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On Approach for Analysis of Distribution of Temperature During Effects of Radiation on Biological Tissues

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***Abstract** Different types of irradiation take essential role in biological processes directly related to human health. Currently they are widely using in clinical practice. In this situation one can find several works to determine therapeutic effects, which were obtained by actions of the irradiation on living organisms. One type of irradiation of tissues of the considered organisms is electromagnetic radiation. A consequence of the radiation tissues of organisms is their heating. In this paper we introduce a model and an analytical approach to analyze distribution of temperature at effect of radiation on biological tissues. We consider a possibility to control of heat transport in biological tissues by choosing of conditions of heating. Also we present an analytical approach for analysis of the obtained model. The approach takes into account changing of parameters of the considered processes on coordinate and time as well as their nonlinearity.*

***Keywords:** Effect of Radiation; Biological Tissues; Prognosis of Heat Transport; Control of Heat Transport; Analytical Approach for Analysis.*

I. INTRODUCTION

Different types of irradiation take essential role in biological processes directly related to human health [1-6]. In the present time they are widely using in clinical practice. In this situation one can find several works to determine therapeutic effects, which were obtained by actions of the irradiation on living organisms. One type of irradiation of tissues of the considered organisms is electromagnetic radiation (including of radiation of visible range). A consequence of the radiation tissues of organisms is their heating. Some estimations of penetration of electromagnetic and other types of radiation in organisms as well as heating of biological tissues as a result of the penetration [1-6][10][11][12]. Main aim of the present paper is formulation of model for analysis of the heating of the organism due to electromagnetic radiation. An accompany aim is formulation of analytical approach for analysis of the obtained model. The approach shall takes into account changing of parameters of the considered processes on coordinate and time as well as their nonlinearity.

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II. METHOD AND RESULTS OF SOLUTION

In this section we consider the following model of generation and redistribution of heat in tissues of an organism during and after electromagnetic irradiation. Spatio-temporal distribution of temperature in the considered case was determined as solution of the following equation

$$\rho c \frac{\partial T(r,t)}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2 \lambda(r)\frac{\partial T(r,t)}{\partial r}\right] + S_l(r,t) + S_b(r,t), \quad (1)$$

where $T(r,t)$ is the temperature of heating in tissue of an organism due to electromagnetic irradiation; ρ is the density of the above tissue; c is the specific heat of tissues; t is the current time; $\lambda = \alpha \rho c$ is the thermal conductivity of tissue; α is the thermal diffusivity of tissue; $S_l = \mu \varphi E$ is the volumetric density of heat, which was obtained in tissue due to irradiation; μ is the absorption coefficient; φ is the total illumination of the tissue in the considerate area; E is the radiation energy density per unit time. Blood can absorb or release heat depending on how its temperature correlates with the temperature of the surrounding tissue. The term S_b is the volumetric drain or energy source and can be written as follows: $S_b = \rho \ c \{\rho_b D \ (t)[T_b - T(r,t)]\}$, ρ_b is the density of blood; T_b is the temperature of blood; $D \ (t)$ is the blood flow density. Boundary and initial conditions for the equation (1) could be written as

$$T(r,0) = f(r); \quad -\lambda(r)\frac{\partial T(r,t)}{\partial r}\bigg|_{r=-0} = 0;$$

$$-\lambda(r)\frac{\partial T(r,t)}{\partial r}\bigg|_{r=R} = \frac{S_l(r,t) + S_b(r,t)}{\pi R^2}. \quad (2)$$

The considered model is more common in comparison with previously published one. In this situation it is attracted an interest appropriate method of solution of equation (1). In this situation we solved the Eq. (1) by method of averaging of functional corrections [7-9]. In the framework of the approach we replace the required function $T(r,t)$ on the not yet known average value α_1 of this function in the right side of Eq. (1). The replacement gives a possibility to obtain the following relation to determine the first-order approximation $T_1(r,t)$ of the considered temperature in the following form

$$T_1(r,t)=\int_0^t \frac{S_l(r,\tau)+S_b(r,\tau)}{\rho c}d\tau + f(r). \quad (3)$$

Approximations of temperature with larger order n could be obtained in the framework of the standard procedure [7-9], i.e. by replacement of the required function $T(r,t)$ on the following sum $T(r,t) \to \alpha_n + T_{n-1}(r,t)$ in the right side of the Eq. (1). The following replacement gives a possibility to obtain the following relation to determine the second-order approximation of the considered temperature

$$T_2(r,t)=\int_0^t \frac{1}{r^2\rho c}\frac{\partial}{\partial r}\left[r^2\lambda(r)\frac{\partial T_1(r,\tau)}{\partial r}\right]d\tau + \int_0^t \frac{S_l(r,\tau)+S_b(r,\tau)}{\rho c}d\tau + f(r). \quad (4)$$

Analysis of spatio-temporal distribution of temperature of tissue under influence of electromagnetic irradiation has been done analytically by consideration of their the second-order approximations. Analytical results were checked by comparison with results of direct numerical simulation.

III. DISCUSSION

In this section we analyzed dependences of temperature of tissue under influence of electromagnetic irradiation on time at different values of parameters. Figure 1 shows typical dependences of the considered temperature on time at different values of heat, which was obtained in tissue due to irradiation. Increasing of number of curves corresponds to increasing of value of the considered heat. In this case we take into account increasing of temperature of the considered tissue during irradiation and cooling of the tissue after finishing of the above irradiation. Figure 2 shows typical dependences of the considered temperature on time at different values of the considered temperature at different values of square of the irradiated part of tissue and fixed value of power of irradiation. Increasing of number of curves corresponds to increasing of value of the considered square.

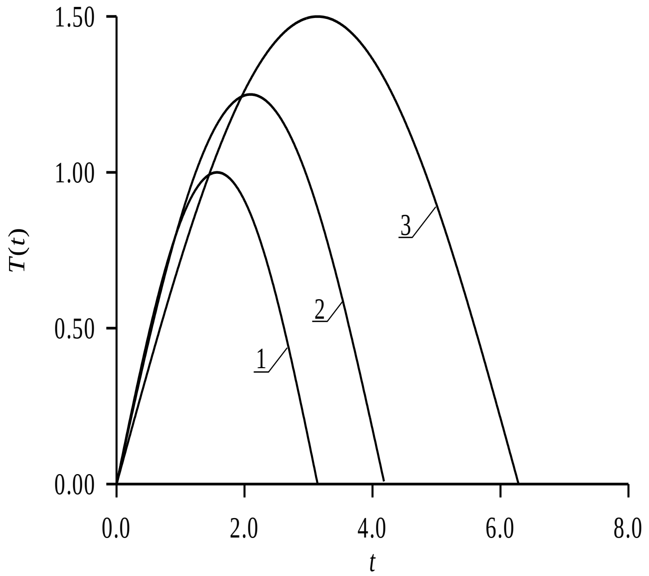

Fig. 1. Typical Dependences of the Considered Temperature on Time at Different Values of Heat, which was Obtained in Tissue Due to Irradiation. Increasing of Number of Curves Corresponds to Increasing of value of the Considered Heat

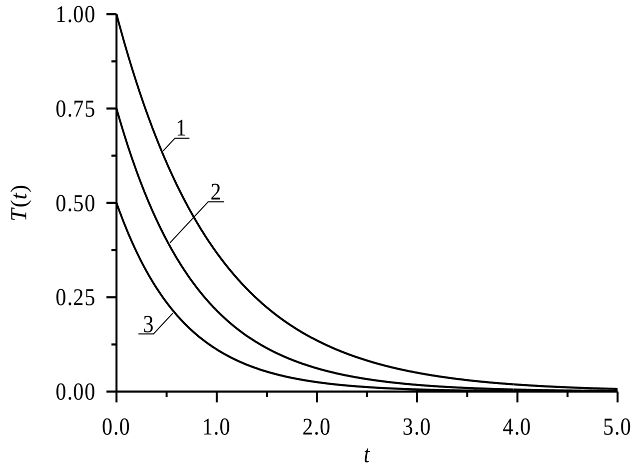

Fig. 2. Typical Dependences of the Considered Temperature on Time at Different Values of the Considered Temperature at Different Values of Square of the Irradiated Part of Tissue and Fixed Value of Power of Irradiation. Increasing of Number of Curves Corresponds to Increasing of value of the Considered Square

IV. CONCLUSION

In this paper we introduce a model for analysis of distribution of temperature at effect of radiation on biological tissues. We consider a possibility to control of heat transport in biological tissues by choosing of conditions of heating. Also we introduce an analytical approach to analysis of the above temperature.

DECLARATION STATEMENT

Funding	No, we did not receive.
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Authors Contributions	I am only the sole author of the article.

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AUTHOR PROFILE

Evgeny Leonidovich Pankratov, was educated Nizhny Novgorod state university (Nizhny Novgorod city, Russia) with full doctor degree in physics and mathematics. Now he has a position of a full professor. Area of scientific interests of Evgeny Leonidovich Pankratov is prognosis of processes in physics, biology and economics with appropriate development of models and analyt-ical approaches for solution of equations, which were used in the considered models. Now he have 600 published papers in area of his research.