects. The difference is captured by a simple rule based comparison

Fig. 7. Comparision of the R_0 and R_∞ rule for the measurements performed in healthy and stroked hemsphere

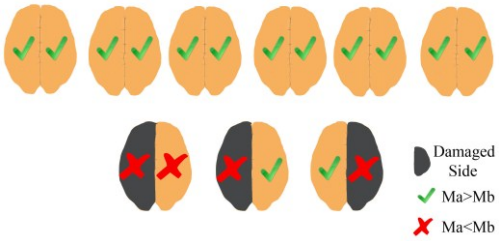

Fig. 6. Comparision of R_∞ values between Ma and Mb measurements in both volunteers and stroked patients.

between the values of R_0 and R_∞ obtained from the EBIS measurements and it is possible to produce a complete differentiation.

The analysis performed in this paper is very limited and refers only to two values. Other EBI parameters like the characteristic frequency of the reactance and susceptance spectra could be studied. The acquisition of the impedance spectrum with a good resolution, 255 points distributed in three decades, would allow spectral analysis directly on the measurement and not through models.

Obviously due to the low number of patients these results are limited and cannot be used to generalize. However, since differences in EBI measurements taken on stroke brains at a single frequency have been reported previously [14-16], it was expected that the EBI spectra of a brain suffered from stroke would exhibit different spectroscopy values than EBIS measurements from healthy brain. Even if this was expected, this work is the first to confirm it by findings in experimental EBIS data from patients who suffered stroke.

In [14-16] changes in the impedance of brain tissue at single frequency were confirmed with hundreds of stroke patients. The preliminary results shown in this paper require the same type of validation. Validation work is also being planned at Karolinska University Hospital in Stockholm including also acute stroke patients.

V. Conclusion

Transcephalic measurements of Electrical Bioimpedance Spectroscopy contain tissue information that can be used to differentiate between healthy brain tissue and brain tissue that has suffered stroke. If these results are successfully validated in larger population data sets, Electrical Bioimpedance Spectroscopy measurement technology might enable the development of a diagnostic tool for prompt detection of acute stroke. Given the characteristic of EBI technology, portable and affordable, such tool could be most probably implemented for ambulatory use.

Acknowledgments

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