http://dx.doi.org/10.35596/1729-7648-2025-23-1-54-59

Original paper

UDC 004.94

MODELING THE EFFECTS OF DIRECTED CONTACT DIATHERMY ON BIOLOGICAL TISSUE

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Abstract. Directional contact diathermy is one of the most promising methods of physiotherapy. To study it, biophysical modeling of the effect of capacitive-resistive energy transfer (TEKAR therapy, or TR therapy) on biological tissue was carried out in the COMSOL Multiphysics environment using the finite difference method. A model of a biological object exposed to TR therapy was created. The visualization of the distribution of temperature and electric potential in the volume of the model is carried out. The dependence of the heating intensity on the frequency of alternating current is determined. The dynamics of temperature changes in each layer of biological tissue is shown.

Keywords: directional contact diathermy, TR therapy, TECAR therapy, modeling environment, biophysical modeling, tissue properties, COMSOL Multiphysics.

Conflict of interests. The authors declare no conflict of interests.

For citation. Navitskaya H. Y., Kamlach P. V., Likhacheuski D. V., Bandaryk V. M., Davydov M. V. (2025) Modeling the Effects of Directed Contact Diathermy on Biological Tissue. *Doklady BGUIR*. 23 (1), 54–59. http://dx.doi.org/10.35596/1729-7648-2025-23-1-54-59.

МОДЕЛИРОВАНИЕ ЭФФЕКТОВ НАПРАВЛЕННОЙ КОНТАКТНОЙ ДИАТЕРМИИ НА БИОЛОГИЧЕСКИЕ ТКАНИ

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Аннотация. Направленная контактная диатермия является одним из наиболее перспективных методов физиотерапии. Для ее изучения в среде COMSOL Multiphysics было проведено биофизическое моделирование воздействия с помощью передачи емкостно-резистивной энергии (ТЕКАР-терапии, или TR-терапии) на биологическую ткань с использованием метода конечных разностей. Создана модель биологического объекта, подвергнутого воздействию TR-терапии. Выполнена визуализация распределения температуры и электрического потенциала в объеме модели. Определена зависимость интенсивности нагрева от частоты переменного тока. Показана динамика изменения температуры в каждом слое биологической ткани.

Ключевые слова: направленная контактная диатермия, TR-терапия, среда моделирования, биофизическое моделирование, свойства тканей, COMSOL Multiphysics.

Конфликт интересов. Авторы заявляют об отсутствии конфликта интересов.

Для цитирования. Моделирование эффектов направленной контактной диатермии на биологические ткани / А. Е. Новицкая [и др.] // Доклады БГУИР. 2025. Т. 23, № 1. С. 54–59. http://dx.doi.org/10.35596/1729-7648-2025-23-1-54-59.

Introduction

Directed contact diathermy, also known as transfer energy capacitive and resistive (TECAR) therapy or TR therapy, is one of the advanced therapeutic and preventive methods of physiotherapy. Currently, the method is most common abroad. In order to create a basis for the development of this type of medical equipment as a domestic analogue, it is necessary to investigate the method of directional contact diathermy and describe its features. To prove the effectiveness of the method, it is important to investigate the processes occurring in biological tissues when they are exposed to TR therapy. To do this, it is necessary to create a model that displays the result of the application of directional contact diathermy in real time. As a result of the analysis of software modeling environments that allow creating physical models of the impact on biological tissue, the COMSOL Multiphysics modeling environment was selected, characterized by the greatest efficiency in relation to the creation and analysis of a model of the impact of directional contact diathermy on biological tissue [1].

Experiment method

The effect model of TR therapy is based on the Joule heating model, which includes the physics of electric currents and heat transfer in solids [2]:

$$\mathrm{rot}H = J; \quad (1)$$

$$\mathrm{rot}E = -(dB/dt); \quad (2)$$

$$\mathrm{div}B = 0; \quad (3)$$

$$\mathrm{rot}D = \rho, \quad (4)$$

where H is magnetic field strength; J is total current density; E is electric field strength; B is magnetic induction; D is electrical induction (electric flux density); ρ is volumetric density of an external electric charge.

The total current density in equation (1) can be represented as:

$$J = J_{ext} + J_i + J_v + J_D, \quad (5)$$

where J_{ext} is current density supplied from an external source; J_i is density of induced currents; J_v is the current density generated in a conductor moving at speed; J_D is the current density of electric displacement.

In equation (5), the current density supplied from an external source and induced currents can be determined using Ohm's law in differential form:

$$J_{ext} = \sigma E_{ext}; \quad (6)$$

$$J_i = \sigma E, \quad (7)$$

where E_{ext}, E_i are the vector electric field strengths created by external sources and induced currents, respectively; σ is electrical conductivity, which can be either a scalar value or a reference value.

The relationship between the electric flux density D and the electric field strength E is determined by the expression

$$D = \varepsilon E = \varepsilon_0 E + P = \varepsilon_0(1 + \chi_e)E = \varepsilon_r \varepsilon_0 E, \quad (8)$$

where ε is absolute permittivity; ε_0 is dielectric constant of air; P is polarization; χ_e is electrical susceptibility; ε_r is relative permittivity [3].

In COMSOL Multiphysics, a geometric model of the effect of directional contact diathermy on a part of the human body was built (Fig. 1). As an example, the upper part of the forearm is used to create a model. This choice is due to the fact that the structure of this part of the body is quite easy to imagine as a model. To simulate the process of exposure of directed contact diathermy to biological tissue, the model of biological tissue is simplified to the main components: skin, adipose tissue, muscle tissue, bone tissue. For the problem under consideration, geometry was created from cylindrical primitives.

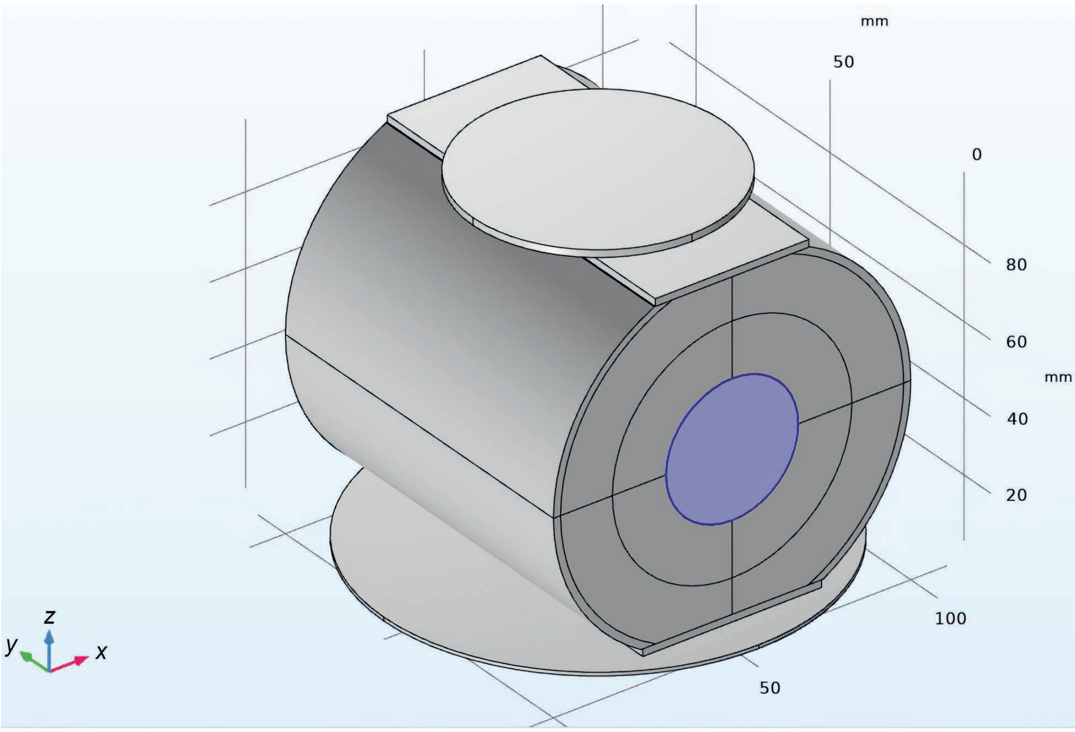


Fig. 1. Geometric model in COMSOL Multiphysics

Directional contact diathermy devices use active and neutral electrodes. In the model, the active electrode is represented as a disk with a radius of 35 mm, 2 mm thick, the neutral electrode is represented as a disk with a radius of 60 mm, 1 mm thick. The material used to create the electrodes is copper.

The simulated part has a diameter of 100 mm, corresponding to the real average size of the forearm. The sizes of the primitives correspond to the sizes of the layers of biological tissues. Appropriate materials have been identified for each layer of biological tissue. These materials are presented in the COMSOL embedded materials library, Bioheat section. In COMSOL, basic characteristics are automatically set for each material, such as heat capacity at constant pressure, density, thermal conductivity, frequency coefficient, activation energy.

In the "Electric currents" section, functions such as stationary analysis, frequency domain analysis, small signal analysis and time domain modeling are supported in all spatial dimensions. In the time and frequency domains, capacitive effects are also taken into account. The physical interface solves a current conservation equation based on Ohm's law using a scalar electric potential as a dependent variable. An important physical condition for interaction at the interface between different media and internal boundaries is continuity, which is a natural boundary condition:

$$nJ = 0. \tag{9}$$

The Heat Transfer module is a package that allows you to simulate heat flows in an environment using special physical interfaces and functions optimized for heat transfer analysis. It comes with a collection of ready-made examples and models that appear in the Heat Transfer module accompanying the model library. The Heat Transfer in Solids module uses the following heat conduction equation as a mathematical model for heat transfer in solids:

$$\rho C_p \frac{dT}{dt} = -(\nabla q) + Q + Q_{red}, \tag{10}$$

where C_p is heat capacity; T is absolute temperature; Q is heat source, q is the heat flow, it is the viscous stress tensor; Q_{red} is thermoelastic damping heat source.

Fourier's law of thermal conductivity

$$q = kT, \tag{11}$$

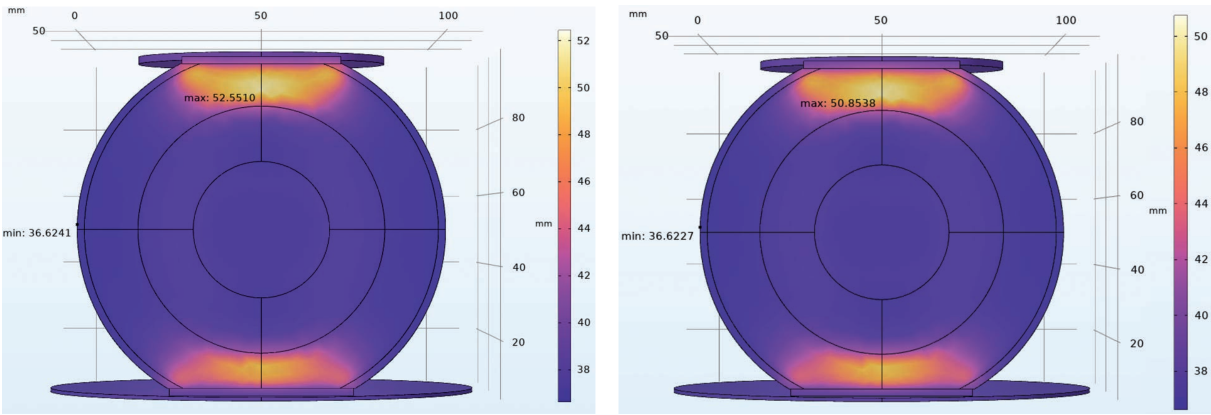
where q is flow vector; T is temperature gradient [4].

The finite difference method was used to simulate the effects of directional contact diathermy. The advantages of this method are as follows: the simplicity of the method itself makes it easy to implement it in a computer environment. Also, the simplicity of finite difference calculation makes it possible to solve problems faster than other computational methods.

The domain of continuous change of arguments (for a one-dimensional problem, these are variables *x* and *t*) is replaced by a finite (discrete) set of points (nodes) $\{xi\}$, $\{ti\}$, called a grid. Instead of continuous argument functions, discrete argument functions defined at grid nodes and called grid functions are considered. The derivatives included in the differential equation are replaced (approximated) using the appropriate difference relations. In this case, the differential equation is replaced by a system of algebraic equations (difference equations). The initial and boundary conditions are also replaced by differential initial and boundary conditions [5].

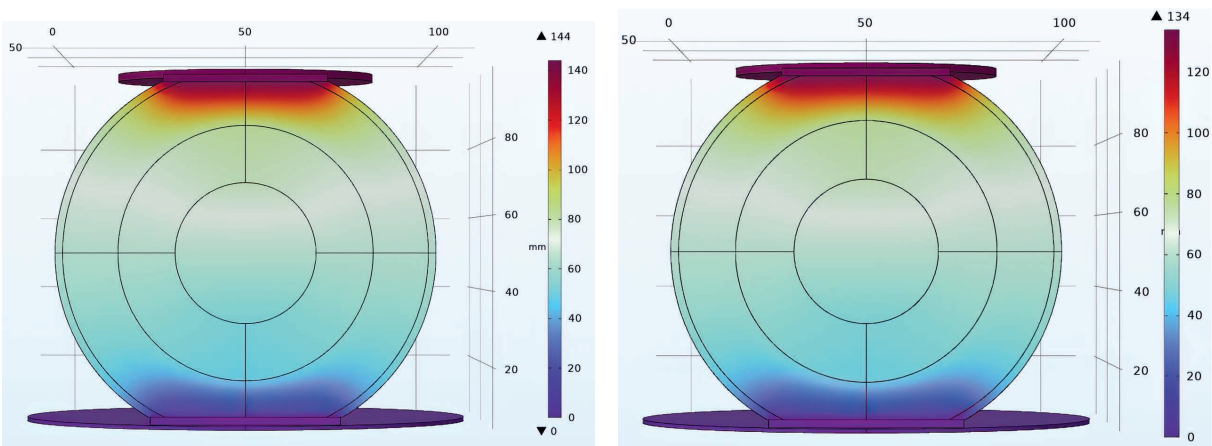
Results and their discussion

The main value that the program calculates is the spatial distribution of temperature at a certain frequency. Additionally, the distribution of potential in the volume of the model is visualized. For comparison, the figures show the results of calculations at frequencies of 400 kHz and 1.2 MHz – the most frequently used frequencies from the presented ones. Fig. 2, 3 present the results of modeling the distribution of the heating intensity and the distribution of the electric potential.



a *b*

Fig. 2. A screenshot of the visualization of the temperature distribution at a frequency of:
a – 400 kHz; *b* – 1.2 MHz



a *b*

Fig. 3. A screenshot of the visualization of the distribution of electric potential at a frequency of:
a – 400 kHz; *b* – 1.2 MHz

The minimum temperature value at a frequency of 400 kHz is 36.6 °C, the maximum is 52.6 °C. The minimum temperature value at a frequency of 1.2 MHz is 36.6 °C, the maximum is 50.8 °C.

The results of the impact of diathermy on the human body with the distribution of heating intensity at control points at different frequencies are presented in Tab. 1. Control points were determined for each component of the biological object model.

Table 1. Temperature at control points when exposed to alternating current of different frequencies

Frequency	Heating temperature, °C, at control points			
	Skin	Adipose tissue	Muscle tissue	Bone tissue
300 kHz	39.5	42.9	43.2	37.0
400 kHz	39.4	42.7	43.0	
448 kHz	39.3	42,6	43.0	
480 kHz	39.3	42.6	43.0	
500 kHz	39.3	42.5	42.9	
520 kHz	39.2	42.5	42.9	
800 kHz	39.0	42.3	42.7	
1.0 MHz	38.9	42.1	42.5	
1.2 MHz	38.7	42.0	42.4	
1.5 MHz	38.6	41.7	42.3	

Tab. 2 shows the maximum temperature values in the volume of the model when exposed to various alternating current frequencies.

Table 2. Maximum temperature values in the volume of the model when exposed to various alternating current frequencies

Frequency	300 kHz	400 kHz	448 kHz	480 kHz	500 kHz	520 kHz	800 kHz	1.0 MHz	1.2 MHz	1.5 MHz
Maximum temperature value, °C	52.9	52.5	52.4	52.3	52.2	52.2	51.5	51.1	50.8	50.4

During the analysis of the results obtained, it was found that during the procedure of directional contact diathermy, the maximum temperature value in the biological tissue decreases with increasing frequency of alternating current. The largest temperature dynamics is observed in muscle tissue.

Conclusion

The intensity of heating in tissues under the influence of directional contact diathermy varies when passing through a biological object and depends on the structure and bioelectric properties of tissues, the frequency of alternating current and the time of exposure. For further clinical studies, it is necessary to simulate the effects of TR therapy on biological tissue at the molecular level. This will make it possible to most accurately show the effect of diathermy on tissue cells, and describe the mechanism of therapeutic action of TR therapy. As a result of the analysis of the data obtained, it will be possible to determine the most effective method of exposure, which, in turn, will help create a basis for the development of a domestic analogue of the directed contact diathermy apparatus.

References

1. Smith J., Lee M., Kim D. (2020) Artificial Intelligence for Medical Diagnosis: A Comprehensive Review. *Journal of Medical Systems.*
2. Rokach L. (2010) Pattern Classification Using Ensemble Methods. *World Scientific Publishing ISBN: 978-981-12-0195-0.* https://www.doi.org/10.1142/11325.
3. Balogh E. P., Miller B. T. (2015) *The National Academies of Sciences. Improving Diagnosis in HealthCare*. Washington, National Academies Press.
4. Singh S. P., Singh S. (2014) Application of Fuzzy Logic in Medical Diagnosis: A Review. *International Journal of Computer Science and Mobile Computing*. 3 (3), 181–187. https://www.doi. org/10.11648/j.net.20190702.15.
5. Topol E. (2019) *How Artificial Intelligence Can Make Healthcare Human Again*. New York, Basic Books Publ.
6. Beleites C., Salzer R., Sergo V. (2018) Validation of Soft Classification Models Using Partial Class Memberships: An Extended Concept of Sensitivity & Co. Applied to the Grading of Astrocytoma Tissues. *Journal of Chemometrics*. 32 (5).

7. Liu Y., Wu R., Yang A. (2023) Research on Medical Problems Based on Mathematical Models. *Mathematics*. 11. https://doi.org/10.3390/math11132842.
8. Danchenko O., Bedrii D., Haidaienko O., Bielova O., Kravchenko O., Kuzminska Y. (2021) Mathematical Support of Theinformation System for Decisionsupport in the Sphere Ofhealthcare. *Scientific Journal of Astana IT University.* (6), 23–37. https://doi.org/10.37943/AITU.2021.89.31.003.
9. Novitskaya A. E. (2024) Choice of Modelig Environment to Create a Model of the Impact of Directed Contact Diathermy on Bio-Tissue. *Electronic Systems and Technologies, Materials of the 60th Scientific Conference of Graduate Students, Undergraduates and Students of BSUIR.* 306–309 (in Russian).
10. Alekseev V. F., Piskun G. A., Kalinovsky D. V., Ivliev I. A. (2018) Modeling of Joule Heating in the Comsol Multiphysics Environment. *Doklady BGUIR*. 117 (7), 90–95.
11. Leshchenko V. G. (2018) *Workshop on Medical and Biological Physics.* Minsk, Belarusian State Medical University.
12. Smolyanov I. A., Sarapulov F. N., Sarapulov S. F., Bychkov S. A., Tarasov F. E. (2021) *Mathematical Modeling of Electromechanical Installations in the Comsol Multiphysics Environment*. Ural University Publishing House (in Russian).
13. Myrzakerimova A. B., Kolesnikova K. V., Nurmaganbetova M. O. (2024) Use of Mathematical Modeling Tools to Support Decision-Making in Medicine. *Procedia Computer Science*. 231, 335–340. https://doi.org/10.1016/j.procs.2023.12.213.

Authors' contribution

All authors contributed equally to the writing of the article.

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