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IMPROVEMENT IN THE RESOLVING POWER OF IMPEDANCE THERMO- AND TOMOGRAPHY OF BIOLOGICAL TISSUES

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We analyzed the possibility for measuring the temperature of the internal structures of a body by using low-frequency currents. We show ways for solving the problem of the limited resolving power of the impedance thermo- and tomography method and present the results of the experiments conducted.

At the present time there are a number of methods for noninvasive measurement of temperature of internal biological tissues. The most developed method of thermography is IR imaging based on a principle of recording thermal radiation of a body in a range of waves on the order of 3–20 μm [1, 2]. The method is suited for investigating radiation of the skin surface, since the depth of the biological tissue, from which emission occurs, is about 100 μm. Since there is an interrelation between internal organs and the state of the skin, it is possible to carry out internal diagnosis.

Microwave radiation in a frequency range of several hundreds of MHz provides more information on the internal state. In the centimeter and millimeter wave ranges the characteristic depth from which radiation emanates amounts to 1.5 mm for the wavelength of 3 cm. However, in contrast to IR radiation, horny layers of epidermis, hair, and clothing are transparent for microwave radiothermal radiation. Thus, the microwave radiation.opens up new possibilities for noninvasive monitoring in surface tissues.

There is also the possibility of obtaining a temperature distribution in the depth of a bioobject on its thermal acoustic radiation, because acoustic waves in the ultrasonic frequency range 1–30 MHg pass through biotissue. The maximum depth from which temperature can be measured by acoustic thermography is about 7 cm [3].

Apart from the above methods, of interest is the study of the possibility of measuring the body temperature by passing an electric current through several electrodes located on the body surface and measuring voltage response to them. It is known that the electric characteristics of the biotissue (electrical conductivity and dielectric permeability) depend on temperature [4]; therefore, temperature distribution can be inferred from the pattern of resistance distribution in biotissues. The advantages of this method consist in the possibility for measuring the temperature of internal deep-lying tissues, carrying out prolonged continuous measurement of temperature, as well as in the relative simplicity of the apparatuses used.

However, in view of the low resolving power, to date the method is at the level of laboratory investigations. The limited resolving power is first of all attributed to the complexity of the human organism from the viewpoint of a passive electric circuit, to the nonlinearity of the magnitude of the biotissue resistance, and to the influence of undesirable side effects (transitional contact impedance).

To solve the first problem, we should use a multielectrode measuring system and apply a powerful computational apparatus. The number of electrodes can reach 128, but this causes difficulties in design and use. Usually, a 32-electrode architecture is selected.

The lines of current flow through biotissues are curved (Fig. 1a); this makes the reconstruction of an image very difficult and degrades the quality of a thermographic picture. To overcome this effect, it is necessary to apply a method of forming a certain structure of currents inside a body by supplying a certain electric-field profile to electrodes. In other words, it is necessary to "focus" an electric current and direct it on the organ under examination. For example, if we apply the same potential to three neighboring electrodes, then side electrodes will affect the

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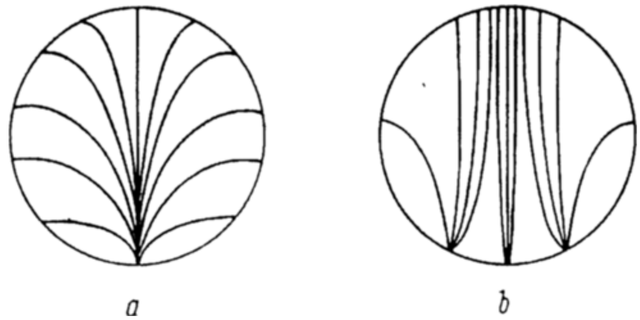

Fig. 1. The lines of current flow through a body in the case of applying two different structures of voltage: a) one electrode is a current source, the remaining electrodes are receivers; b) three electrodes are current sources.

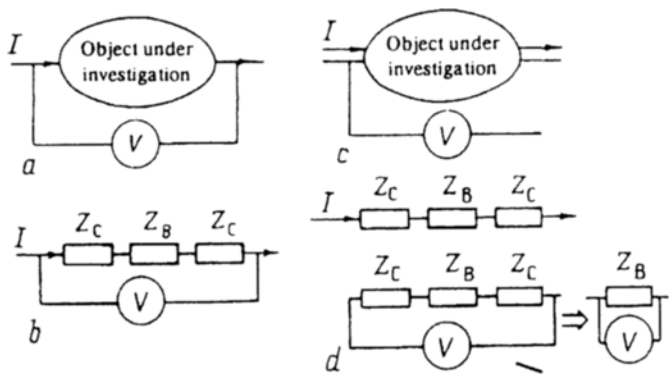

Fig. 2. Two-electrode (a) and four-electrode (c) schemes for measuring impedance and their equivalent schemes (b and d).

current of the central electrode, "rectifying" it and preventing its spreading over the volume (Fig. 1b). Since a multielectrode system is used, it offers a possibility to rotate an electric "ray" and view the whole bioobject, extracting a maximum amount of information on its temperature. Thus, the formation of special (optimum) structures of current makes it possible to substantially increase the resolving power.

Active schemes used for investigation of electric characteristics of biotissues (precisely such is the method of the impedance thermo- and tomography) usually involve injection of current and the response of voltage on electrodes located on the body surface is measured. The measured voltage is the drop in voltage along the line of current flowing through a series circuit consisting of the body impedance Z_B and the surface contact electrode – skin impedance Z_C (Fig. 2a, b). According to [5], the magnitude of the impedance Z_C oscillates from 100 Ω to 10 kΩ at a frequency of 10 kHz, while the magnitudes of the impedances of the body itself lie in the range 100 Ω–3 kΩ [6]. Thus, the electrode-skin contact resistance is commensurable with the impedance of interest for us and the drop in voltage on Z_C will be rather large and of the same order as the drop in voltage on Z_B. Consequently, it is necessary to use such measurement methods that would allow us to avoid the problem of contact impedance.

One of the most effective methods is a four-electrode scheme of measurement. Here the current is passed between one pair of electrodes, whereas the voltage is measured between the other pair (Fig. 2c), thereby minimizing an error in the measurement of Z_B.

From Fig. 2b it is evident that in a two-electrode scheme voltage is measured along the current line at the resistance $Z = Z_B + 2Z_C$. In a four-electrode scheme, the electrodes intended for measurement of voltage are connected to the high-resistance amplifier of a voltmeter, which restricts the current flow through these electrodes, and as the input resistance of the amplifier is large (on the order of MΩ), then the resistances of Z_C can be neglected (Fig. 2d). The impedances of both the body and skin depend strongly on the position of the electrodes [7]; therefore to avoid errors in measurement, it is necessary to locate the injecting and measuring electrodes closer to each other. The most optimum solution is to place one electrode inside the other, i.e., to make a composite electrode. It is

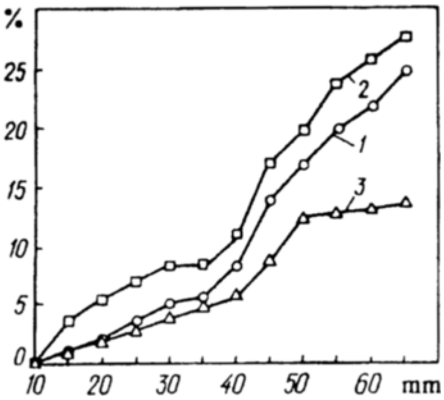

Fig. 3. Dependence of the relative change in voltage (%) on the target diameter (mm) for three structures of applied distribution of potentials. 1) single-electrode scheme; 2) screening scheme; 3) scheme of descending potentials.

desirable that the area of the injecting electrode be sufficiently large for obtaining a more homogeneous structure of the field under it. At the same time, the measuring electrode must be small in order to determine the voltage at a concrete point on the body surface. Therefore, the outer electrode has a larger area and is intended for injection of current, while the inner one is intended to measure voltage.

To confirm the above considerations, as well as to demonstrate and investigate the potentialities of the impedance thermo- and tomography method, we created a device and carried out several experiments.

A 15 kHz-frequence voltage was supplied from a G3-112/1 master oscillator to a number of individually voltage-controllable current generators. Each generator is made on operational amplifiers (OA), thus guaranteeing a high output impedance for a range of loads from 100 Ω to 5 kΩ. The leads of each current generator are directly connected to a corresponding electrode. The voltage response from the injected current was measured by a V7-16A voltmeter that was connected in series to the electrodes by means of a special switch.

To carry out an experiment, we made a phantom, which was a 165 mm-diameter plastic cylindrical container along whose perimeter 12 composite stainless steel electrodes were located uniformly. The outer electrode had an area of 300 mm^2 and the inner 95 mm^2. The container was filled with salt solutions of different specific resistances. Targets of different diameters and conductivities were placed in the middle of the container, with an equivalent volume of the solution pouring out. Measurements were carried out with and without a target. The aim of our investigations was to determine the smallest diameter of a target that can be detected by the method of electric impendance thermo- and tomography. For this purpose, it is necessary to apply a certain distribution of the potential U to the phantom. In our work we used the following schemes:

1) a single-electrode scheme: voltage of a positive level is applied to one electrode and of a zero level to the other, i.e., $U = (+1; 0; 0; ...; 0)$, where +1 and 0 are the levels of voltages for the active and passive electrodes, respectively;

2) a screening scheme: voltage of the same level is applied to three adjacent electrodes: $U = (+1; +1; +1; 0; ...; 0)$;

3) a scheme of descending potentials: distribution of voltages is applied to electrodes: $U = (0; +0.5; +0.66; +0.83; +1; +0.83; +0.66; +0.5; 0; ... 0)$.

The results are shown in Fig. 3.

It is evident that a 15 mm-diameter target can be distinguished on a homogeneous background. The second structure of the surface potential distribution gives the best results, thus confirming the above considerations.

The measurements of the impedance of a wrist and an elbow have shown that using ordinary electrodes yields the values of 1.07 kΩ for the wrist and 1.3 kΩ for the elbow, whereas composite electrodes, i.e., a four-electrode scheme, gives values of impedances equal to 180 and 230 Ω, respectively. Similar measurements on the phantom did not reveal an important difference in the results, since the electrode-electrolyte impendance is insignificant in contrast to the electrode-skin impedance.

Thus, the results of the experiments conducted confirm the effectiveness of application of the four-electrode scheme of measurement and of the most optimum structure of the applied potential for a significant improvement in the resolving power of the impedance thermo-and tomography.

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