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Methodology of Teaching the Subject of "Electrical Conductivity and Resistance of Organs" Based on the Integration of Sciences

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Abstract

The development of any field depends more on the specialist of that field.A specialist must have deep knowledge.In the effective organization of the process of teaching students in higher education institutions, the training of good specialists and mature personnel in this field is achieved as a result of the use of modern pedagogical technologies in the training of personnel.In this article, one of the newest and most important sciences of modern medicine, which emerged on the border of different departments of physics based on the mutual integration of biological and physical sciences, is covered by the example of "Electrical conductivity and resistance of organs".The main task of the science of "medical electronics" is to study the working principles of medical electronic devices, the physical properties of living organisms and their measurement methods.The methods designed for the practical analysis of the processes taking place in a living organism, for example, from some molecules and their collections to cells, their categories, tissues, and organs, as well as the conductivity and resistance of whole organisms, are presented.

Keywords:medical electronics, physics, biology, tissue, biostructure, alternating current, direct current, integration,dielectric,capacitance resistance, frequency.

Introduction

Advances in modern medicine are largely based on advances in physics, technology, and medical equipment. The mechanism of devices for accurate diagnosis and treatment of diseases is often explained based on the concepts of medical electronics. Therefore, students of medical universities acquire special knowledge in technical, biological physics, and electronics in general in the science of "Medical electronics", which is based on physics and is directed to solving problems of medical-biological and diagnostic and treatment devices [1,2,3].

The ideological direction is of great importance in the course "Medical electronics", which helps students understand the processes occurring in a living organism, that is, biological objects of varying complexity (from individual molecules and their collections to cells, their groups, tissues, organs, whole organisms) helps to understand, study, analyze [4,5].

Materials and methods

These research methods are based on the properties of biological tissue to be both a conductor and a dielectric at the same time. Electrical conductivity and dielectric conductivity of the biological environment are complex functions of the magnitude of the currents and their frequency, as well as the physiological state of the biological object. If you choose the optimal mode of electrical measurement parameters (voltage, current, frequency, technology), you can perform a group of research methods in which the values of electrical conductivity and conductivity describe the physiological state of the entire biological object.

Resistance of living tissues to alternating electric current

Measurements of total resistance (impedance) of living tissue made at different frequencies show that the resistance of the tissue is maximum at direct current and is equal to R_1 (ω=0) and o' as the frequency of alternating current increases, the impedance first decreases rapidly, and then reaches a.A certain value of Z_2 remains almost constant (Fig. 1).The dependence of the impedance on the frequency shows that there are no elements with inductance in living tissues, but there are elements with capacitive properties. The simplest electrical circuit equivalent to living tissue, which gives the same frequency dependence, is shown in Fig. 2.

The complete expression of the impedance of such a circuit, and therefore the impedance of living tissue at any frequency, is given by the formula:

$$Z=\frac{R_1\sqrt{R_2^2+X_c^2}}{\sqrt{(R_1+R_2)^2+X_c^2}}$$

or

$$Z=\frac{R_1\sqrt{1+R_2^2\omega^2C^2}}{\sqrt{1+(R_1+R_2)^2\omega^2C^2}} \tag{1}$$

Here is tissue capacitance $X_S=\frac{1}{\omega S}$ determined by its dielectric components (cell membranes, adipose tissue, epidermis) and the magnitude of resistances R_1 and R_2 (and $R_1 >> R_2$) of conductive structures of biological tissues (skin, tissue fluid, blood, cytoplasm, etc.).

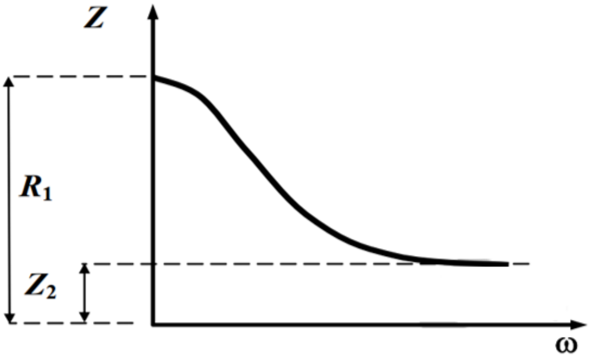

Figure 1. Typical frequency dependence of living tissue impedance

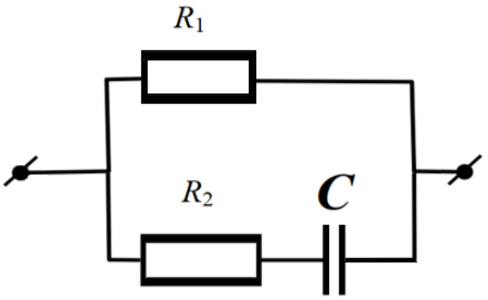

Figure 2. Electrical equivalent circuit of living tissue

In the equivalent circuit shown in Figure 2, direct current can only flow through the resistor R_1, because the resistance of the capacitor C is infinitely large for it [6,7]. But for alternating current, as the frequency increases, the capacitive resistance decreases and thus the total resistance of the circuit decreases. At very high frequencies, the capacitive resistance tends to zero ($X_c \to 0$), and the impedance has the lowest value determined by the formula:

$$Z=\frac{R_1R_2}{R_1+R_2} \tag{2}$$

It should be remembered that each tissue is characterized by its own values of parameters R_1, R_2 and C of the equivalent circuit. For example, the active resistance in direct current for the skin is very high and $R_1 \sim 10^4$-10^6Ohm, and at high frequencies, it decreases by 10-20 times. For soft blood-filled tissues, R1 is small ($R_1 \sim 10^2$Ohm) and at low frequencies is less than their capacitive resistance, so often the equivalent circuits of soft tissues are expressed only by their active resistance R_1.

At medium and high frequencies, for which $X_c << R_1$, leads to the circuit.The resistance of the lower branch (Figure 2) will be significantly less than R_2, X_2 and R_1.The mainstream flows through the lower branch.Therefore, the impedance of the circuit at these frequencies can be estimated by a simple formula:

$$Z=\sqrt{R_2^2+\left(\frac{1}{\omega C}\right)^2} \tag{3}$$

For direct current (ω=0) and low frequencies, this formula does not apply, but at medium and high frequencies it gives satisfactory results if $R_1 >> R_2$and X_c. it can be seen that the resistance value R_2 determines the lowest value of tissue impedance at high frequencies.

The dependence of the tissue impedance on the frequency of the alternating current is determined by the physiological state and morphological characteristics of the tissues, which makes it possible to use the measurement of their electrical conductivity in biological and medical research. The methods of measuring the electrical conductivity of tissues are carried out at sufficiently low voltages (less than 50 mV) and weak currents that do not damage the tissues and do not change their physicochemical processes [8,9].

Under the influence of harmful factors (high temperature, strong ultrasound, ionizing radiation, etc.), as well as tissue death, membrane permeability increases, and their partial or complete destruction is observed. These processes lead to a decrease in the role of tissue capacitance resistance, and the frequency dependence of its impedance is weakened. For "dead tissue" it almost disappears.

Figure 3 shows the impedance frequency dependence for three different samples of the same tissue:

1. the sample was not exposed to any external influences;
2. the tissue is briefly heated, which led to partial destruction of cell membranes;
3. A sample of tissue exposed to boiling for a long time causes destruction of the membranes ("dead tissue").

It can be seen that the resistance of dead tissue is almost independent of frequency. Therefore, the frequency dependence of the impedance can be used to evaluate the viability of body tissues, in particular, to evaluate the quality of the graft during tissue and organ transplantation.

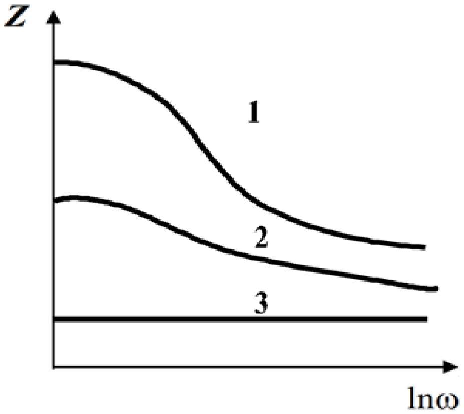

Figure 3. Frequency dependence of impedance for different tissue samples (see comments in the text)

According to B.N. Tarusov's proposal, the tension of the tissue can be quantitatively characterized by the coefficient K, called the polarization coefficient (Fig. 4), which is the ratio of the tissue impedance Z_H measured at a low frequency (about 10^3 Hz) to its impedance Z_B at a high frequency (10^6- 10^7 Hz):

$$K = \frac{Z_H(v = 10^3)}{Z_B(v = 10^6)} \tag{4}$$

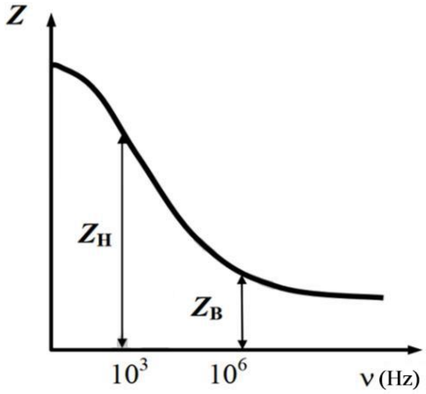

Figure 4. Dependence of the tissue impedance on the current frequency and determination of the values included in the formula (4).

For living tissue, this coefficient is significantly greater than one (K>>1) and depends on the ability of tissues to exchange substances. Thus, for the liver of mammals, it is 9-10 and higher than for the muscles of the organism.

Study of electrical resistance of biological tissues

In practice, the value of electrical resistance of biological tissues is used more as a diagnostic sign than conductivity. To determine the biological state of the biostructure, tissue resistance is measured, among other things, based on a bioassay (Table 1).

Table 1. Resistance values measured in direct current for some types of biological tissue

Biotissue	*ρ, Om•m*
Cerebrospinal fluid	0.55

Blood	1.66
Muscle tissue	2.0
Nervous tissue	14.3
Adipose tissue	33.3
Dry skin	10 5
A veil over the bone	10 7

If the studied sample has the correct geometric shape and constant cross-section, as shown in Figure 5, the two-probe (two-electron) method is used.

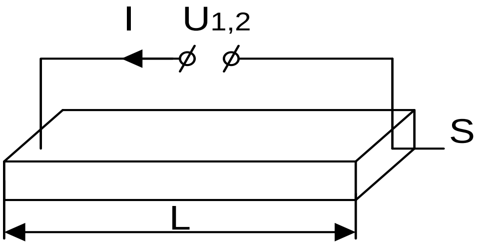

Figure 5. The two-probe method detection scheme

The resistivity of the sample was determined by a well-known formula.

$$r=\left(SU_{1,2}\right)/\left(LI\right), \tag{5}$$

Where$U_{1,2}$ is the voltage applied to the sample;
I- current in the connection;
S, L– a cross-section of the sample and its length, respectively.

The main advantage of the two-electrode method is its simplicity. Disadvantages include a systematic error caused by an incorrect fit of the biological tissue sample size, so the method is mainly used for the determination of biofluids poured into a measuring cuvette. An additional measurement error is introduced by the electrode-medium contact resistance. The four-probe (electrode) method is free from the listed disadvantages.The four-probe method does not require creating ideal Ohmic contacts with the sample (it is possible to measure the resistance of various shapes, including volumetric samples directly in the living organism), but the linear resolution exceeds the distance assuming the existence of a flat surface. l is shown in Figure 6 between the probes.

When solving the problem of the distribution of electrical potentials in biological tissues using the Laplace equation, the resistance is found as a function of the current between the first and fourth probes and the measured voltage between the second and third probes generated by an external voltage source in the spherical coordinate system:

$$r=\left(2\pi lU_{23}\right)/I14 \tag{6}$$

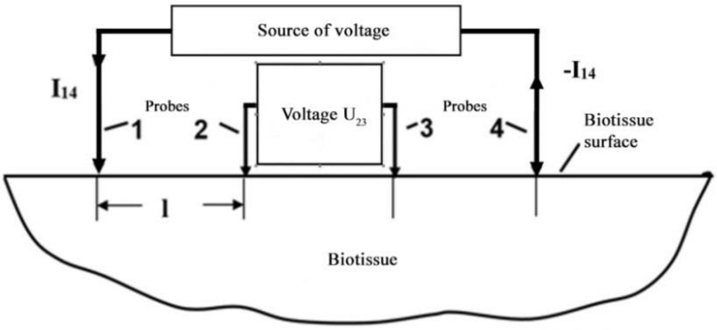

Figure 6. Measurement scheme with four probe methods

The distance between the electrodes l choose the same, in addition to the linear location of the probes, the location along the ends of the square is used; the calculation formula should be given with constant coefficient precision.When conducting a large number of studies as a biomedical indicator, it is enough to determine the total resistance between the electrodes, not their value.The impedance measurement scheme with the two-electrode method is shown in Fig. 7.

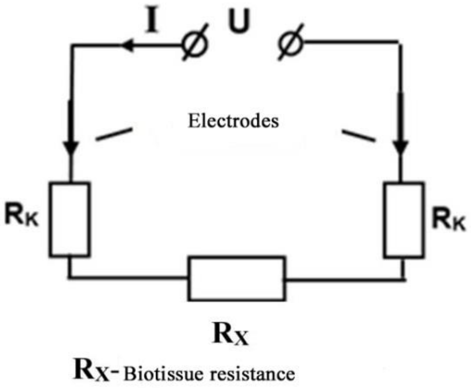

Figure 7. Equivalent circuit of the two-electrode method

It can be assumed that the value of the contact resistance RK between the metal electrodes and the surface of the biological tissue at both contact points is the same due to the series introduction of the voltage source (U), the electrodes and the resistance R_X into the electrical circuit formed by a part of the biological tissue. Obviously,

$$R_X + 2R_K = U / I \tag{7}$$

the expression is valid.

Since the information component is the value of R_X, the two-electrode method only works if the condition $R_X>>2R_K$is fulfilled, then $R_X \approx U/I$.

The four-electrode method makes it possible to significantly reduce the effect of contact resistance when using a voltmeter with a large input resistance [9,10].

Let's distinguish two schemes in the diagram(Fig. 8): the first voltage source with a current flow formed by it, resistance R_K,R'_X, R_X, R'_X; the second - with current I′, resistance R_{VX} (input resistance of the voltmeter), with current formed by R'_X, R_X, R'_X. the resistance of tissue sections between the first and second and third and fourth electrodes and the value of the resistance determined by R_X.

According to the method of contour currents, the following equation applies:

$$(I - I')R_X = (2R_K + R_{\mathrm{mea}})I'. \tag{8}$$

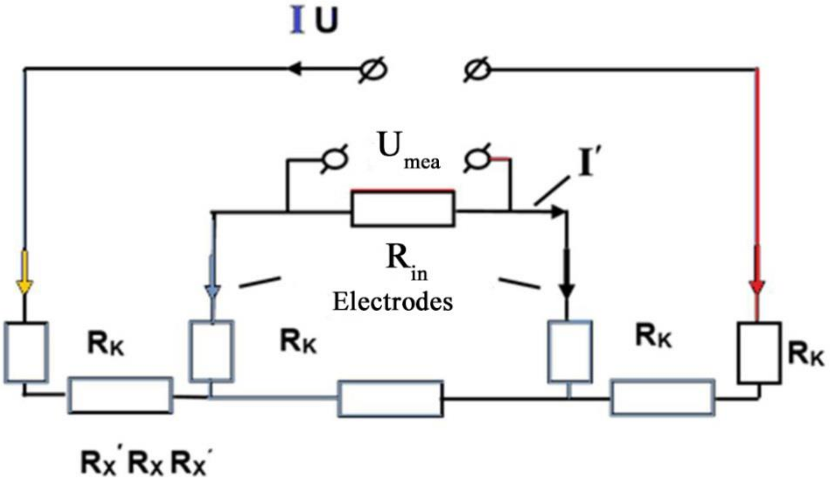

Figure 8. Equivalent circuit of the four-electrode method

If we take into account that the measuring voltmeters used in practice ensure the fulfilment of the condition $R_{VX}>>2RK$ and therefore $I>>I'$, we get $IR_X=R_{kir}I'$. The voltage is measured with a voltmeter, $U_{mea.}=R_{in}I'$and then $R_X=U_{mea}/I$. Thus, by measuring the magnitude of the current between the extreme (according to the picture) electrodes and the voltage between the internal voltages, the desired resistance of biological tissues is found.

Measurement of parameters of electro-skin resistance in the direct current found use in one of the private research methods.

Electrical conductivity of biological tissues in alternating current

The total resistance (impedance) of biological tissues depends significantly on the frequency of the current. The nature of this dependence is related to the capacitive and Ohmic properties of biological tissues. Capacitance characteristics are explained by the specific characteristics of the structure of cell membranes, which act as dielectrics in "biocapacitors", conductive plates containing the electrolyte of intracellular and intercellular fluids. Measurements have shown that the current flowing through the living biological medium is ahead of the applied voltage in phase (Table 2).

Table 2. Values of the phase shift angle obtained at a frequency of 1 kHz for different biological environments

Bio-environment	*Angle of advance from current, grad*
Human skin	55
Nervous tissue	64
Muscle tissue	65

The inductive properties of biological tissues have not been determined. At frequencies up to units of MHz, the equivalent electrical period of biosystems is 3.5 sec.

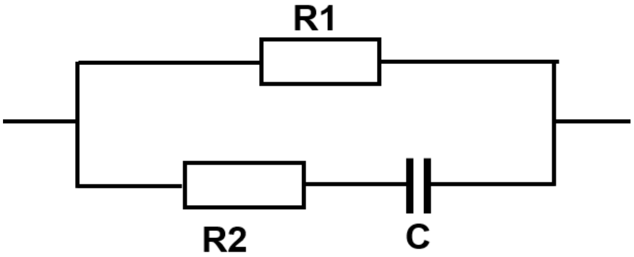

Figure 9. Equivalent period of biosystems in alternating current

The value of the active resistance R_1 corresponds to measurements and direct current. R_2 describes active losses in internal structures. The characteristic dependence of the impedance of biological tissues on the frequency, up to several tens of megahertz, is shown in Fig. 10.

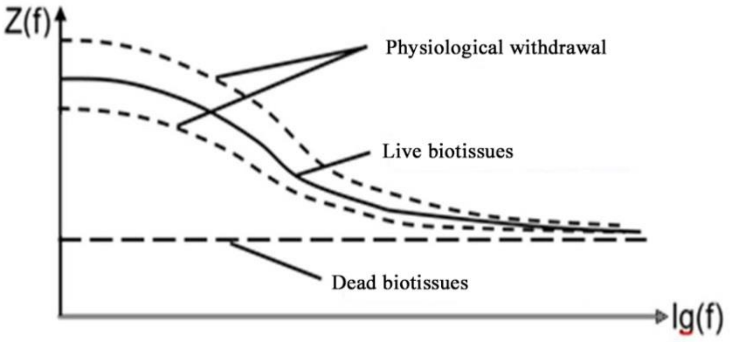

Figure 10. Frequency dependence of biological tissue impedance

The dependence of the impedance on the frequency allows for evaluating the viability of the tissue, which is used to determine the limits of necrosis and the suitability of bio substances for transplantation. The physiological change reflects different states of a biological object in the process of vital activity. Thus, the following can be used for research purposes:

- dependence of the angle of change of voltage and current depending on the capacitance characteristics of biological tissues;
- frequency dependence of impedance as an indicator of the vitality of body tissues;
- the dependence of the impedance of biological tissues on their physiological state at the specified frequency of research.

The first two relationships have found practical application in several analytical research methods. The latter formed the basis of physiological methods for studying blood flow in the body.

Summary

For students learning the science of "Medical Electronics" in higher educational institutions, physics-mathematics, biophysics, and the knowledge gained from electronics are considered not only an important element but also to deeply study the principle of operation of diagnostic and therapeutic medical devices, in addition, it provides extensive support in the comprehensive coverage of biochemical and biophysical processes in the human body. Of course, this is one of the very important factors for the formation of "Medical Electronics" as a specific science. The formation of the future highly qualified medical work as a perfect specialist is not only possible to study physical processes and laws, to master the principles of operation of medical devices based on them, to obtain accurate anatomic information that helps in all aspects.

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