IMPROVEMENT PROPOSAL OF COMPUTER MODELLING OF CANCER DESTROYING DURING THE CRYOSURGERY

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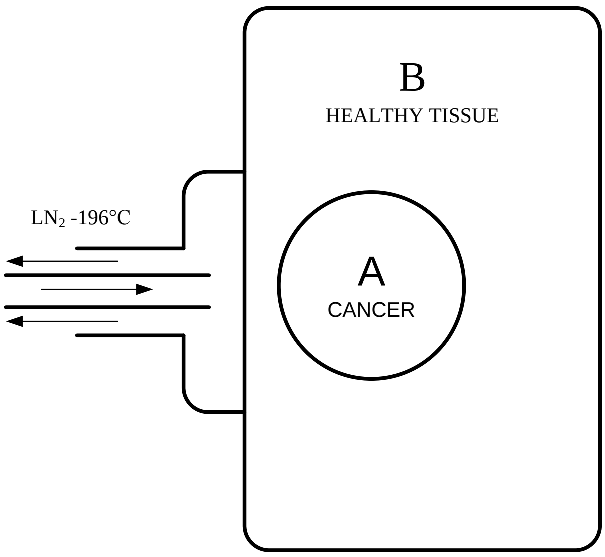
Abstract: This paper deals with heat distribution in human tissues. The Bioheat equation is used for modeling of heat transfer in tissues. Software application Cryomodel is described in this paper. The Cryomodel is realized in Matlab software for simulation of cryosurgery operation. Simulation is realized in 3D space of tissue. The Cryomodel contains many adjustable parameters like: Temperature and diameter of cryoprobe and properties of tissue. The Cryomodel considers four layers of tissue and one centre of cancer. Layers of epidermis, dermis, subcutaneous fat and muscle for example. Optimization of tumor destroying is the main aim of this study. The improvement proposal is based on improvement of thermal properties in tumor. This software application should be a good planning tool for doctors in practice.

Keywords: Improvement proposal, Cryosurgery, Cancer, Matlab, Bioheat equation, Simulation

1. ÚVOD

In medical applications of heat stimulations of tissue (hyperthermia and hypothermia) attributes of biological material for heat conduction and its effect on microcell system is used. Biological destroying effects on cell nucleus or cellulosa during the hyperthermia and gradient hypothermia are known. Injury of healthy cells is problem of applied hypothermia in radial direction from critical volume to cryoprobe [1], [2].



Obrázek 1: Scheme of cryosurgery

This paper deals with possibility of basic matter application into cell space. See Figure. 1. First way is application of basic matter into healthy cells in space B. Second way is application of basic matter into cancer cells in space A to shorten of cryoprobe application and minimizing of injury of the surrounding healthy tissue.

The Bioheat equation which is used in this paper was formulated by Henry Pennes in 1948. This fundamental equation is used without serious changes till now. The Bioheat equation is extended equation of heat transfer. All types of heat transfer diffusion equations are partial differential equation (PDE) of parabolic type. The Bioheat equation is:

$$\rho C \frac{\partial T}{\partial t} = \nabla\left(k\nabla T\right) + \rho_b w_b C_b \left(T_b - T\right) + \rho q_{met} \tag{1}$$

where ρ is density of tissue [kg/m^3], C is specific heat capacity [J/(kg.°C)], T is temperature [°C], t is time [s], k is thermal conduction [W/(m.°C)], b is blood, w_b is blood perfusion [l/(s.kg)] and q_{met} is metabolic heat generation rate [W/kg]. It is necessary to rewrite the Bioheat equation into formula (3) for computer processing. This equation is expressed by explicit method using a forward difference at time p and a second-order central difference see equation (2).

$$\frac{T_j^{p+1} - T_j^p}{\Delta t} = \alpha \left[\frac{T_{j+1}^p - 2T_j^p + T_{j-1}^p}{\left(\Delta x\right)^2}\right] \quad ; \quad \alpha = \frac{k}{\rho C} \tag{2}$$

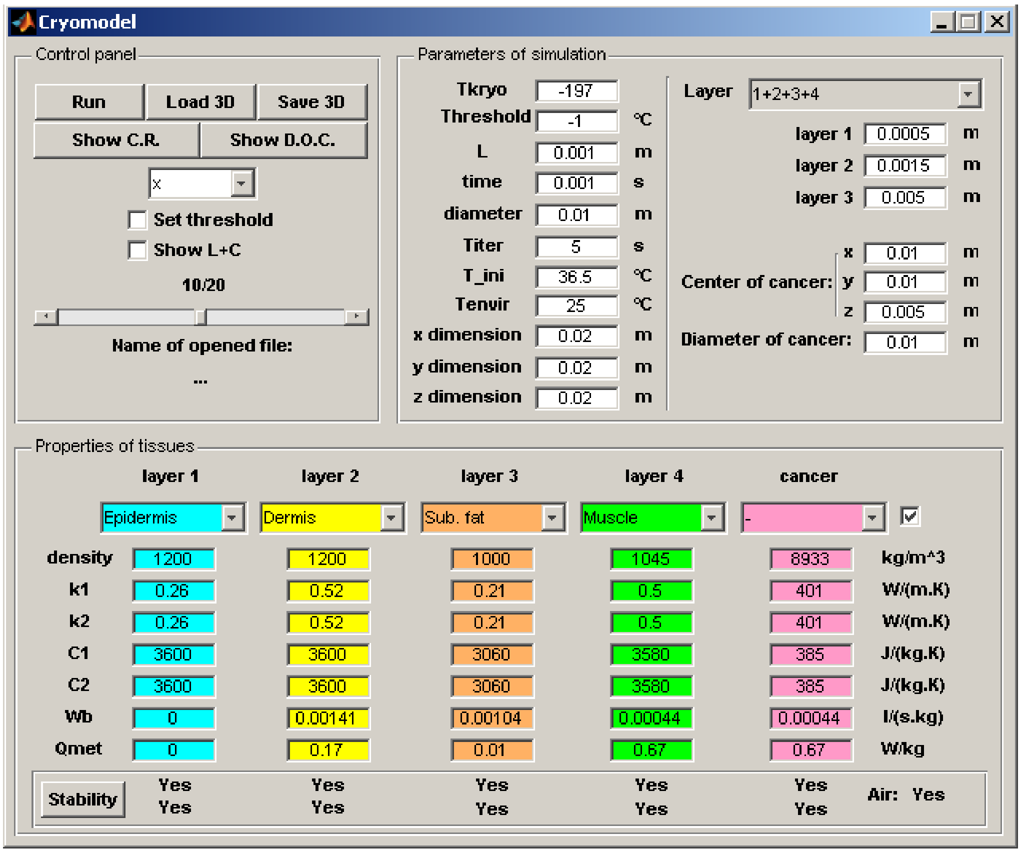
$$\begin{aligned} T_{i,j,k}^{p+1} = {} & \frac{\Delta t \cdot k}{\rho C_{i,j,k}\left(\Delta x\right)^2} \cdot \left(T_{i+1,j,k}^p + T_{i-1,j,k}^p + T_{i,j+1,k}^p + T_{i,j-1,k}^p + T_{i,j,k+1}^p + T_{i,j,k-1}^p - 6T_{i,j,k}^p\right) + \\ & + \Delta t \cdot \frac{\rho_b w_b C_b T_b + \rho q_{met}}{\rho C_{i,j,k}} + T_{i,j,k}^p \cdot \frac{\rho C_{i,j,k} + \Delta t \rho_b w_b C_b}{\rho C_{i,j,k}} \end{aligned} \tag{3}$$

where p is time level, i,j and k are calculated grid points, Δt is time [s], Δx is edge of voxel [m]. [3], [4]

2. THE CRYOMODEL APPLICATION

The Cryomodel application is able to solve a distribution of low temperatures in different human tissues. The temperature distribution is realized only for 3D space. Minimal dimension of edge of 3D space is limited by diameter of cryoprobe. This application counts with frozen and unfrozen regions also. It means that properties of tissues are depended on state (frozen/ unfrozen). This threshold is between -1°C and -8°C. The lower boundary is used in this study. Practical consequences of used frozen/ unfrozen condition are following: Frozen regions have higher thermal conduction and lower specific heat capacity than unfrozen regions therefore cooling rate and depth of penetration of low temperature are better for frozen state regions. This finding is fundamental. The Cryomodel consist three main sections. See Figure. 2.

“Control panel” section contains controls of simulation like Run, Save, Load and others. Check box "Set threshold" enables to see the region of killed cells (temperature below -13°C) only. User can select slice position (x means, that x = position of slider and y, z are from 1 to x dimension, z dimension). Button "Show C.R." shows cooling rates in defined depths 1, 2, to, 9 mm. Condition of cooling rate about 200 °K.min^{-1} is necessary for good freezing process during the cryosurgery. “Show D.O.C” displays temperature dependence on depth.



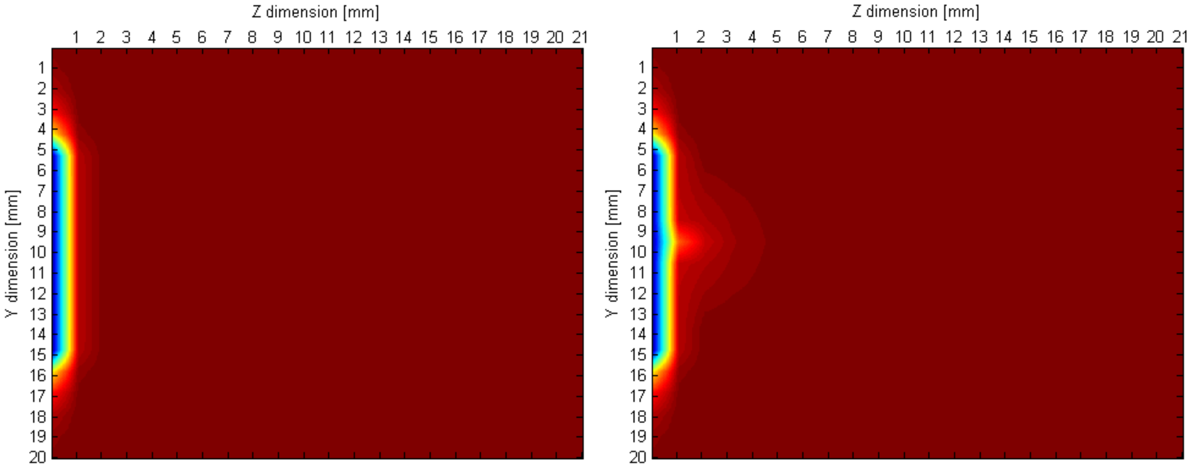
Obrázek 2: The interface of software application Cryomodel.

In “Parameters of simulation” section is possible setup temperature and diameter of cryoprobe, dimensions of 3D matrix, layers and globe of tumor, time step, edge of voxel, threshold and time of during the simulation. The Cryomodel considers four layers of tissue and globe which represent a tumor. Setup of layer 4 is used for whole 3D matrix if the popup menu "Layer" is set on "4".

The “Properties of tissues” section consist density, thermal conductivity, specific heat, blood perfusion and metabolic heat generation. For each of four layers is possible select type of layers from popup menu and determine stability of simulation.

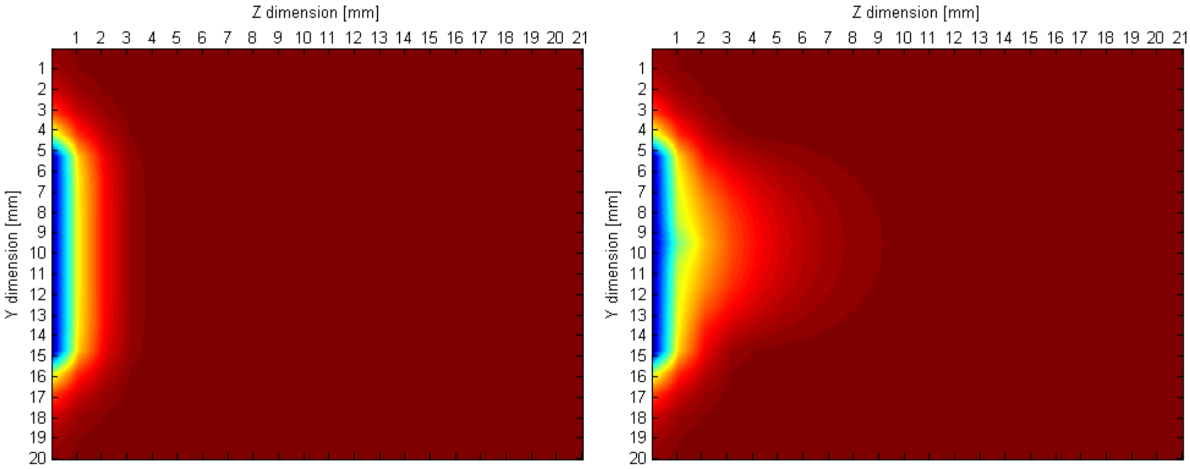
3. IMPROVEMENT PROPOSAL

The main goal of improvement tumor destroying is based on increasing of thermal conductivity and decreasing of specific heat in tumor. In this case is higher drain of heat from tumor and time of cryoprobe application is shorter also. Healthy tissues are then less injured. Only the theoretical hypothesis is described in this paper. The globe of tumor is filled with thermal properties of optimized tumor. Surrounding space is filled with thermal properties of human tissue in four layers, epidermis, dermis, subcutaneous fat and muscle in this case. Average thermal conductivity of human tissue is about 0.5 W.m-1.K-1 and average specific heat is about 3600 J.kg-1.K-1. On left side of Figure 3 is displayed a result of simulation after 1 s. Freezing of optimized tumor is than shown on right side of Figure 3. We can see a difference of cooling depth between them. The greater cooling depth is in the case of optimized tumor. The differences between improved and non improved tumors are time dependent. Results after 10 s and 60 s are on Figure 4 and Figure 5. We can state efficiency of cancer improvement is quite good. The cooling depth of improved tumor after 60 s of stimulation is greater than tumor without improvement about 2 mm.



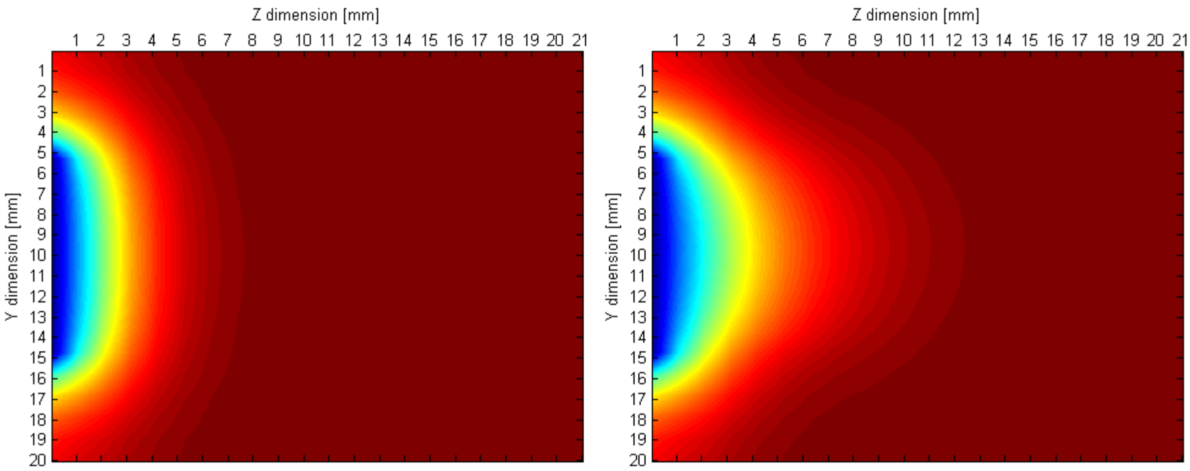
a) b)

Obrázek 3: a) Result after 1 s stimulation. b) Improved tumor after 1 s stimulation.



a) b)

Obrázek 4: a) Result after 10 s stimulation. b) Improved tumor after 10 s stimulation.



a) b)

a) Result after 60 s stimulation. b) Improved tumor after 60 s stimulation.

All results were calculated with Cryomodel software with 1 mm edge of voxel. These figures were modified with interpolation algorithm of fifth order.

4. CONSLUSION

This model study is based on finite difference method and numerical solution of Bioheat equation by Mr. Pennes (1948). The Cryomodel application has been tested for some properties of human tissue and has been compared with result from real experiment with potato. Only the model situation is describe in this paper. For confirmation of theoretical hypothesis the parameters of improved globe of tumor has been used. The greater cooling depth is in the case of improved tumor. The differences between improved and non improved tumors are time dependent. Longer application of cryoprobe on improved tumor has higher efficiency of freezing. Next research will be focused on real experiments. The aim is to find a procedure of real tumor and wart destroying improvement.

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