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Dielectric properties of the tissues with different histological structure: Ex vivo study

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KEYWORDS

Dielectric properties

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Conductivity

ABSTRACT

This study aimed to estimate the dielectric properties of tissues with different histological structures. For this, specimens of fibrous (n=9), muscular (n=7), and fatty (n=11) human tissues were studied. The estimation of dielectric permittivity and conductivity of these specimens was tested with a program and apparatus device for near-field resonance microwave sensing, including 5 applicators with different depths of study. Results of the study demonstrated that this technology can visualize the shape, localization, and linear decisions of biological objects. The currently used method allows distinguishing the tissue histological type. It was stated that fibrous tissue has a maximal level of median and highest dielectric permittivity, and the minimal value of this parameter was fixed for fatty specimens (in 4.26 and 4.53 times lower than in fibrous one, respectively). Muscular tissue has an intermediate value of dielectric permittivity, approaching a level close to fibrous tissue.

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1 Introduction

Currently, there is a wide range of medical imaging technologies; among these some most common are ultrasound, computer, and magnetic resonance imaging (Gladkova and Sergeev 2007; Schertlen et al. 2002; Turchin 2016; Bogomolova et al. 2017). On the other hand, not all types of tissues including integumentary tissues, including the skin and the nearest subcutaneous layers can be effectively visualized with a sufficiently high resolution (Arsenyev et al. 2011; Turchin 2016; Bogomolova et al. 2017; Martusevich et al. 2017). These facts necessitate the need for further search for new medical imaging methods based on other physical principles and their experimental and clinical testing (Naito et al. 1997; Raicu et al. 2000; Schertlen et al. 2002; Hayashi et al. 2005; Kostrov et al. 2005; Baloshin et al. 2011; Martusevich et al. 2017; Martusevich et al. 2018).

In this regard, attention is drawn to the possibilities of near-field resonant microwave sensing, which allows an integral assessment of the dielectric properties of biological objects (Raicu et al. 2000; Schertlen et al. 2002; Reznik and Yurasova 2006; Baloshin et al. 2011). This technology characterized both the generalized and deep structure parameters of biological samples without any restrictions on morphological tissues analyzed (Naito et al. 1997; Schertlen et al. 2002; Hayashi et al. 2005; Arsenyev et al. 2011; Baloshin et al. 2011; Bogomolova et al. 2017; Martusevich et al. 2018). Microwave sensing makes it possible to carry out non-invasive and non-destructive diagnostics of any living tissues (Schertlen et al. 2002; Kostrov et al. 2005; Arsenyev et al. 2011; Baloshin et al. 2011). This technique potentially can conduct non–contact research including through physical barriers i.e. bandages or wound coverings (Schertlen et al. 2002; Bogomolova et al. 2017; Martusevich et al. 2018). At the same time, the possibilities and diagnostic prospects of near-field microwave sensing in experimental and clinical medicine have not been fully studied (Schertlen et al. 2002; Arsenyev et al. 2011; Bogomolova et al. 2017; Martusevich et al. 2018). In this regard, the work aimed to identify the features of the dielectric properties of various types of tissues.

2 Material and methods

Samples of fibrous (n=9), muscular (n=7), and adipose (n=11) human tissue has been removed intraoperatively and were used for the study. To assess the dielectric properties of these biological samples, a hardware and software complex for near-field resonant microwave sensing was used, this complex was supplemented by a system of 5 applicators (Kostrov et al. 2005; Martusevich et al. 2017; Martusevich et al. 2018).

To assess the dielectric properties, tissue fragments were placed on a plastic Petri dish, the lid of which was mapped, representing a navigation grid for point-by-point sensing with an area of up to 50X30 points in increments of 5 mm. Using this grid, a matrix of resonant frequencies was obtained, based on which the dielectric permittivity and conductivity were determined, and forming a microwave profile of the object and its environment. The results were processed using the Statistica 6.0 program.

3 Results and Discussion

Results of the current study established that the use of near-field resonant microwave sensing unambiguously determined the boundaries of the visualized object, regardless of its shape and histological structure. Thus, the analysis carried out by one-dimensional linear scanning of a biological sample, beginning and ending outside of it, indicated a significant and statistically significant decrease in the perceived frequency in the area strictly corresponding to the localization of a fragment of fibrous tissue (Figure 1).

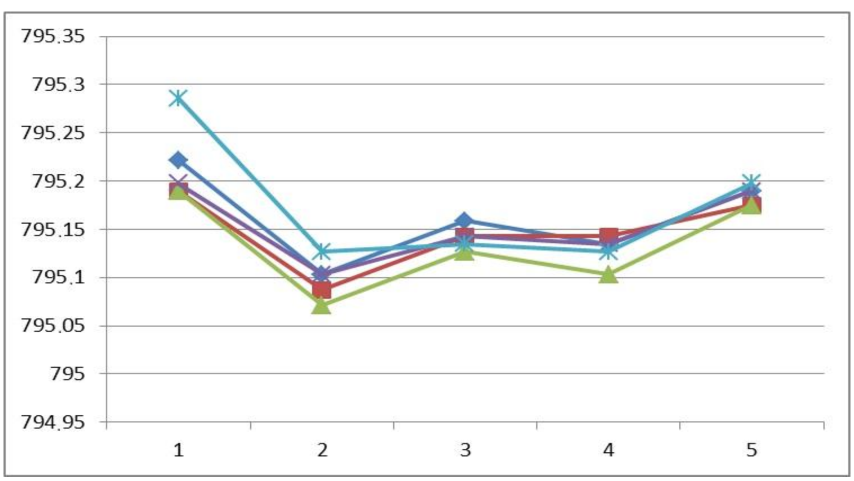

Figure 1 Effect of various microwave fragments on various fibrous tissue using an applicator with a maximum penetration depth of 5 mm (each line corresponds to one tissue fragment; the numbers on the OX axis indicate the measured point: 1 and 5 – points lying outside the biological tissue fragment, 2-4 – points in the projection of the biological tissue fragment)

The data obtained by one-dimensional scanning of a fragment of fibrous tissue are also confirmed by the two-dimensional study of these samples of biological tissue. In addition, the use of a similar, close to tomographic technology makes it possible to demonstrate the deep heterogeneity of a tissue fragment. This particularly justifies the possibility of assessing the structure of the skin changed as a result of thermal exposure (burn). It should be emphasized that specified homogeneity of the tissue sample occurs both in terms of dielectric permittivity (ε) and the conductivity of the object (σ). So, whenever using a sensor that can evaluate the dielectric properties of an object at a depth of 2 mm, the peculiarities of the location of the object in the Petri dish should be taken into account so that the radiation can capture only the surface layers of the sample. This ensures only a minimal displacement of the dielectric constant. With the increase in the depth of sensing to 3.5 mm, sensor No. 3 can be used which leads to a more significant change in the parameter, the clearest visualization of the studied sample is provided at the maximum depth of sensing used (5 mm.). The pattern recorded in this case fully corresponds to the localization, shape, and linear dimensions of the fragment of biological tissue.

Concerning conductivity, the nature of the "response" of the signal depends to a lesser extent on the depth of sounding (Figure 2, right column). According to this indicator, a picture close to the dimensions of the analyzed object is recorded for all sensors but are slightly different in shape from the real one only according to the readings of sensor No. 3.

In general, the conducted experiment with a sample of intraoperatively removed tissue made it possible to verify the possibility of detecting the localization, shape, and linear dimensions of the biomaterial by the method of near-field resonant microwave sensing on the created software and hardware complex.

In the second part of this experiment, a comparative assessment of the effect of the tissue histotype on the nature of the displacement of the microwave pattern indicating the dielectric properties of the object was carried out (Figure 3).

It has been established that both fat and muscle tissue have satisfied visualization using near-field microwave sensing, and this concerns the assessment of the shape and size of the samples. At the same time even without additional mathematical processing, the differences in the shift of the resonant frequency of radiation that occurs between these histological types of biological objects and consequently the variability of their dielectric properties can be reported. Thus, muscle tissue, which has a significantly higher density compared to fat and increased metabolic activity of cells, also demonstrates a more distinct shift in the resonant frequency.

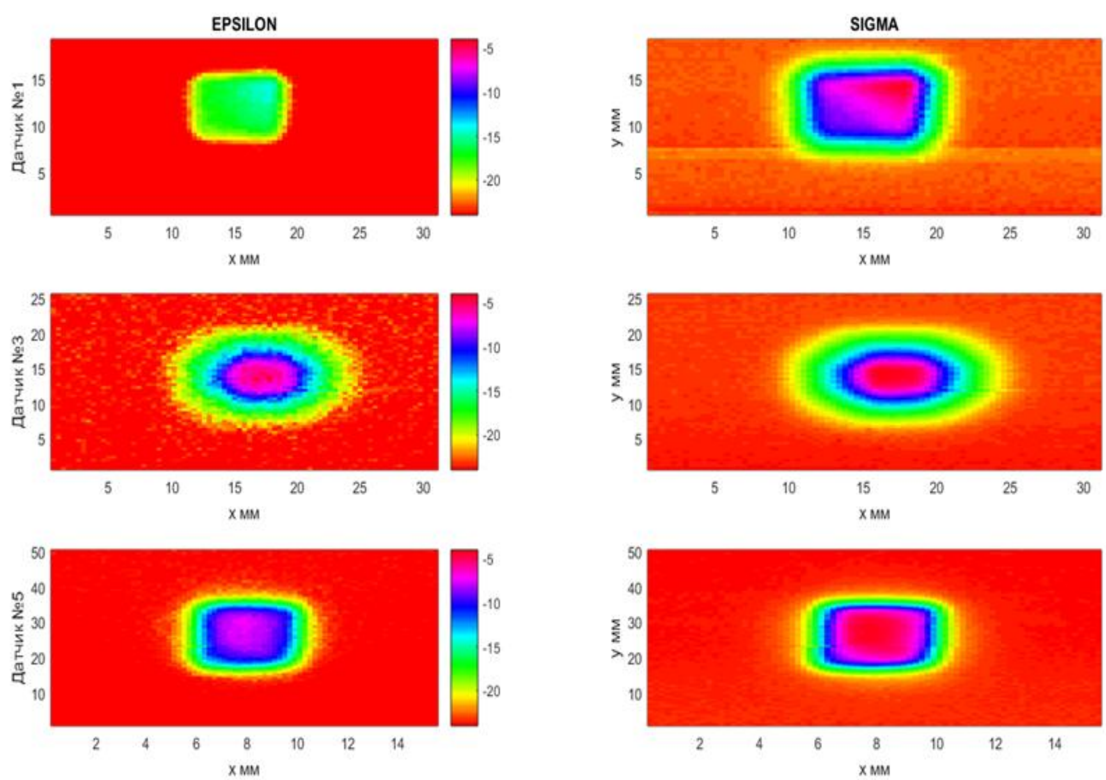

Figure 2 Results of two-dimensional scanning of a fragment of fibrous tissue by various sensors-probes for permittivity (ε) and conductivity (σ)

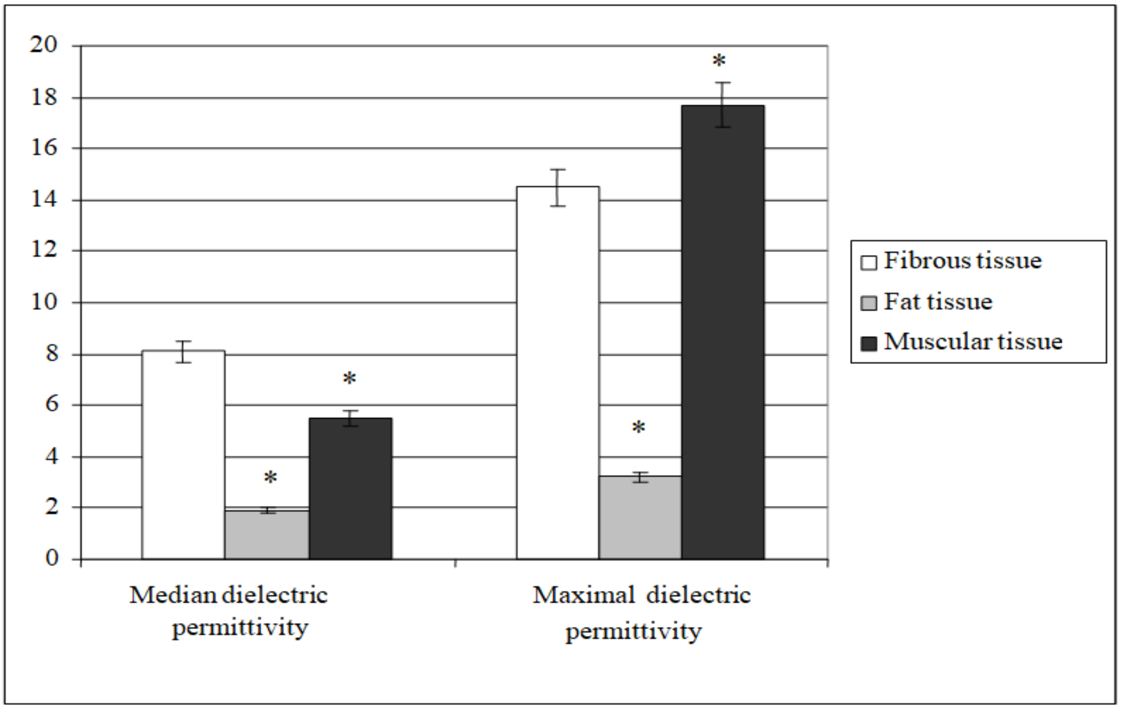

Figure 3 The level of average ($\Delta\varepsilon_{cp}$) and maximal ($\Delta\varepsilon_{Max}$) dielectric permittivity of fragments of various tissues; * revealed a level of statistical value ($p<0.05$) of differences in fibrous tissue

Based on the microwave pattern, the adipose tissue is less unambiguously changed with the dielectric permittivity in a small central area of the sample. Such differences in the dielectric properties of tissues of various histological types make it possible to talk about the diagnosis of the condition of the burn wound and the periwound zone, as well as to assess the depth of thermal damage to the skin and underlying tissues, creating a fundamental justification for instrumental diagnostics in combustiology.

To quantify the dielectric characteristics of tissues of various histological structures, the average ($\Delta\varepsilon_{cp}$) and maximal ($\Delta\varepsilon_{Max}$) dielectric permittivity of the samples was calculated (Figure 3). It has been revealed that fibrous tissue has the highest level of both average and maximum permeability, while the lowest value of the indicators turned out to be characteristic of adipose tissue, for which the average permeability was 4.26 times lower than that of fibrous ($p<0.05$) and the maximum – 4.53 times, respectively ($p<0.05$). Muscle tissue occupies an intermediate position between them and approaches more to the level of fibrous tissue which is due to the sufficiently high density of muscles and their high metabolic activity.

Results of the study revealed that as a thermo-modification the dielectric characteristics of bio-tissue are significantly transformed. This might be because these are significantly dependent on the content of water in the studied object (Reznik and Yuasova 2004; Kostrov et al. 2005; Hayashi et al. 2005; Martusevich et al. 2018), and when heated, there is a significant decrease in tissue hydration. Similar dynamics of the parameter were reported in previous studies, which included a comparative assessment of the dielectric properties of the skin and subcutaneous structures in healthy Wistar rats with model thermal trauma (Bogomolova et al. 2017; Martusevich et al. 2018). This confirms the diagnostic informativeness of the analysis of the dielectric permittivity of tissues under the influence of high temperatures, including thermal burns. This indicates a violation in metabolic shifts which cause changes in the ionic composition of the intercellular substance, osmolarity, and other physical and chemical characteristics (Hayashi et al. 2005; Ida et al. 2016; Turchin 2016). These facts can be used as an experimental justification for the possibility of detecting the boundaries of thermal tissue damage that occurs in real burns.

Conclusion

Thus results of the experiment made it possible to objectify the diagnostic value of the technology of near-field resonant microwave sensing on real biological samples. In addition, the possibility of the hardware and software complex to visualize the shape, localization, and linear dimensions of a biological object has been also confirmed. It is also shown that the studied technology can differentiate tissues of various histotypes. At the same time, it was found that fibrous tissue has the highest level of both average and maximum dielectric permittivity, while the lowest value of the indicators turned out to be characteristic of adipose tissue, for which the average permeability was 4.26 times lower than that of fibrous tissue, and the maximum was 4.53 times, respectively. Muscle tissue occupies an intermediate position between them, approaching more to the level of fibrous tissue.

Conflict of interest

None declared.

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