Investigation of electrodynamics parameters of biological tissues

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Pathological and physiological processes in living tissues are usually accompanied by variation of their electrodynamic parameters; hence study of dielectric permittivity and conductivity of bio-objects is of considerable interest for various medical applications.

Diagnostics of skin pathologies without using the hystomorphologic method is required in dermatology. Tissue sampling (biopsy) refers to minor operations and is often undesirable for patients with abnormality in carbohydrate metabolism, vascular pathology, and eruption on unclothed parts of the body (face, neck, and hands).

The estimation of viability of organs in vivo in the case of acute pathology and organs conserved for their further transplantation is necessary in surgery. The processes of tissue ischemia and reperfusion complications are the result of violation of the fine cellular mechanisms, diagnostics of which cannot be carried out by the known diagnostic techniques (X-ray, ultrasound). These processes can be recognized only by means of biopsy with further optical or electron microscopic analysis; this procedure is time-consuming, whereas a clinician does not have much time at his disposal.

The aim of the study is to consider the opportunities of resonance near-field microwave sounding for estimation of viability of parenchymal organs in critical states, determination of pathologic processes, differential diagnostics of various dermatoses, and control of medical maintenance.

The method of resonance near-field microwave probing can be explained as follows. The area of a medium located in the near field of a probing electrically small antenna affects its impedance. This feature enables one to provide high spatial resolution. If the antenna is connected to the resonance system as a load, the resonance frequency shift and the Q-factor variation can be used to estimate the electromagnetic parameters of the medium and then the state of the examined object.

Diagnostic probes for passive measurements of the electrodynamic features of parenchymal organs and sensors for investigation of skin of dermatologic patients have been developed. A high-Q microwave resonator placed on a segment of the coaxial line is employed as a resonance system. The eigen frequencies of the sensors are $\omega_0 \sim 2\pi \cdot 800$ MHz and the Q-factor is $Q_0 \sim 150$. The spatial resolution and the sensitivity are determined by the design and sizes of the electrically small antenna.

If Z_0 is the internal impedance of the antenna, Z_{medium} is the impedance of the antenna contacting with the medium, and $Z_{medium} < \rho$ (ρ is the wave resistance of the coaxial resonator), according to [1] one

can obtain the equation of the resonance curve $U_{res}(\omega)$ of the sensor

$$U_{res}(\omega) = U_0 \left[16 Q_0^2 \left(\frac{\omega - \omega_0}{\omega_0} + \frac{1}{\pi\rho} \operatorname{Im}(\delta Z_x) \right)^2 + \left(1 + \frac{4}{\pi} \frac{Q_0}{\rho} \operatorname{Re}(\delta Z_x) \right)^2 \right]^{-\frac{1}{2}}$$

$\delta Z_x = Z_0 - Z_{medium}$, U_0 is the signal amplitude in the resonance curve maximum.

From the equation $U_{res}(\omega)$ one can easily obtain the relation between the resonance characteristics of the sensor and the impedance features of the electrically small antenna

$$\omega_{res} - \omega_0 = -\frac{1}{\pi} \frac{\omega_0}{\rho} \operatorname{Im}(\delta Z_x)$$

$$\max(U_{res}) = U_0 \left(1 + \frac{4}{\pi} \frac{Q_0}{\rho} \operatorname{Re}(\delta Z_x) \right)^{-1}$$

Electrodynamic characteristics of skin of 32 cases of psoriasis, 10 cases of atopic dermatitis, and 13 cases of lichen acuminatus (LA) were studied at the Research Institute of Dermatology and Venereology (the city of Nizhny Novgorod).

It is stated that the dielectric permittivity and conductivity of skin of dermatologic patients (cases of psoriasis, atopic dermatosis, and lichen acuminatus) are lower than those of healthy skin. The patients were examined before treatment, in the course of treatment, and after it. As the patients recovered, the dielectric permittivity and conductivity of tissues in the area of the focus of disease in all three groups of patients approximated the values of healthy skin.

In the exacerbation stage, the difference between healthy and damaged skin were more distinct in the case of psoriasis. In the regress stage, the dielectric permittivity and conductivity of tissues in the area of psoriatic focuses of disease were analogous to ε and σ of tissues in the case of atopic dermatitis. Hence in the cases of psoriasis and atopic dermatitis, the method is diagnostically significant only when a disease is active.

When studying the electrodynamic characteristics of skin in the case of lichen acuminatus, it was found out that if the dielectric permittivities of tissues in the case of psoriasis and in the case of LA coincided, the conductivities in these cases differed by factor of 2.

This permits drawing a conclusion on the possibility of diagnostics in the cases of psoriasis and LA at arbitrary stages of disease.

Differential diagnostics of pathologic processes in parenchymal organs is carried out. It is shown that the

measuring systems are sensitive to physiological and pathological properties of tissues. The possibility to determine tumor focuses of disease in an organ and the limits of their growth is demonstrated. Study of a remote material (fig. 1) confirmed high accuracy and sensitivity of the measuring complex. The difference in sensor indications in measurement of various types of tissues is well seen in fig. 2.

It should be noted that near-field systems are sensitive to arbitrary, even slight, variations of blood flow in tissues abounding with blood vessels.
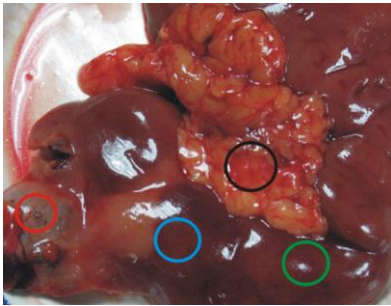

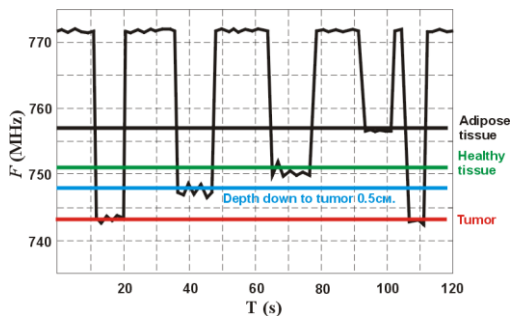**Fig. 1.** Examined object (kidney). Circles show the measuring areas

Fig. 2. Resonance frequency shift of sensor depending on the features of an examined tissue.

Electrodynamic characteristics of parenchyma of kidneys under the conditions of thermal and cold ischemia are measured in time dynamics. Laboratory animals (rabbits) were used in the studies. The process of multiorgan sampling for transplantation was simulated completely. Kidneys were irrigated with a cooled solution of kustodiol (additive) through the aorta and appropriate arteries until blood was fully eliminated from the organ. Measurement results of the resonance frequency of sensor (dielectric permittivity) on time are given in fig. 3. The results show a difference between cold and thermal ischemia of organs; the signal frequency variation depends directly on the rate of ischemic damage.

Besides the probe contacting with the examined tissue, a sensor based on the resonance contact sensor was fabricated and tested; it responded to small additives occurring as a result of diffluence in the conserving liquid irrigating the organ prepared to transplantation and being in the critical state. Additive sampling was made in definite periods. The result obtained unambiguously demonstrates the relation between the electrodynamic characteristics of kustodiol varying in

the experiment, as diffluence products accumulate in it (fig. 4). Having a set of gage curves, one can carry out express diagnostics of viability of an organ during several seconds.
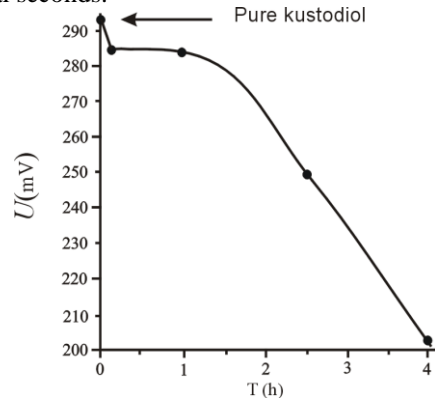

Fig. 3. Variation of the signal amplitude of sensor at the resonance frequency on pump time. The examined liquid is "kustodiol". (Thermal ischemia)
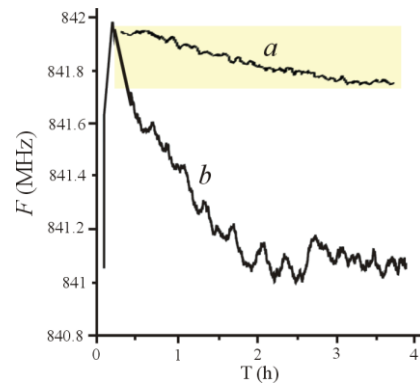

Fig. 4. Variation of the resonance frequency of sensor in time; the sensor are in contact with parenchyma of a kidney (a) cold ischemia, (b) thermal ischemia.

When comparing measurements of the electrodynamic parameters of the parenchimatous tissue and the additive, it is seen that the occurrence of diffluence products in kustodiol slightly "delays", which agrees with recent publications on results of marginal (cadaveric) transplantations of kidneys [2].

References

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