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ELECTRICAL CHARACTERISTICS OF FEMALE AND MALE HUMAN SKIN

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Abstract – Bioimpedance spectroscopy (BIS) is a popular method for characterizing the electrical properties of biological tissues. In this study, BIS measurement data of female and male human skin were analyzed and compared. The electrical characteristics of tissue were followed according to four-parameters of the Cole-Cole model: low frequency resistance R_0; high frequency resistance R_∞; relaxation time τ and parameter α. Individual electrical characteristics of human skin were determined for 30 women and 30 men. The distribution and one-way analysis of variance (one-way ANOVA) of the Cole-Cole parameters R_0, R_∞, τ, α within the human population indicated their different dependence on gender. Parameter α, which is higher in the female subjects (α =0.83±0.03) than in the male subjects (α=0.7±0.05), is strongly dependent on gender (p=0). Parameter R_∞ also significantly depends on gender (p=0.002), while τ and R_0 seem to be slightly related to gender (p>0.05).

Key words: Bioimpedance spectroscopy (BIS), electrical characteristics, human skin, Cole-Cole parameters

INTRODUCTION

Bioimpedance spectroscopy (BIS) is a non-invasive, low cost, and widely used diagnostic method (Grimnes et al., 2008; Kyle et al., 2004). It is based on the study of the passive electrical properties of biological tissues. Passive electrical properties are related to tissue electrical response to the exposure to external electrical energy. Thus, the tissue is characterized as a hypothetical electrical circuit composed of resistors, capacitors and inductors. Practical use of passive electrical properties as a diagnostic method started in the middle of the 20th century and has been developing in a variety of ways that are now used for multiple applications (Prasad et al., 2008; Cornish et al., 2001; York et al., 2009; Neves et al., 2000; Martens et al., 2004; Amaral et al., 2011; Tang et al., 2009). These applications include determining the electrical characteristics of normal healthy tissues, organs or the whole body, as well as the electrical characteristics of tissue pathological changes (Aberg et al., 2005; Sun et al., 2010; Zou et al., 2003; Gupta et al., 2008). Therefore, BIS is widely used for analyzing and modeling botanical elements (Jesus et al. 2008; Elwakil et al. 2010), tissue monitoring (Ivorra, 2003), drug delivering (Curdy et al., 2000), total body water (Jaffrin et al., 2006), fat free mass (Kyle et al., 2005), and blood compound analyses (Ivorra, 2003).

Human skin, as the largest and easily available organ, is the object of many BIS investigations (Kim et al., 2006; Yamamoto et al., 1976; Prokhorov et al., 2000; Curdy et al., 2000; Qiao et al., 1995; Mikolajewska et al., 2011). However, there are no literature data dealing with the electrical characteristics of human skin as a factor strongly dependent on gender. Having in mind that the electrical properties of human skin could be modeled by the Cole-Cole equation

(material and methods), in this paper we focused on the distribution of four Cole-Cole parameters R_0, R_∞, τ, α and their dependence on gender.

MATERIALS AND METHODS

Electrical measurements

The proposed experimental method uses two electrode techniques. The electrodes were made of stainless steel, diameter d=1 cm, and the distance between the electrodes was 6 cm. Bioimpedance measurements were performed using a Solatron 1255+1280 impedance analyzer, as well as a MerIm10 impedance analyzer at different frequencies ranging from 10 Hz-100 kHz, at sinusoidal voltage input 0.1 V. Impedance magnitude, phase and frequency were routinely obtained.

Experimental material and protocol

Bioimpedance spectroscopy was performed at room temperature (22°C), 60 subjects (30 male and 30 female), aged 23-30 years. Before each measurement, the skin was wiped with ethanol to avoid the influence of sweat on the results. Stainless steel electrodes were wetted with bidistilled water and placed on the forearm skin. BIS measurements were carried out at each frequency in the range 10 Hz-100 kHz.

Bioimpedance spectroscopy and the Cole-Cole model

Bioimpedance is usually measured by applying an alternating electrical current from an external source to a living organism. Complex impedance of a biological tissue comprises two components: real resistance and imaginary reactance

$$Z = Z' + jZ''$$

BIS is based on the impedance measurements at each frequency from the frequency range. In the BIS technique, impedance measurements made at each frequency were plotted in the (Z', Z") plane, forming a semi circle (Fig.1).

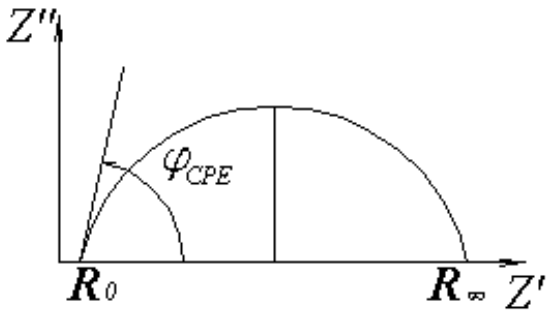


Fig.1 Cole diagram with characteristic impedance points used to determine parameters: R_0, R_∞, τ and α.

The mathematical model of biological tissue invented by Kenneth Stewart Cole and Robert Hugh Cole (Cole et al., 1941) consists of three hypothetical circuit elements:

1. low frequency resistance R_0; 2. high frequency resistance R_∞; 3. constant phase element (CPE), connected as shown in Fig. 2. CPE is a fractional capacitor and its impedance is

$$Z_{CPE} = 1/(j\omega C)^{\alpha}$$

where C denotes the capacitance and α is an exponent in the range $0 < \alpha \leq 1$. The Cole-Cole impedance is then:

$$Z = R_\infty + \frac{R_0 - R_\infty}{1 + (j\omega\tau)^{\alpha}} = Z' + jZ''$$

and

$$(j\omega)^{\alpha} = \omega^{\alpha}\left[\cos(\alpha\pi/2) + j\sin(\alpha\pi/2)\right]$$

(Elwakil et al., 2010).

In order to characterize the individual human tissue, finding the values of the four parameters (R_0, R_∞, τ, α) is required. To determine these values, an impedance analyzer is used to measure human skin *in vivo* and a Cole plot is constructed as shown in Fig. 1. A circular arc is obtained by applying least squares regression, from which R_0 and R_∞ can be directly found, and the angle

$$\varphi_{CPE} = \alpha \frac{\pi}{2}$$

enables the calculation of α (see Fig. 1). The frequency at which |Z''| is maximal and is equal to 1/τ.

Data analysis

To reveal the differences between the female and male Cole parameters (R_0, R_∞, τ, α), one-way analysis of variance (one-way ANOVA, MATLAB 6.5) was executed. The statistical significance was calculated at the level of $p < 0.05$.

RESULTS AND DISCUSSION

Bioelectrical spectroscopy measurements *in vivo* were performed on the forearm skin of 60 healthy volunteers. The electrical measurement data of each skin were used for the calculation of four Cole-Cole parameters as described above. Of the 60 screened subjects, 30 were female and 30 male. The volunteers were aged 23-30 (Table1).

In Table 1 the results of comparative analysis of human skin Cole-Cole parameters α, τ, R_0, R_∞ are shown**.** The influence of gender on each of the four Cole-Cole parameters were statistically analyzed by its mean ± sd, median values, f values (interclass/intraclass variance) and p values. The distribution of each individual Cole-Cole parameter related to the distinct gender groups is shown as box plots (Fig. 3). Box plots are used as a convenient way to graphically depict groups of numerical data through their five numbers, summarized as the smallest observation (sample minimum), lower quartile (Q_1), median (Q_2), upper quartile (Q_3), and largest observation (sample maximum).

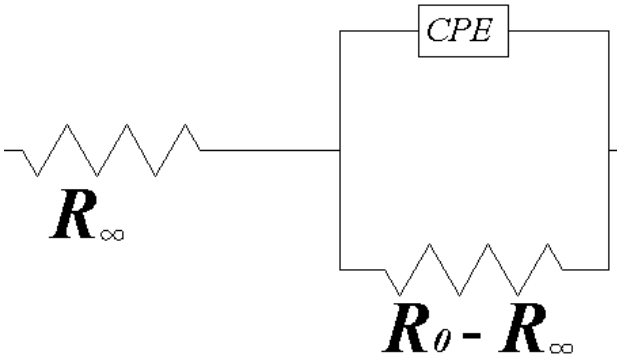


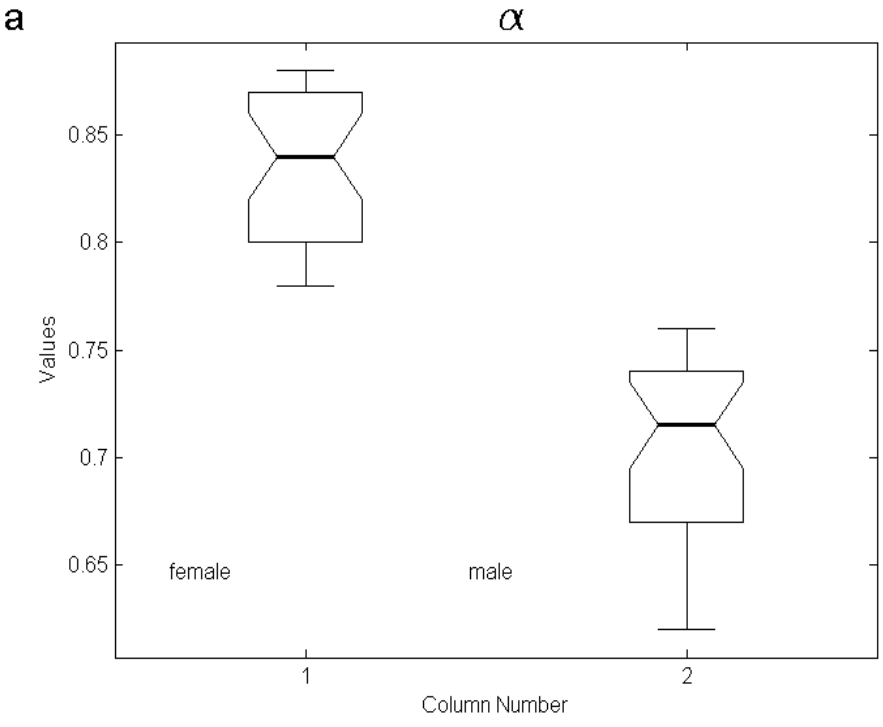
Fig. 2 Equivalent electrical circuit with three elements: a low-frequency resistor R_0**,** a high- frequency resistor R_∞ and a constant phase element (CPE).

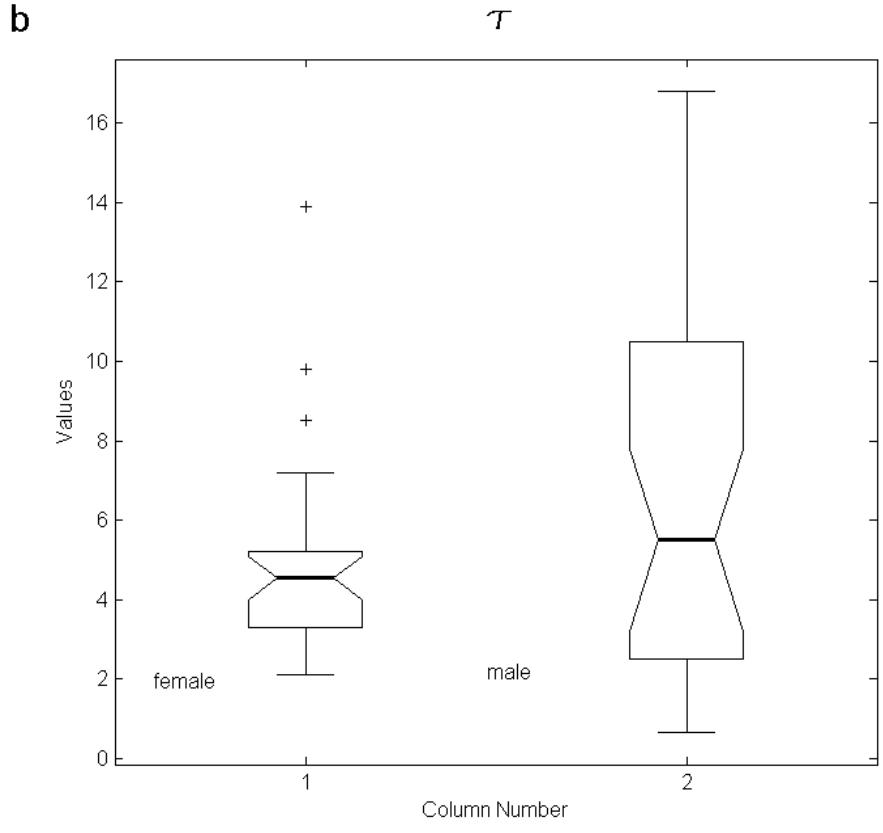
Parameter α was found to be highly significantly in regards to gender. The mean value for α estimated for the female population was 0.83±0.03 and for the male 0.70±0.04 (Table 1). The significance of the mean value difference between the groups was confirmed by one-way ANOVA since f=168.62, p=0. This result demonstrates that α values for women and α values for men are completely separated. The box plot also visually presented total α value separation, related to gender groups (Fig.3a).

Next, we analyzed female and male group distributions related to relaxation time τ. Table 1 shows

Table 1. Comparison of four Cole-Cole parameters between female and male human skin

	female		male		p	F
	mean ± sd	median	mean ± sd	median		
No of subjects	30		30			
age	26.5±3.5		26.5±3.5			
α	0.833±0.034	0.84	0.699±0.045	0.715	0	168.62
τ [ms]	4.83±2.53	4.55	6.43±4.50	5.5	0.0962	2.86
R_0 [Ω]	1160143±2328510	515000	2304803±3882058	752500	0.1714	1.92
R_∞ [Ω]	1421.085±1013.983	1358.5	683.467±766.8508	325	0.0024	10.1


a
α
0.85
0.8
0.75
0.7
0.65
Values
female
male
1
2
Column Number


b
τ
16
14
12
10
8
6
4
2
0
Values
female
male
1
2
Column Number

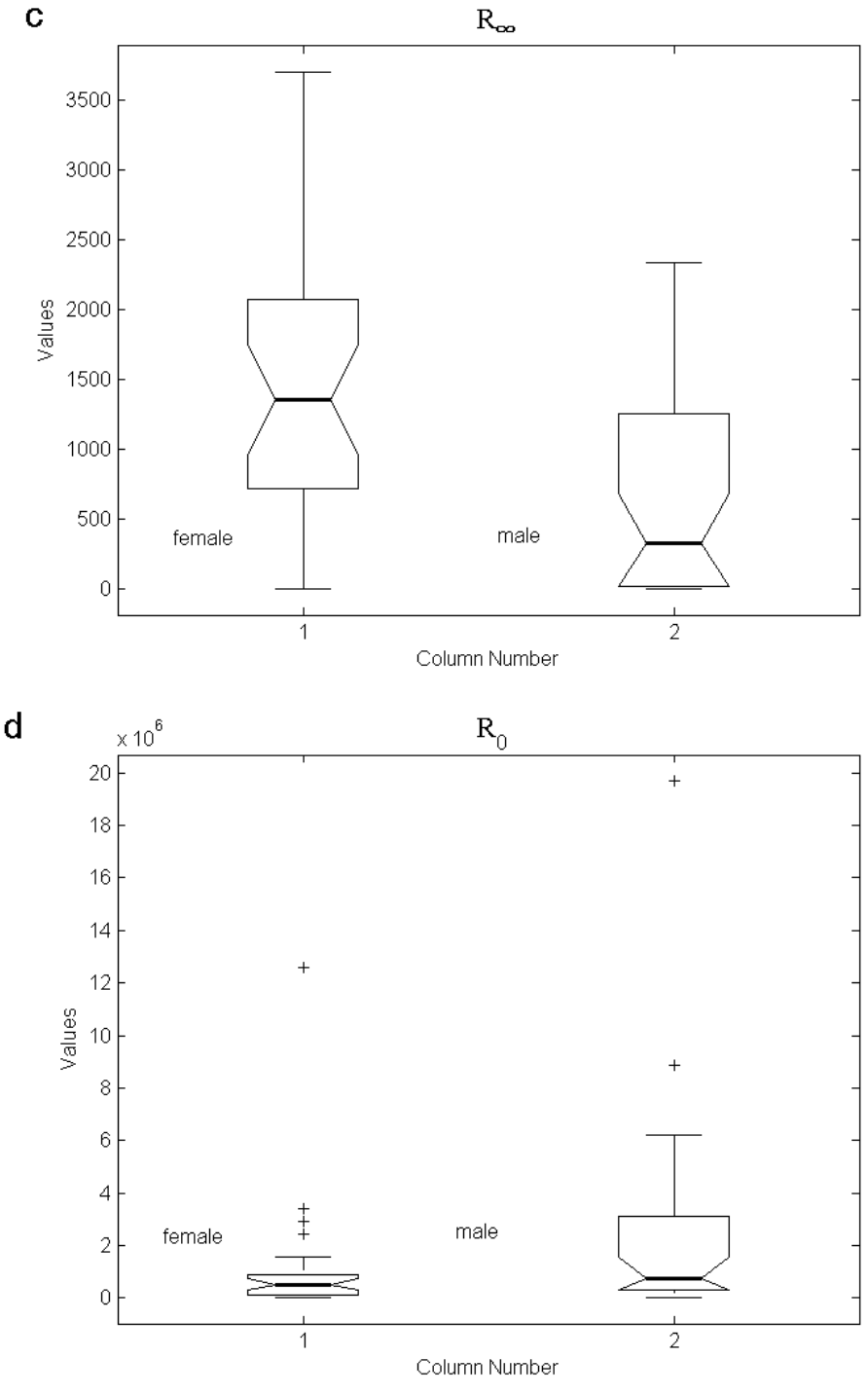


Fig. 3. The box plot of distribution of Cole-Cole parameters within female and male human population: a) parameter α; b) relaxation time τ ; c) high frequency resistance R_∞ and d) low frequency resistance R_0. The box is drawn between the quartiles, with a thick line at the median value. The whisker indicates range of the data, with outliers shown as crosses.

that the mean values of τ are lower for females (4.83 ms) than for males (6.43 ms). However, since p=0.09, the difference between the female and male groups is not statistically significant. In Fig. 3b, the box plot of relaxation time distribution among the female and male volunteers demonstrated that there is a different dispersion of τ values. The upper quartile (Q_3) is considerably lower for women than for men, while the lower quartile (Q_1) is slightly different in these two gender groups. The median value is lower for females (4.55 ms) than for males (5.5 ms). The observation also suggests that relaxation time is shorter and that dispersion of τ values is smaller for women than for men.

In Fig. 3c, the box plot presents the distribution of parameter R_∞. The median (Table 1), upper quartile (Q_3) and lower quartile (Q_1) values clearly depict differences between the two groups related to R_∞. This is confirmed by the different mean values for women (1421.085±1013.983 Ω) and men (683.467±766.851 Ω). Group distinction related to R_∞ is statistically significant since f=10.1, p=0.002 (Table 1).

Box plots that represent distribution of R_0 within female and male populations are shown in Fig. 3d. The upper quartile value (Q_3) for the men is clearly higher than for the women, while the median value (Table 1), as well as lower quartile value (Q_1), are slightly lower in women than in men. In spite of difference between the mean values of R_0 for the female (1160143±2328510 Ω) and male subjects (2304803±3882058 Ω), it is impossible to distinguish the two groups by R_0 since p=0.1714 (Table 1).

The obtained values of parameters α, τ, R_0 and R_∞ are in agreement with literature data (Kim et al., 2006; Yamamoto et al., 1976; Prokhorov et al., 2000; Curdy et al., 2000; Qiao et al., 1995;, Mikolajewska et al., 2011). It is interesting to note that the standard deviations of parameters α, τ, and R_0 were greater in men than in women, while the opposite was found only for R_∞. However, the biological interpretation of the significantly higher mean values of α and R_∞ found in women, and their eventual link to values of concrete biophysical quantities existing in the two genders, remains to be explored.

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