# *In vivo* electrical characteristics of human skin, including at biological active points

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**Abstract**—*The aim is to compare the mean values of the in vivo electrical characteristics of biological active points (BAPs) with those of the surrounding human skin. The impedance measurements at BAPs and on the surrounding skin are carried out in vivo on ten young, healthy people. The results of the measurements show that the BAP resistance $R_P$ is smaller, and the capacitance $C_P$ is higher, than the corresponding values for skin, $R_S$ and $C_S$, respectively, these differences are larger at low frequencies (at $f = 3$ Hz, $R_S/R_P = 3.19$ and $C_P/C_S = 3.2$). The mean values of the impedance measurements at the BAPs are different from those measured on the skin. The dependence of $R_P$ and $C_P$ on the pressing force, in the range of about 1–5 N, for the BAPs, has a smaller slope than that observed for the surrounding skin. An equivalent circuit for the BAPs is proposed that describes sufficiently well the experimental results obtained. These results show that the large dispersion in the observed impedance characteristics of the human body measurements in different body regions can be related to the influence of the BAPs present under the electrodes.*

**Keywords**—*Human skin, Biological active point, Impedance, Electrical characterisation of skin*

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## 1 Introduction

ELECTRICAL MEASUREMENTS of human skin, with the help of different impedance methods, are non-invasive and widely used for various clinical applications, such as bio-electrical impedance analysis, electrical impedance tomography, investigation of transdermal drug delivery and others (HANNAN *et al.*, 1995; BARBER *et al.*, 1983; LANCKERMEIER *et al.*, 1999; GRIFFITHS, 1995).

In all these impedance investigation methods, two or more electrodes of different shape and size are used, being applied to human skin in different regions of the body. However, none of these papers takes into account the fact that there are around a few thousand biological active points (BAPs), also known as the acupuncture points. These points are not uniformly distributed across all parts of the human skin, and their resistance to direct current differs from the resistance of the surrounding skin (VOLL, 1955; NAKATANI, 1956; SOMASUK and LISENKO, 1994). Furthermore, it has been found (KRAMER, 1972) that the capacitance of the BAPs measured at a frequency of 50 Hz was higher than that of the surrounding skin. We can therefore expect that the impedance characteristics of these points differ from the characteristics of the surrounding skin and thus influence the results of impedance measurements (because different numbers of BAPs can be present under electrodes in different cases).

The purpose of this paper is to report the difference in electrical characteristics between the BAPs and the surrounding human skin found in the *in vivo* experiments.

## 2 Experimental procedure

The measurements of BAPs and the surrounding human skin (at a distance of 5–10 mm from the BAP) were carried out *in vivo* on ten young, healthy people, 18–22 years old (the mean value of their age was 19.1 years, with a standard deviation of 1.41). The general method of measurement offered by Voll, as well as his system of BAPs (VOLL, 1955), constitutes the basis of our study, because his method is based on the experimental results that indicate that the DC conductivity of a BAP differs from the conductivity of the surrounding human skin. The measurements were taken on the BAPs located on the fingers, hands and palm of the hand.

The electrical properties of skin in different people depend on several personal characteristics, such as the presence and activity of sweat glands; the presence of other appendageal pathways; the thickness and composition of stratum corneum; colour of skin; age and sex (MCADAMS *et al.*, 1996). In addition, the DC electrical properties of the BAPs also depend on the physiological state of the person (healthy, stressed, aroused, etc.).

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On the basis of these experimental data, a few distinct electrodermal methodologies were developed (VOLL, 1955; NAKATANI, 1956) that were based on the measurements of the DC resistance of BAPs. However, in the Voll method, it is established that the mean value of resistance for all healthy people lies in the range of 50–65 relative units and does not depend on sex, age, etc. Therefore, in this work, we used the mean values of the parameters measured at different points on healthy, young people.

An alternating voltage with an amplitude of 100 mV was applied through two brass electrodes (brass electrodes are used in the Voll method). One of them was a cylinder, with a diameter of 30 mm, that the patient held in one hand; the second, the active point electrode, with a diameter of 3 mm, was placed on the BAP or on the skin (at a distance of 5–10 mm from the point) of the other hand or another part of the body. This active electrode was put at an angle of about 45° with respect to the skin surface at the location of the BAP or on the skin nearby. This measuring method is the same as that used in the Voll method and is described in detail in WERNER *et al.* (1989) and LEONHARDT and SARKISYANZ (1980). Typically, the time needed to take one point measurement, in the frequency range investigated, was 1.5–2.0 min. It was observed that, during this time, a measurement at a fixed frequency had variations in resistance and capacitance not exceeding 10–15%; these variations, are probably related to the drift of the electrical parameters of the point.

Before the measurements, the skin was wiped with ethanol to avoid the influence of sweat on the results. Furthermore, to improve the electrical contact, the point electrode was wet with bidistilled water. We used bidistilled water, as in the Voll method, so that our results can be compared with those obtained using commercial devices that use DC.

Another important factor to be taken into account during the measurement of a BAP is the possible change in the area of contact when a conductive electrode gel is used. It is difficult to place the active electrode directly on the BAP, because the exact position of the acupuncture point depends on the specific anatomic bone structure of each person.

We used the following measuring procedure: first, we placed the active electrode in the region were the BAP was expected to be found; then, the electrode was moved around that position until the maximum value of capacitance and minimum value of resistance were found. This procedure is similar to that followed in the Voll method, in which the location of a BAP is found when the DC resistance has its minimum value. Compared with the Voll method, the method that we propose in this work is more accurate, because we use two parameters to find the position of the acupuncture points. As a conductive electrode gel has a lower resistivity than that of bidistilled water, uncontrolled changes in the contact area can greatly increase the measurement error.

The electrical measurements were carried out with an impedance gain-phase analyser,* in the frequency range of 3 Hz–1 MHz for impedance measurements and in the range of 3 Hz–30 kHz for the resistance and capacitance measurements.

## 3 Results and discussion

From the literature (VOLL, 1955; SOMASUK and LISENKO, 1994; KATIN, 1995), it is well known that the resistance measured at a BAP with DC depends on the pressing force of the active electrode on the skin, but it is basically independent of the pressing force on the other electrode. The results are reproducible with DC (with a diameter for the active electrodes of 3 mm) within the range of forces of 10–11 N (SOMASUK and LISENKO, 1994). In this force range, the resistance of skin is basically constant after it reaches a saturation value. Therefore, to obtain reproducible results, it is necessary to choose the appropriate pressing force applied to the skin by the active electrode. For this purpose, a spring-loaded active electrode was made that allowed us to control the pressing force.

For simplicity, the reported resistance and capacitance measurements were obtained at two fixed frequencies. Fig. 1 shows the mean value of *in vivo* capacitance and resistance measurements against the applied force of the active electrode. The Figure shows results for ten people; on each person, 15 BAPs and 15 points on the skin were measured. These measurements were taken at frequencies of 10 Hz and 180 Hz. This Figure includes the standard deviation of the measurements as error bars for each point. The relatively large standard deviation for the skin is a result of the measurements being taken in different regions of skin with different impedances (ROSELL *et al.*, 1988). At the same time, the resistance and capacitance of BAPs at different points of the body of healthy people are variable over a smaller range and correlate with DC measurements (KATIN, 1995; SOMASUK and LISENKO, 1994).

As can be seen from Fig. 1, the behaviour of the resistance and capacitance measurement at the BAPs (Figs 1*a* and *b*), in the pressing force range of 2–5 N (less than using DC), is basically independent of the applied force, whereas the corresponding parameters for the skin (Figs 1*c* and *d*) near the BAPs has a greater dependence on the applied force. Our measurements also show that, in practice, the results do not depend on the pressing force on the passive electrode. That is probably owing to the fact that the surface of the palm of the hand has a large enough number of acupuncture points and zones, and also that the pressure produced by the palm surface on the passive electrode, which has a large area, varies over a small range. Considering the results presented above, all reported measurements were

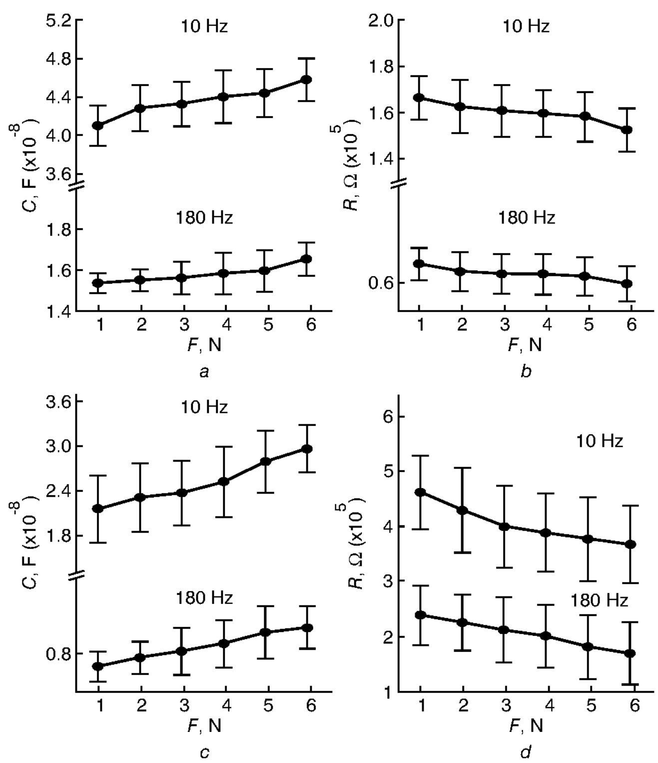


**Fig. 1** *Dependencies of mean values for (a, c) capacitance $C_P$ and (b, d) resistance $R_P$ measurements on pressing force obtained in vivo on (a, b) BAPs, and (c, d) skin ($C_S$ and $R_S$, respectively) on ten people*

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conducted under a pressing force value of 3 N. Under these conditions, the capacitance of BAPs is higher and the resistance is smaller than the corresponding values of skin.

The last conclusion is more evident in Fig. 2, where the dependence of the mean capacitance values $C_P$ (Fig. 2*a*) and mean resistance values $R_P$ (Fig. 2*b*) are shown as a function of the measuring frequency, for the BAPs and for the skin ($C_S$ and $R_S$, respectively).

The ratio of the mean capacitance value found in the BAPs $C_P$, measured at 200 BAPs (20 BAPs on each person), to that found on the nearby skin $C_S$ (ten measurements on each person) for each frequency is displayed in Fig. 2*c*. Similar ratios of the mean resistance value of the skin $R_S$ to that of the BAPs $R_P$ are shown in Fig. 2*d*. As can be seen from these Figures, the difference between the capacitance and resistance values, at and away from the BAPs is quite large, particularly at low frequencies. For instance, at $f = 3$ Hz, $R_P/R_S = 3.19$, and $C_P/C_S = 3.2$.

Fig. 3 shows the mean values of the impedance data (solid lines) measured *in vivo* on ten people (on each of them, five BAPs and five points on the skin were measured), for (*a*) 50 biologically active points located on the hands and for (*b*) the corresponding 50 points of human skin at a distance in the range of 5–10 mm from the BAPs.

The impedance spectrum of skin (Fig. 3, curve *a*) in our measurements is qualitatively similar to the one reported by other authors (KALIA and GUY, 1995; KALIA *et al.*, 1996), but, in our case, the imaginary and real components are larger because we have used smaller-area electrodes. The impedance locus has the well-known form of a depressed semicircular arc. The impedance spectrum for the BAPs differs from that obtained for the skin: for the BAPs, we can see that the spectrum is formed by two poorly resolved semicircles.

There are many electrical models of skin described in the literature, from a simple RC circuit to more complicated circuits with constant phase elements (LANCKERMEIER *et al.*, 1999; KALIA *et al.*, 1996; KONTTURI *et al.*, 1993; KONTURRI and MURTOMAKI, 1994; DORGAN and REILLY, 1999; SASSER *et al.*, 1993). In all these models, the data are described using only one semicircle, whereas we clearly have two semicircles. We have only found one exception: a hypothetical model in a review of 1996 (MCADAMS *et al.*, 1996) proposes a model with three semi-arcs: the first representing the electrode–electrolyte impedance, at frequencies below 1 Hz, the second representing the skin impedance, at the frequency range of 1 Hz–10 kHz, and the third representing the underlying tissue impedance from 100 kHz to 10 MHz.

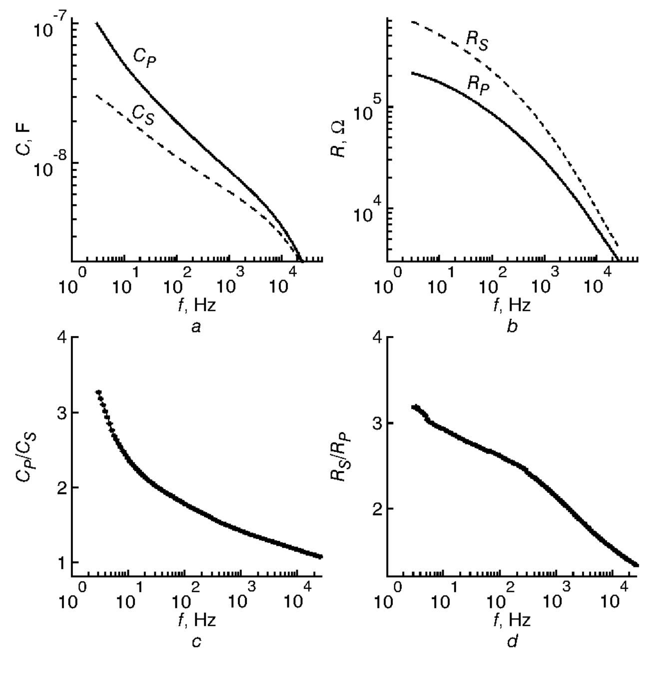


**Fig. 2** *Dependencies of mean values for (a) capacitance $C_P$ and (b) resistance $R_P$ measurements on frequency, measured in vivo (——) at BAPs and (- - - -) on skin on ten people. (c) Ratio of mean capacities measured on BAPs $C_p$ to that measured on skin $C_s$. (d) Ratios of mean resistance measured on skin $R_s$ to that measured on BAPs $R_p$*

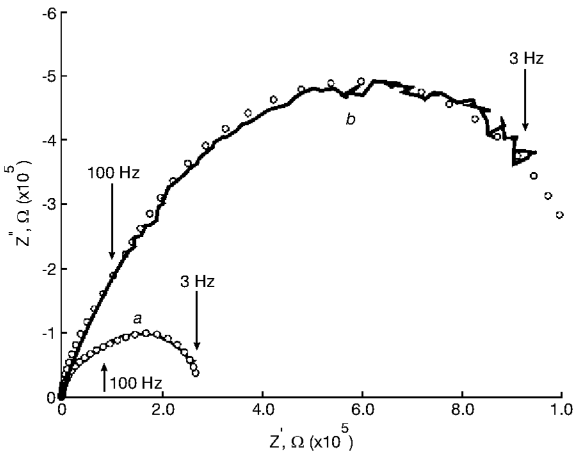


**Fig. 3** *(——) Impedance spectra for (a) BAPs and (b) skin. (○) Results of fit with help of equivalent electrical circuit shown in Fig. 4*

Based on our experimental results, we propose the following equivalent electrical circuit for the skin and BAPs.

In our measurements, the skin is in series with the human body, or the human body is in series with the BAP, because one electrode is kept by the patient in one hand, and the second is placed on the BAP or on the skin of the other hand, or on the body. As can be seen from Fig. 3, a major portion of the impedance spectrum of human skin lies in the frequency range of 3–100 Hz; this is in good agreement with an earlier paper (LANCKERMEIER *et al.*, 1999). The major portion of the impedance arc for human skin is in the frequency range of 10–100 Hz. The mean impedance value spectra of the biologically active points has two poorly resolved semicircles.

The simple equivalent circuit that we propose to model the experimental results is shown in Fig. 4. The model consists of the equivalent circuit of the skin described in KONTTURI and MURTOMAKI (1994), in series with the resistance $R_R$ and the capacitance $C_R$ of the body. We have chosen the model of skin proposed in a previous report (KONTTURI and MURTOMAKI, 1994), because it contains an additional $R_2$ $C$ circuit without

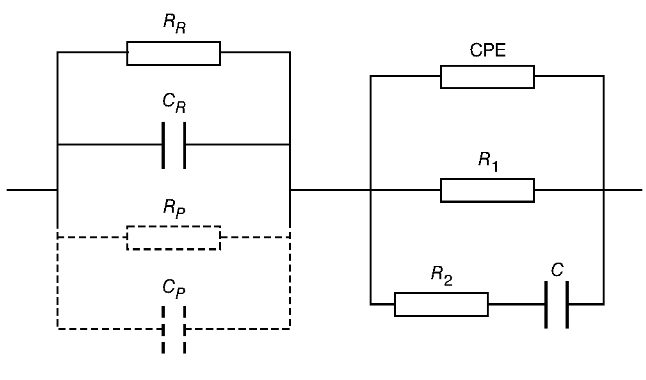


**Fig. 4** *Equivalent electrical circuit for skin and BAP*

*Table 1 Comparison of parameters for equivalent electrical circuits used for simulation of skin and BAPs*

| Component<br>Point | $Y_{CPE}$, $10^{-8}\,\Omega^{-1}$ | $\alpha_{CPE}$ | $R_1$, kΩ | $R_2$, kΩ | $C$, nF | $R_B$, kΩ | $C_B$, nF | $R_p$, kΩ | $C_p$, nF |
|---|---|---|---|---|---|---|---|---|---|
| Skin | 3.70 | 0.80 | 120 | 1.568 | 4.10 | 970 | 23.10 | – | – |
| BAPs | 3.70 | 0.80 | 120 | 1.568 | 4.10 | 970 | 23.10 | 184.47 | 49.90 |
| Error of estimation, % | 8.66 | 2.16 | 5.60 | 17.96 | 7.62 | 3.19 | 3.78 | 15.28 | 4.16 |

which it is impossible to obtain a good correlation between our experimental impedance and the fitted model, in the module and theta planes.

The equivalent circuit that describes the impedance of skin consists of (KONTTURI and MURTOMAKI, 1994):

(*a*) a constant phase element (CPE) with $Z_{CPE} = Y^{-1}(j\omega)^{-\alpha}$, where $\alpha$ is related to the fractal dimension of the skin's surface and can be considered as a measure of the roughness of the skin's surface, $\omega$ is the angular frequency, and $Y$ is the admittance of the CPE
(*b*) $R_1$ which is the ohmic resistance of skin
(*c*) $R_2$ and $C$ in KONTTURI and MURTOMAKI (1994), which have no physical interpretation, but, by analogy with other reports (SASSER *et al.*, 1993), we propose that these elements describe the intracellular compartments of skin, at the same time as the $R_1$ CPE describes the extracellular compartment of skin.

From the results presented in Fig. 2, we can see that the resistance of BAPs is smaller and the capacitance is larger than the corresponding values of the surrounding human skin in all the frequency range of measurements. Therefore it is necessary to include in the equivalent circuit for the BAPs, in parallel with the resistance and capacitance of the body, the additional resistance $R_P$ and capacitance $C_P$, which must produce the effect demanded. The physical interpretation of these elements can be based on the results of the morphological investigations of the BAP areas. It has been previously mentioned (PORTNOV, 1987; MACHERET and KORKUSHKO, 1993) that, in the area of BAPs under the stratum corneum, there is a larger concentration of the nervous plexuses, microcirculation vessels and mast cells than in the surrounding skin.

The investigation of electrodermal reflex reported previously (KATIN, 1995) has shown that, under the influence of an electrical signal on one of the BAPs, the electrical resistance of other points, connected to the same internal organ, changes as well. Thus, the functioning of a BAP is connected with one of the following known structures: peripheral nervous trunks, outside elements of muscles as fascias of tendons and interspinal connecting ways in the form of neuron chains (predominantly sympathetic to relationship) (MACHERET and KORKUSHKO, 1993). Hence, we can propose that $R_P$ and $C_P$ could be connected with some elements of the anatomic nervous system that transmit electrical signal well and are present in the area of the BAPs.

The described equivalent scheme is different from those proposed before (LANCKERMEIER *et al.*, 1999; KALIA *et al.*, 1996; KONTTURI *et al.*, 1993; KONTURRI and MURTOMAKI, 1994; DORGAN and REILLY, 1999; SASSER *et al.*, 1993) by an additional R-C circuit. In the case of the skin, the parameters $R_R$ and $C_R$ of the body are such that the low-frequency depressed semicircle dominates. In the BAP reading, the additional resistance $R_P$ and capacitance $C_P$ are due to the appearance, in the impedance spectrum of the BAPs, of the two low- and high-frequency semicircular arcs.

Using this equivalent circuit, a non-linear fit, with the help of the ZView program, was carried out to find the numerical values of the chosen components. The results of this fit are shown in Fig. 3 (open circles) and in Table 1.

First, we find the parameters of skin (in circuit without $R_P$ and $C_P$). From this simulation, we find the values of $Y_{CPE}$, $\alpha$, $R_1$, $R_2$, $C$, $R_R$ and $C_R$.

Then, using the values found, the BAP simulation was carried out, taking into account the presence in the circuit of the additional elements $R_P$ and $C_P$. Such an approach seems to be appropriate, as the results of the simulation and the experiment measurements show good agreement (Fig. 3).

## 4 Conclusions

It has been found that the electrical characteristics of the BAPs, studied in this work, differ from those corresponding to the surrounding skin: the dependence of the resistance and capacitance on the pressing force at fixed frequency; the frequency dependencies of capacitance and resistance; and the impedance spectrum.

We proposed an equivalent circuit for the BAPs that includes an additional resistance and capacitance, in parallel with the resistance and capacitance of the human body. We assume that these additional elements are related to some elements of the anatomic nervous system that transmit the electrical signals well and are present in the areas of the BAPs. This equivalent circuit describes our experimental results sufficiently well.

From the results obtained, we propose that the observed reports in the literature about the large dispersion of the *in vivo* impedance characteristics of the human body, measured in different regions of the body, can be related to the influence of the biological active points present under the area of the electrodes. For better reproducibility of results, it is preferable, if possible, to place electrodes away from of the BAP areas. This problem needs further investigation, but we can conclude that the BAPs influence the impedance measurements, especially in the low-frequency range.

Another conclusion that can be deduced from these measurements is that, to locate better the exact position of a BAP, low-frequency measurements in the range of 3–100 Hz offer a better opportunity, because the difference between the resistance and capacitance of the BAPs and the surrounding skin is maximum.

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