A Characteristics of Human Skin Impedance Including at Biological Active Points

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Abstract: The electrical characteristics of biologically active points (BAPs) compared with those of the surrounding human skins are studied. And we confirm that BAPs have lower resistance and higher capacitance than the surrounding skins do. We also find that BAPs have higher characteristic frequency than surrounding skins and the impedance spectra of BAPs sometimes have two semicircles on the complex impedance plane. We propose the skin impedance model that is proper to the BAPs and this circuit describes our experimental results sufficiently well.

1. Introduction

Electrical impedance measurements of human skin are non-invasive, no discomfort, no known risk, and no side effects. So these could be used for various clinical applications, such as bioelectrical impedance analysis, electrical impedance tomography, investigation of transdermal drug delivery, and others. But most of these investigations don't take into account that on the human body there exist several thousands of biologically active points (BAPs, or acupuncture points), with different physical characteristics among them and also different from those of the surrounding skins[1]. For the better understanding of electrical characteristics of human skin, we need to research about BAPs. Since the 1950s, the electrical characteristics of the BAPs have been studied, first by Nakatini[2] and followed by Niboyet[3], Zhu[4], Voll[5], Reichmanis[6], and Chen[7]. They found that BAPs have the lower electrical resistance or impedance than nearby surrounding points. But these researches are concentrated on the resistance and potential measurements and the frequency characteristics of BAPs are not considered. Prokhorov[8] found that BAPs have lower capacitance than surrounding skins using impedance spectroscopy.

We have studied electrical impedance characteristics of BAPs compared with those of the surrounding human skins. It is found that the frequency that has a peak reactance value of the BAPs is higher than that of the surrounding skins. Prokhorov proposed that the impedance spectra of BAP consist of two semicircles, and those of surroundings have only one. But our results of impedance measurements at BAPs have shown that the impedance spectra of BAP don't always have two semicircles. And we propose another skin impedance model and analyze the characteristics of the BAPs.

2. Method and Procedure

The measurements of BAPs and the surrounding human skins were carried out in vivo on three, healthy people, 24-26 years old. The methods of measurements are based on the Voll's method[9]. Two electrode impedance measurement method is used. One is measurement electrode which is the Al-AgCl electrode with a diameter of 4mm (EL204S, Biopac system Inc.) and placed on the BAP or on the skin surrounding of this point. The other is reference electrode, which is a brass cylindrical rod with a diameter of 30mm, which is held in the same hand by examinee. We measured for the same biologically active point Quze (PC3) which is located on the right antecubital region and nearby surrounding point at a distance of 10-15mm from the point. The PC3 points are detected by the characteristics of the BAPs, lower resistance point among the nearby points, which is based on the previous results[2-6]. Before the measurement, the skin is wiped using ethanol and is attached the measurement electrode to avoid influences of sweat on the results, and the examinee lies down on a bed and waits 20 minutes with constant temperature (23-25°C). The measuring system is shown in Fig. 1. This system consists of an digital lock-in amplifier (SR850, Stanford Research Systems), current drive and personal computer, which measures the components of resistance and reactance of the skin in the frequency range of 0.5Hz - 5kHz and maximum error rate is 5%. The measurements are taken using 50 different frequencies from 0.5Hz to 5kHz and the input sine wave current peak value is 1uA. The measurement frequencies are selected by log scale, and the time of measurement is about 4 minutes in one frequency sweep. We measure twice and the two

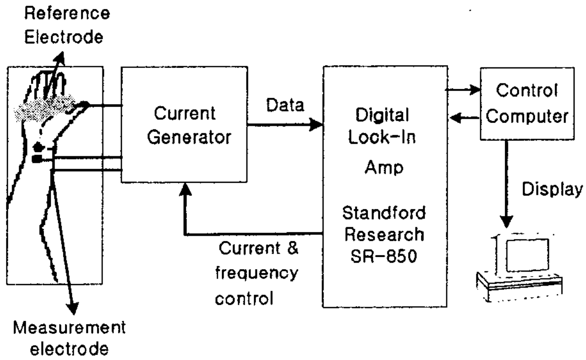

Fig. 1. The block diagram of the measuring system

measuring data are processed by the linear interpolation in time, because the skins are hydrated by wet gel which decreases the skin impedance[10].

3. Results and discussion

With the measuring data on three people, we show the dependence of the resistance and capacitance on frequency, measured for PC3 biologically active point in Fig. 2. The ratio of mean resistance found in the surrounding skin, to that found on the BAPs for each frequency is shown in Fig 2a. Similarly, the mean capacitance value of BAPs, divided by that of the surrounding skin is displayed in fig. 2b. As can be seen from these figures, the resistance of BAPs (R_P) is smaller than that of surrounding skins (R_S) and the capacitance of the BAPs (C_P) is larger than of surrounding skins (C_S) especially at the low frequencies and these results are the same of the previous results[8].

Fig. 3. shows the reactance of the BAPs and surrounding skins as a function of the measuring frequency. These graphs show that all of the characteristic frequencies that have maximum value of the reactance of BAPs are larger than that of the surrounding skins. This means that the response time of the BAPs is shorter than that of the surroundings and the stimulus at BAPs is transferred to the nerve faster than that at the surrounding skins.

For analysis of the measuring skin impedance data, electrical impedance models are necessary. The simplest skin impedance model is the Cole equations in Fig. 4a, which are the empirical equation to describe tissue impedance[11] and consists of two ideal resistors and one constant phase element (CPE) in Eq. 1.

$$Z = R_\infty + \frac{\Delta R}{1 + \Delta R (Z_{CPE})^{-1}} \qquad (1)$$
$$Z_{CPE} = Y^{-1}(j\omega)^{-\alpha}, \Delta R = R_0 - R_\infty$$

Where R_0 is a low-frequency intercept of the locus, R_∞ is a high-frequency intercept of the locus, α is the measure of the deviation from pure capacitive behavior, ω is the angular frequency, and Y is the admittance of the CPE. When Cole equation is plotted on the complex impedance plane, it gives rise to a locus having the form of a minor arc of a circle whose center lies below the real axis like Fig. 4b. This Cole model is good for the macroscopically homogeneous biological tissue. The human skins consist of various kinds of tissue layers and they can be modeled by Cole equation, and each of the Cole models has the semicircle on the complex impedance plane. But the

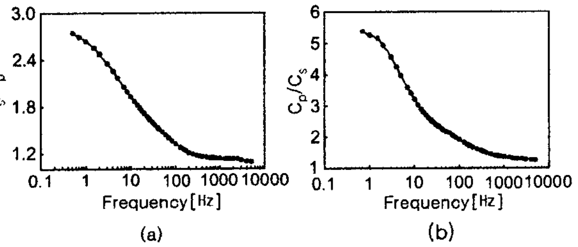

Fig. 2. The ratio of the mean (a) resistance and (b) capacitance between BAPs and surrounding skins.

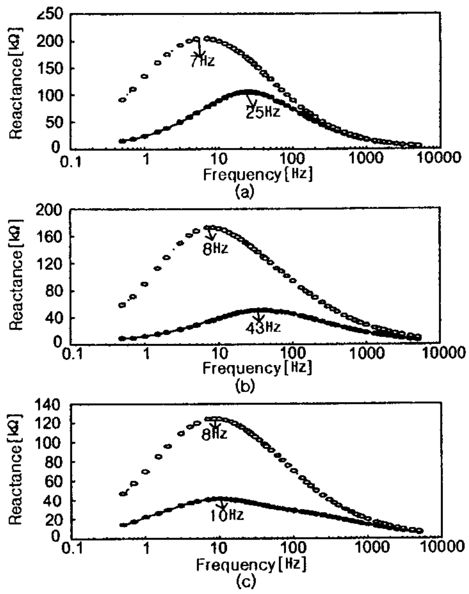

Fig. 3. The reactance values of the BAPs(•) and surroundings(○) on the three peoples

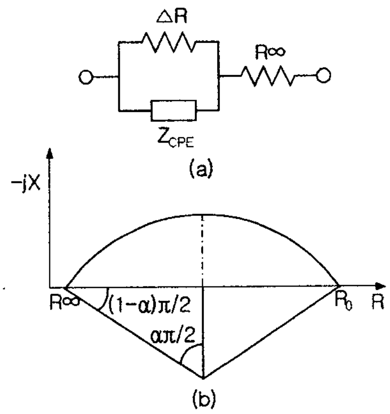

Fig. 4. Cole Impedance Model (a) equivalent electrical circuit, (b) A diagram of a complex impedance locus

measuring impedances of skins are usually fitted to the one Cole equation. If the characteristic frequencies of the Cole equations that are connected in series are similar or the resistances parallel with CPE of one Cole equation are much larger than the others, it looks like that this system has just one semicircle. Prokhorov showed and proposed that BAPs have two semicircles and surrounding skins have one semicircles[8]. But our measuring data about BAPs don't always show two semicircles as shown in Fig. 5. Therefore the electrical model of BAPs consist of two Cole models, but it doesn't always have two semicircles.

Prokhorov proposed electrical impedance model of BAPs which consists of the equivalent circuit of the skin described in Kontturi and Murtomaki[12], in series with the resistance and capacitance of the body. He proposed that the additional resistance and capacitance represented the characteristics of BAPs. But in the impedance model of biological tissue, the Cole model is more proper than the

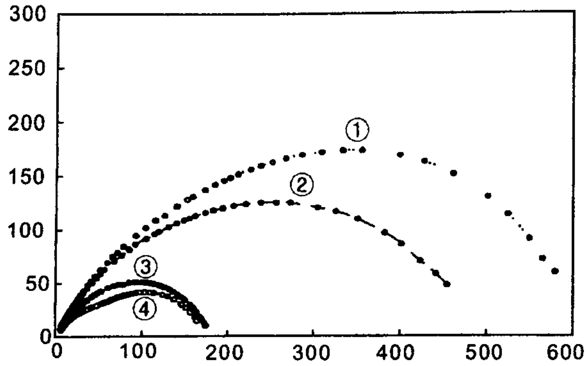

Fig. 5. Two kinds of complex impedance diagram. 1, 2) the locus of the surrounding skin complex impedances which look like one semicircle, 3) the locus of BAPs which also looks like one semicircle, 4) other locus of BAPs which looks like two semicircles

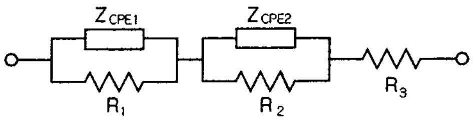

Fig. 6. Equivalent electrical circuit for BAP and skin

parallel circuit of resistance and capacitance[13]. So we use simple two Cole model in series to represent the electrical impedance model of the BAPs and surrounding skins in Fig. 6. For comparing our equivalent circuit with Prokhorov's, a non-linear fit, with the help of the ZView program, is carried out using the measured data which has two semicircles in the complex impedance plane. With the fitting results, we calculate an averaging value of each normalized error of each measuring frequency in Eq. 2.

$$Error = \frac{\sum_{N} \sqrt{\left(\frac{R_f - R_m}{R_m}\right)^2 + \left(\frac{X_f - X_m}{X_m}\right)^2}}{N} \qquad (2)$$

Where, R_m is the resistance of measured data, X_m is the reactance of measured data, R_f is the resistance of fitted data, X_f is the reactance of fitted data, and N is the number of the measuring frequencies. The error of our model is 0.4% and the error of the Prokhorov's model is 3.8%. But these fitting of our model are proper to the measured data which have the locus of two semicircles. If our model is fitted using the one semicircle data, a lot of cases for selecting the value of model components can be obtained and it is difficult to find proper component value.

4. Conclusions

In this paper, the characteristics of the BAPs are studied using impedance spectrum. We confirm that the resistances of BAPs are smaller than that of the surrounding skins and the capacitances of BAPs are larger than that of the surrounding skins. And we also find other characteristics. The characteristic frequencies that have maximum value of the reactance of BAPs are larger than that of the surrounding skins, and BAPs sometimes have the locus of two semicircles on the complex impedance plane. We propose an equivalent electrical circuit for the BAPs using two Cole models in series, and this circuit describes our experimental results sufficiently well.

We just studied BAPs at the PC3. For the further studies, it is needed to study other BAPs in our body.

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