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Electrical Characteristics Analysis of Biological Active Points Using Real-Time Measuring System

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Electrical impedance measurement has been extensively used to study biological systems. These studies generally aim to correlate electrical parameters with tissue structure or physiological events. By extending electrical impedance measurement can obtain various type of information, one of which is biological active point (BAPs: PC6, PC5 and ST-36) information. BAPs (acupuncture points) are specific places in the human body, related to disease conditions. When a needle, moxa, or other implement is applied to a BAP, symptoms related to that point improve. In this paper, BAP measurement can be illustrated by a simple model of an equivalent electrical circuit whose results correlate well with experimental results. The values of the chosen components were determined to be appropriate for the equivalent circuit, using a calculator. According to our experiment result, the reactance and frequency characteristics of BAPs appear different from those of the surrounding skin. The resistance of BAPs are 3–10 times less than those of non-BAPs. Also, the characteristic frequency range of BAPs is 15–30 Hz higher. In this paper, a unique three electrode measurement for distinguishing between BAP and non-BAPs with good precision was proposed. Using the proposed model, a method of realizing the resistance and capacitance of BAPs was presented. The result indicates the possibility of treating the concept of BAPs more objectively.

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1. Introduction

Electrical impedance measurement has been proposed in the study of a large number of physiological events mainly because it is simple to use, inexpensive and noninvasiveness. Different methods have been used for various clinical applications, such as electrical impedance tomography, bioelectrical impedance analysis and the investigation of transdermal drug delivery.[1–3]

In early research, the results of skin impedance measurement were interpreted using an equivalent electrical circuit. This equivalent circuit consists of a shunt resistance-capacitance that works with additional resistance. The shunt resistance-capacitance represents an impedance of epidermis, and the additional resistance represents an impedance of deep tissue in the underlying skin. This theoretical model was based on research that was started by Cole and Barnett.[4–6]

The concept of BAPs (acupuncture points) has since become an extensively studied area in Asia and the West. These points are not uniformly distributed across all parts of the human skin and they can be investigated in various ways for the purpose of scientifically establishing their existence.[7–10] The higher electrical conductance or potential of acupuncture points was first discovered by Nakatani[11] and subsequently confirmed by Niboyet[12] and Zhu *et al*.[13] On the other hand, In 1955 Podshibiaky[14] reported that they found some active skin points. In 1975, Reichmanis[15] designed a matrix electrode that enabled constant skin contact pressure to be achieved. Their double-blind studies proved, once again, that acupuncture points had a lower level of resistance. Reinhold Voll[16] designed an instrument called the Dermatron to measure these properties, and he has continued using it to supplement his clinical diagnoses and therapy since the early 1950s. This testing method has developed into the electrodermal screening test (EDST). The scientific basis of the EDST was presented by Chen *et al*.,[17] in 1996. Prokhorov *et al*.,[18] found that BAPs had lower reactance than surrounding skins using impedance spectroscopy.

Three-electrode measurement[19] has several advantages over two-electrode method measurement.[20] It can measure the impedance of particular positions and the skin impedance of a point more precisely than the two-electrode measurement.

In our review of the literature available, we concluded that the electrical properties of BAPs have not been sufficiently elucidated. Thus, an objective analysis of BAPs is still difficult. BAP experiments are still beset with problems in that they do not they produce reproducible results. Improving the existing three-electrode method enables the measurement of reactance and characteristic frequency.

In conventional techniques, BAPs were found intuitionally. Thus, BAPs resistance and capacitance could not be determined accurately. However, in this research, we develop a method of accurately BAP resistance and capacitance. If successful, a quantitative comparison of experiment results will be possible, and research on BAPs will be a scientific issue.

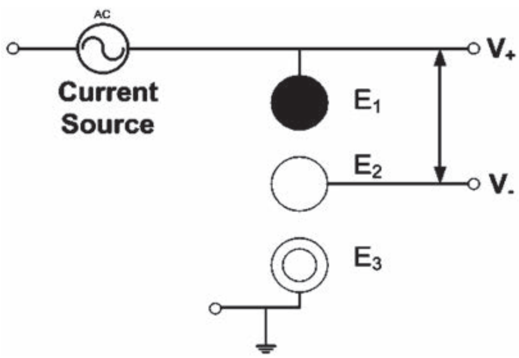
A new equivalent circuit model is proposed, which accurately describes our experimental results. Using a new three-electrode method and electric model the reactance and characteristic frequency of BAPs and the surrounding skin were analyzed objectively using a noninvasive real-time measuring system.

2. Materials and Methods

In this system, impedance measurement is based phase detection. Using a phase detector, the resistance and reactance components of impedance can be obtained with sufficiently high accuracy without interference from noise and drift. The three-electrode method shown in Fig. 1(a) is advantageous in that it can measure the impedance of BAPs under the skin.

In this BAP measurement method, an E_1 electrode is used to apply current and to measure voltage. An E_1 electrode is attached to the skin whereby it can measure BAPs. The reference electrode (E_2) is attached near the measurement electrode. Finally, the ground electrode (E_3) is attached at least 10 cm away from the measurement electrode.

(a)



(b)

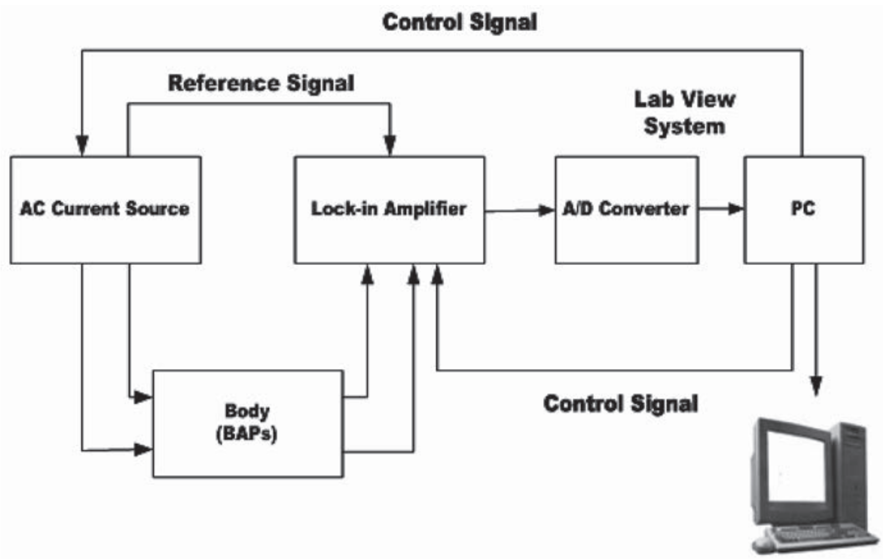


Fig. 1. (a) Construction of electrode system for impedance measurements by a constant- current method. ● (E_1) is the measurement electrode and current source. ○ (E_2) is the reference electrode. ◎ (E_3) is the ground electrode. (b) block diagram of BAPs measuring system.

The conventional three-electrode method entails moving the E_2 electrode to enable measurement. In this research, however BAPs and the surrounding skin were measured by moving the E_1 electrode, which is an efficient means of identifying whether BAPs are present.

Floating electrodes (E_1) are filled with electrolyte gel and then are attached to the surface of the skin using a double-sided adhesive tape ring. These electrodes enable quite stable measurements and are suitable for many uses. This stabilizes the measurement of epidermal layer resistance.

The impedances of BAPs and the surrounding skin were measured in healthy adult male volunteers. Ag-AgCl electrodes (4 mm in diameter, EL 258H Biopac System Inc) which are unpolarizable were used as measuring tools and reference electrodes. The electrode paste used was a conductance cream (EC33 skin conductance/resistance measurement). The ground electrode used was an ECG electrode (Biopac EL 503) with a diameter of 10 mm.

Each subject was instructed to lie down on a bed and wait for 20 min at constant temperatures (23–25°C). Before the electrodes were attached, the skin of the subject was wiped with ethanol to eliminate the effect of sweat. To improve electrical contact, the measuring electrode was wetted with double-distilled water.

Reactance measurements were taken at BAPs: both PC6 and PC5 on the left forearm and ST36 on the left leg. The measuring electrode was attached directly to the BAPs, or at about 5–10 mm from the BAPs. The reference electrode was placed 10 mm from the measurement electrode. The BAPs were located with an acupuncture detector (Kim's Oriental Medicine Clinic).

The measuring system is shown in Fig. 1(b). This real-time measuring system consists of a digital lock-in amplifier (SR830, Standard Research Systems), an AC current source (Keithley 6221), and a Labview control system (National Instrument PXI) and is controlled by a personal computer through GPIB (general-purpose interface bus). It measures the components of the reactance and characteristic frequency of the skin in the frequency range between 1 Hz to 1 kHz. The measurements were taken at 50 different frequencies between 1 Hz to 1 kHz. The input peak current was set below 10 μA at maximum to suppress electrical stimulation as much as possible. The total time required for the frequency sweep measurement was about 2 min. The measurement was conducted twice and the two sets of data were processed by linear interpolation with time.

3. Results and Discussion

The problem of oriental medicine up to now has been that, while it is an effective form of medicine in practice, it has been difficult to objectively demonstrate its principles. To provide a valid demonstration, it is necessary to identify the existence of the meridian line and acupuncture points. We used electrical impedance measurement to achieve this goal.

BAPs may show special electrical properties. Various investigations have been conducted to locate these points using skin impedance measurement. However, some issues had been raised by this technique. For instance, Carrol and Rowley[21] pointed that the impedance was mostly due to the contribution of the stratum corneum layers of the epidermis. Thus, we conducted a study based on the hypothesis that BAPs exist underneath the epidermis.

We are able to show the dependence of the reactance on the frequency measured, which were at PC6, PC5, ST-36 and the surrounding skin in Figs. 2(a)–2(c). The characteristic frequencies of the BAPs, which have a maximum reactance are about 15 –30 Hz higher than that of the surrounding skin. Also, the reactances are about 35–77 kΩ lower than those of the surrounding skin in Figs. 2(a)–2(c). BAPs positions of our human body are as following. PC6 is 2 cun above the wrist crease and between the tendons of palmaris longus and flexor carpi radialis. PC5 is 3 cun above the wrist crease and between the tendons of palmaris longus and flexor carpi radialis. ST36 is 3 cun below the patella lower edge and between the tibials anterior muscle and flexor digitorium communis muscle.

In Fig. 2(a), the characteristic frequency of PC6 is about 30 Hz higher than those of non-BAPs. Figure 2(b) shows that the characteristic frequency of PC5 is about 25 Hz higher than those of non-BAPs. In Fig. 2(c), the characteristic frequency of ST36 is about 15 Hz higher than those of non-BAPs.

The proposed simple equivalent circuit is shown in Fig. 3(a). This five-element circuit describes the frequency dependence of the impedance data. R_1 and C_1 show the surrounding skin. In the circuit, the additional parameters R_2 and C_2 are used to demonstrate the BAPs. This is an extension of Reichmanis's electrical circuit model, which was first used to calculate the C component of the equivalent circuit of skin impedance.[22]

Equation (1) is the equivalent circuit equation of the BAP model. Equations (2) and (3) determine resistance (real part) and reactance (imaginary part).

$$Z = \frac{1}{\frac{1}{R_1} + j\omega C_1} + \frac{1}{\frac{1}{R_2} + j\omega C_2} + R_3 \tag{1}$$

$$\mathrm{Re}(Z) = R_3 + \frac{1}{R_1\left(\omega^2 C_1^2 + \frac{1}{R_1^2}\right)} + \frac{1}{R_2\left(\omega^2 C_2^2 + \frac{1}{R_2^2}\right)} \tag{2}$$

$$\mathrm{Im}(Z) = \frac{-\omega C_1}{\left(\omega^2 C_1^2 + \frac{1}{R_1^2}\right)} - \frac{\omega C_2}{\left(\omega^2 C_2^2 + \frac{1}{R_2^2}\right)} \tag{3}$$

In these experiments, the predetermined parameters of skin impedance were cited from the experimental data of skin measurements, which were used a reference (Burton, 1974).[23] Many research projects estimate R_1, R_3 and C_1 have been conducted (Chang, 1994; Ghevondian, 1998).[24,25] Dorin Panescu[26] found that the average skin impedance of the forearm was larger than the average skin impedance of the palm, and that the ratio

(a)

(b)

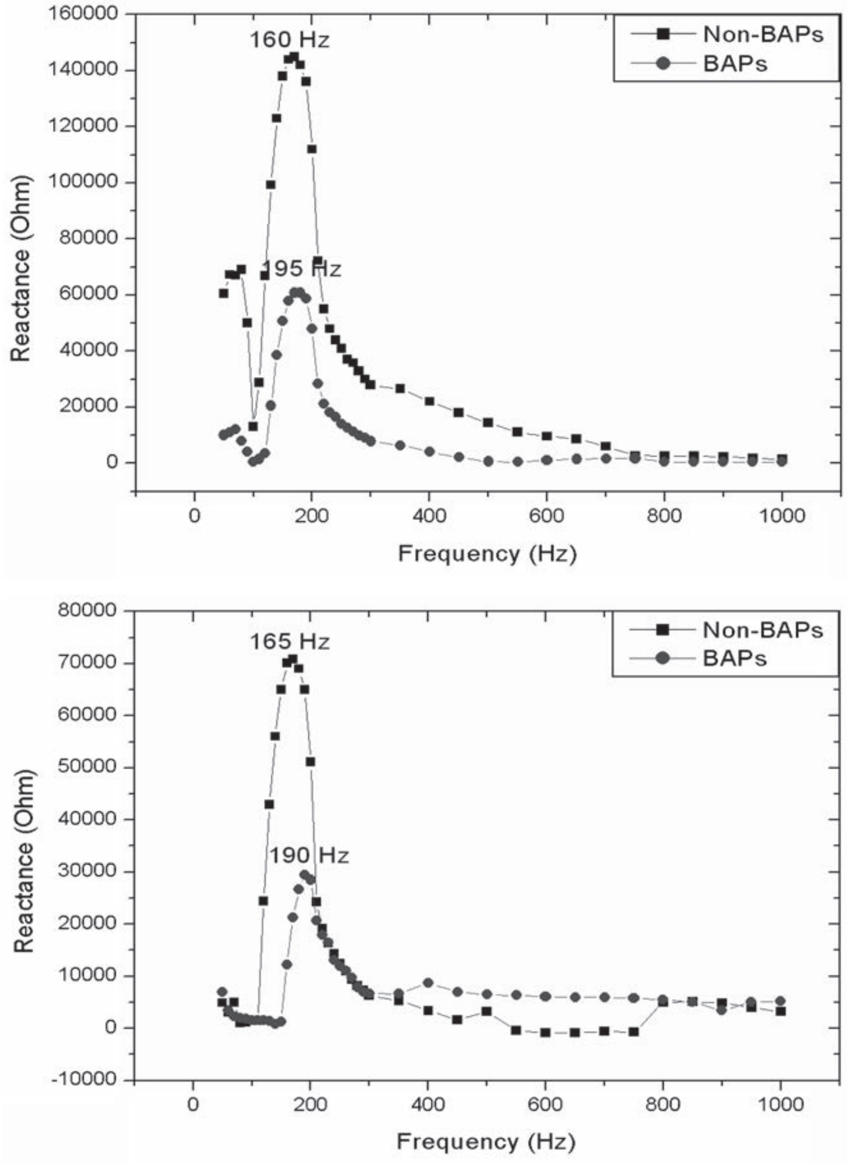


Fig. 2. (a) Results of PC6 (left forearm). the characteristic frequency is about 30 Hz higher than that of the surrounding skins. (b) Results of PC5 (left forearm). the characteristic frequency is about 25 Hz higher than that of the surrounding skin.

between the maximal and minimal skin impedances is larger for the forearm than for the palm. Thus, we set epidermis resistance to be slightly higher than that shown in the results of previous research.

A calculator (Visual C++ program for eq. (3)) was used to determine the values of the

(c)

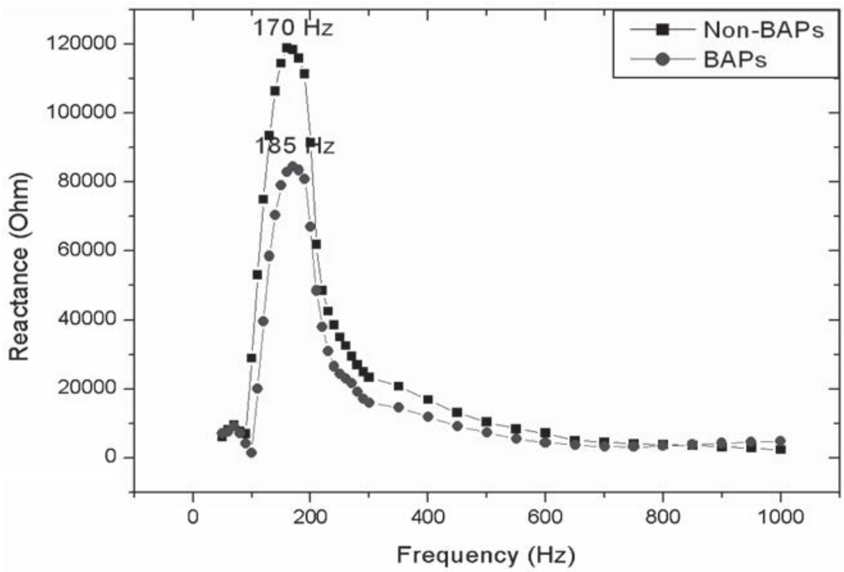


Fig. 2. (continued from the previous page) (c) Results of ST-36 (left leg). the characteristic frequency is about 15 Hz higher than that of the surrounding skin. Results of reactance and characteristic frequency for BAPs and surrounding skin.

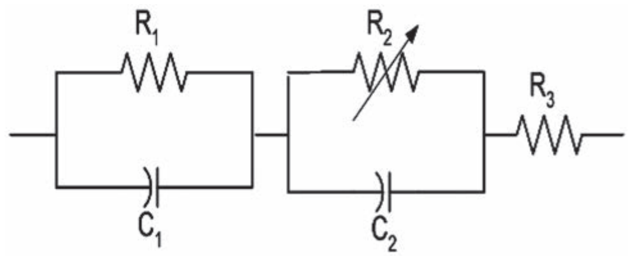
chosen components, which were regarded as being appropriate for the equivalent circuit.

The changes in reactance and characteristic frequency were confirmed using a calculator. These parameter values depended the resistor (R_2) and capacitor (C_2) being placed in the BAPs. In Suhariningsih's study,(27) the BAP resistance was about ten times lower than the resistance of the surrounding skin. For this reason, we set BAP resistance (R_2) to be approximately 3–10 times less than that of the surrounding skin. Figure 3(b) shows a graph of several calculated parameter values in the range of C_2 and R_2 using the proposed model. This graph is similar to the experimental results in Figs. 2(a)–2(c). Furthermore, the similarity between C_2 and R_2 shows the usefulness of the proposed model.

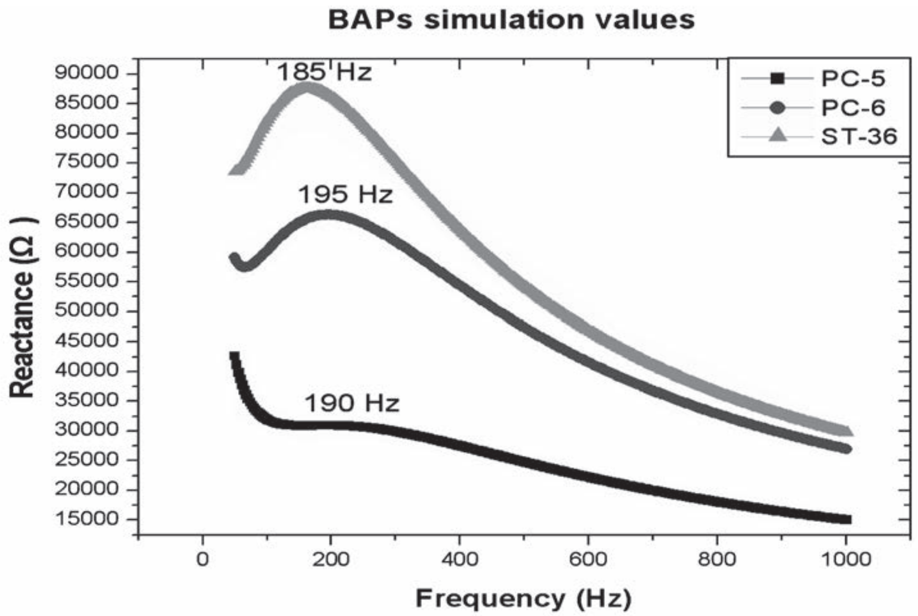
Figure 3(c) shows the program's algorithm for deciding the BAPs' R_2 and C_2. Firstly, the R_2 and C_2 ranges were cited ranges from a previous study (Suhariningsih, 1988).

Figure 3(c) shows typical R_2 and C_2 values obtained using this program. We can deduce theoretical R_2 and C_2 from the experimental characteristic frequency and reactance. Table 1 shows the results of R_2 and C_2 together with the characteristic frequency and reactance.

The characteristic frequency and reactance measured were inputted by a user. In a previous, measurement of BAPs (PC5, PC6, and ST36), the characteristic frequency range was about 185–195 Hz and reactance resistance range was about 30–70 kΩ. Construct of the algorithm used in our program is shown in Fig 3(d). The new BAPS measurement system proposed is superior because of its noninvasiveness and ease of operation.



(a)

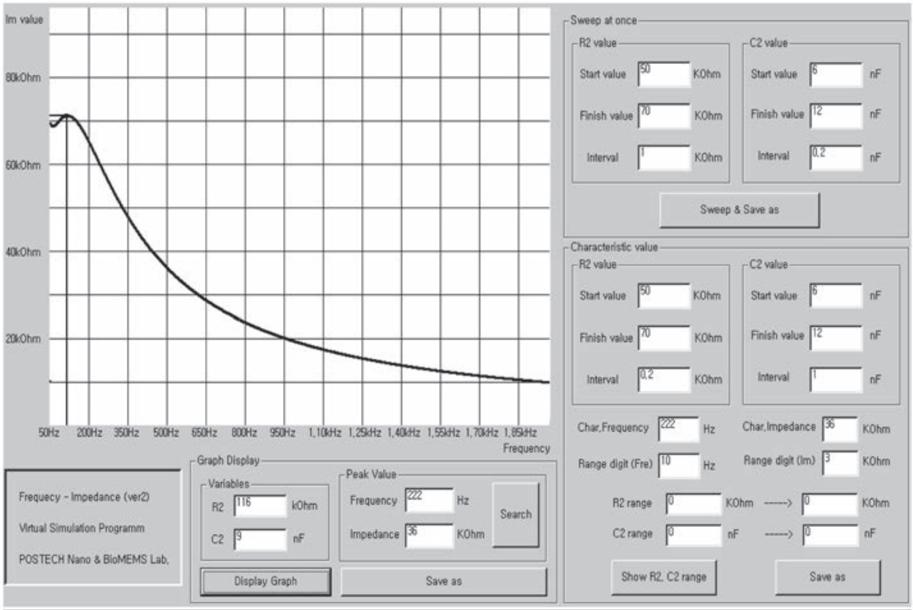


(b)

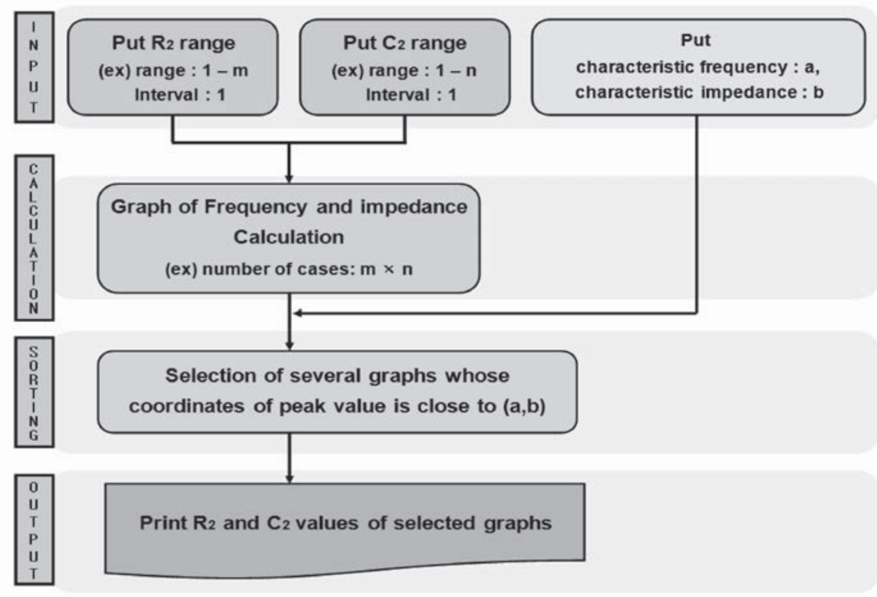
Fig. 3. (a) Proposed equivalent electrical circuit model for BAPs and surrounding skin. The characteristic frequencies of the capacitance are observed when the variable capacitance is tuned to about 5–12 nF. R_2 and C_2 have ranges of at 45–145 kΩ, respectively. The BAP characteristic frequency range was about 185–195 Hz and BAP reactance resistance range was about 32–88 kΩ shown in (b).

4. Conclusion

From previous research studies, the resistance of BAPs has been expected to be lower than the resistance of non-BAPs. However, a method of determining the resistance and capacitance of BAPs has not been reported yet. Here, we presented a method of calculating the resistance and capacitance of BAPs.



(c)



(d)

Fig. 3. (continued from the previous page) These are results the search for of the resistance and capacitance of BAP obtained using a by calculator in (c). Construct of algorithm used in our program in Fig (d).

Table 1
Components of equivalent electrical circuits that were used for skin and BAP calculation

Component point	R_1 (kΩ)	R_2 (kΩ)	C_1 (nF)	C_2 (nF)	R_3 (Ω)
PC6	300	116	90	6	470
PC5	300	48	90	11	470
ST36	300	142	90	5.4	470

We confirm that the reactance of BAPs is smaller than that of the surrounding skin. The characteristic frequencies of BAPs that have the maximum reactance are larger than those of the surrounding skin.

The experimental results obtained can be shown using a simple model of an equivalent circuit. The values of the chosen components were determined to correlate with those of an equivalent circuit as determined using a calculator. Therefore, proposed model can be useful to explain BAPs.

This system has advantages in that it can instantaneously observe the characteristic frequencies and reactances of BAPs. Moreover, R_2 and C_2 could be accurately determined. In future research, we plan to objectively locate and identify BAPs with a dry electrode developed through micro electro mechanical systems (MEMS) technology.

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