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THE TECHNOLOGY FOR CREATING OF SIMULATION OF RADIOFREQUENCY ABLATION

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Abstract In this paper the new technology for creating of the model for simulation was proposed. This technology was illustrated on base of the process of the radiofrequency ablation of thyroid nodules. The tracing of cross-sections of the thyroid lobe was performed to determine the spatial position of the segmented regions on ultrasound images. The surface was reconstructed by sets of these contours and used for the development of the model. The shape of the tumor has been described more accurately as a result. This technique can be used for an individual approach to the surgical planning. It can significantly reduce the risks and help to achive the best results during the planning of operation.

Key words: Image analysis, Symulation, Clinic procedure, Measument

AMS Mathematics Subject Classification: 62H35, 68U20, 94A08

1 Introduction

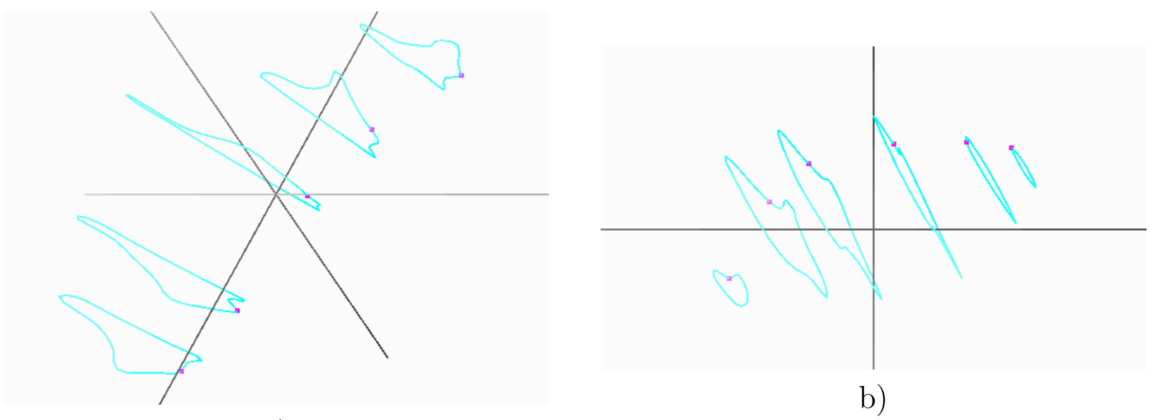
The computer simulation is widely applied nowadays as an auxiliary tool for the planning different medical procedures; this method allows physicians to reduce treatment risks. In particular, such simulation is applied for the radiofrequency ablation (RFA) - a minimally invasive procedure for cancer treatment when a tumor is locally heated and destroyed by a high-frequency alternating current [1] ,[2]. A RFA is considered as an alternative to surgery to remove small tumors. It is clear that there is a risk of skin burns during RFA because the healthy tissue may undergo a destruction together with the pathological formation. In addition there is a risk of a mechanical damage of blood vessels, nerves and other anatomical structures by the electrodes [3]. The computer simulation would allow a pretreatment identifying the zone of the thermal damage and determination of the procedure optimal parameters accordingly with the principles of safety and efficiency.

The pretreatment planning and control of RFA procedure is particularly important for the thyroid tumors on account of the structure and location features of the thyroid glands. The voltage applied to the electrode and the heating time are parameters that must be controlled during the procedure to achieve the certain temperature range.

The finite element method is well known as a powerful tool for the simulation of biophysical processes with complex geometry. This method has been widely used for the simulation procedure of radiofrequency ablation [4]. The generating of three-dimensional mesh (triangulation) of the thyroid gland lobe surface according to ultrasound images is one of the important tasks here.

2 Reconstruction of the three-dimensional surface of thyroid lobe

Ultrasound examination is a basic investigative tool for detecting of thyroid nodules, and the accuracy of this research is constantly increasing [5]. However, some properties of ultrasound such as echo, shadow and reflection can degrade the image quality in contrast to CT and MRI images. It explains difficulty of performing of the semi-automatic and manual segmentation of the thyroid glands and the lack of methods of the automatic segmentation. Method of the image reconstruction by sets of contours of segmented regions corresponding to the thyroid gland cross-sections (fig. 1) on ultrasound images has been used to construct a three-dimensional model of thyroid lobe [6]. Cross-section tracings perform by medical specialists on layers of three-dimensional images obtained by the ultrasound scanning. In order to describe contours one should set the spatial location of the scanning plane and describe points of the segmented region boundary.



a) b)

Figure 1: Spatial tracing of the thyroid gland lobe cross-section of two patients (a,b) on layers of 3D ultrasound images

The one-parameter interpolation and approximation splines constructed by the points on the tracing contours are used to restore surface [6],[7]. Surface in the vector representation, suitable for conversion to simulation package is the result of reconstruction. The results of the surface reconstruction for object contours represented on fig. 1a and fig. 1b are shown in fig. 2 and fig. 3.

The reconstructed surface has been used for computer simulation of RF ablation of thyroid nodes.

3 Construction of the model for simulation of tissue heating under the radiofrequency ablation

A mathematical simulation of the radiofrequency ablation is constructed according to the following physical processes: the absorption of energy of alternating electric current in the tissue, the heat transfer and the thermal tissue damage as a result of heating.

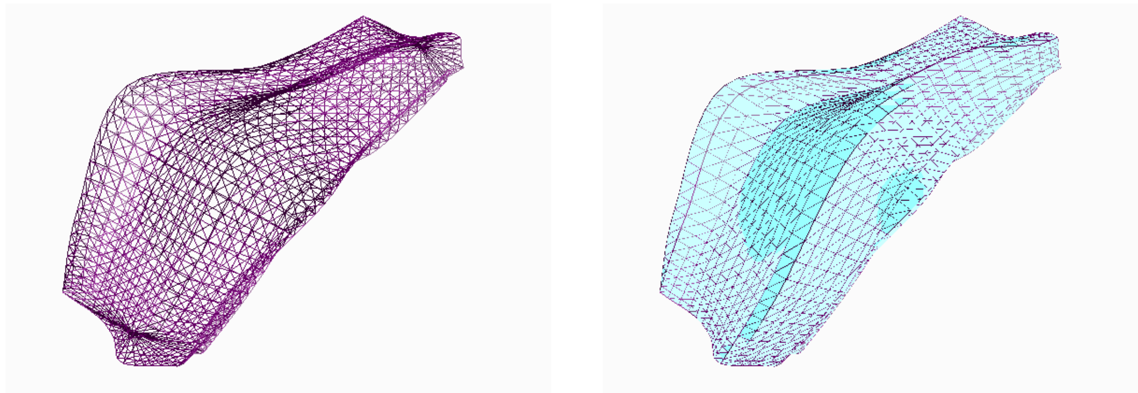


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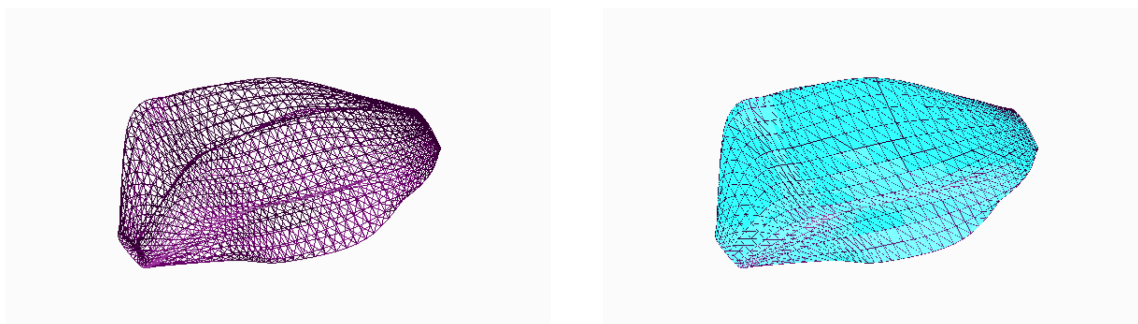
Figure 2: The three-dimensional meshing of object and its surface for contours represented on fig. 1



a) b)

Figure 3: The three-dimensional meshing of object and its surface for contours represented on fig. 1

The passing of the alternating current through the tissue provides its heating only at a very short distance from the electrode, because the electric field in the tissue diminishes rapidly with distance from the electrode. Further heating of tissue occurs through a process of heat transfer [8].

The specific heat capacity is used as a characteristic of AC power absorbed by the tissue: $q = j^2/\sigma$, where j is the current density (A/m^2), σ is the conductivity (S/m). The quasi-static approximation has been used to contrast a model. According to this approximation the tissue does not contain the current sources and the displacement currents can be neglected [9].

Laplace's equation was used as the basic equation for the calculation of the voltage: $-\nabla(\sigma\nabla V) = 0$, where V is voltage. The boundary conditions are V=35V on the electrode surface and V=0 on the external borders. The current density is determined by means Ohm's law: $\overrightarrow{J} = \sigma\overrightarrow{E} + j\omega\overrightarrow{D}$.

Heat transfer equation is used to construct the change in potential and temperature distribution in the tissue during ablation:

$$\rho c_p \frac{\delta T}{\delta t} + \nabla(-k\nabla T) = \rho_b c_b \omega_b (T_b - T) + Q, \tag{1}$$

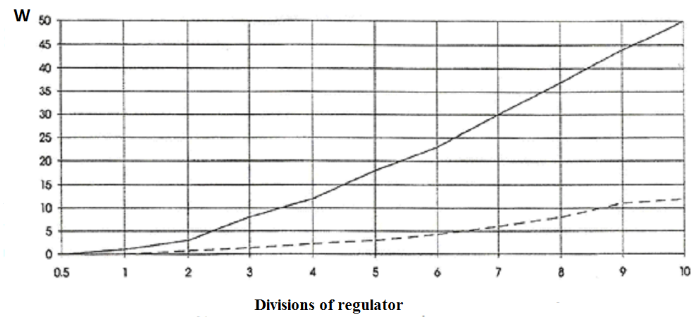


Figure 4: Output power of ELMED BC 50 M/M

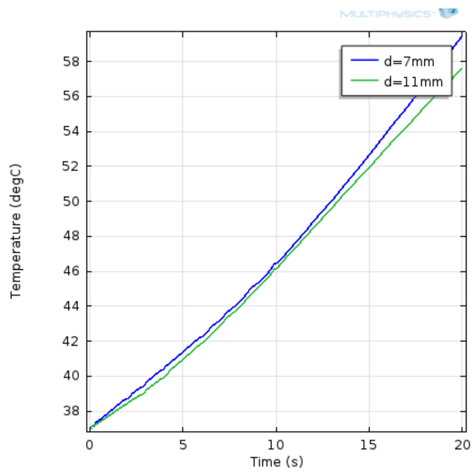


Figure 5: Temperature distribution during RF ablation within 20 s

where ρ is a tissue density, ρ_b is blood density, c_ρ is the tissueпїЅs specific heat, c_b is the bloodпїЅs specific heat, c_b is a tissue temperature, k is the thermal conductivity of tissue, ω_b is perfusion rate, T_b - the arterial blood temperature, Q is the heat source. The constant temperature at the electrode is equal to the blood temperature.

The degree of tissue injury α is calculated according to the Arrhenius equation: $d\alpha/dt = Ae^{(-dE/RT)}$, where A is the frequency factor $(s-1)$, dE is the activation energy (J/mol). These parameters are dependent on the type of tissue. The temperature of the electrode depends on the voltage applied to the electrode. If a sufficient value is not reached, the cancerous tissue is not totally destroyed. At the temperature more than 100^oC the boiling and carbonization of tissue occur, causing the conductivity to decrease rapidly. An efficiency of the procedure is reduced in this case.

The time of 20 seconds was selected for computer simulation of RFA to determine the optimal procedure duration. The selected value of the power at the electrodes for voltage of 35V corresponds to the division 4 of regulator (fig. 4).

The volume of coagulated tissue for a given time is calculated by means of developed simulation. Within the 20 seconds, the temperature at the electrode reaches 168^oC, when the temperature of 58^oC is reached at the tissue volume with diameters of $11mm$ and $7mm$ (see fig. 5).

The simulation was compared to experiments conducted on the preparations of the removal thyroid glands and/or their fragments. Objects were delivered after the surgical treatment and were subjected to RFA immediately. Size of nodes was measured pre and post manipulation. They were divided in such a way that one part was subjected to RFA and the other part was used for the internal control. All changes in the tumor and surrounding tissue were carefully fixed into the research protocol. After the macroscopic analysis the routine histological study and comparison with the control were carried out. Results are presented in table 1.

Table 1: Experimental measurements of the RF lesion size within 20 s

node diameter 1	**node diameter 2**	**lesion diameter 1**	**lesion diameter 2**
11	11	9	7
11	11	4	2
10	5	4	2
15	8	6	5
12	8	6	8
20	20	7	5
10	8	5	5
8	6	3	2
12	10	10	5
17	17	10	7
6	6	6	6
10	14	7	4
6	6	6	6

The table of experiment demonstrates that the real size of the destruction can be significantly smaller than the calculated one. This can be explained by the fact of the electrical characteristics dependence on the time and temperature of electrode heating. If the temperature at an electrode reaches values greater than 100^oC, tissue properties change and its electrical conductivity is reduced. Any change to the conductivity of the tissue surrounding the ablation electrode can cause in the delivered energy. The effectiveness of the procedure is reduced as a result. Additionally blood perfusion is reduced due to coagulation of microvessels a result of increased temperature [10]. It also affects the electrical properties of tissues and establishes difficulties for simulation. Sometimes, a second RFA procedure is required for complete removal of the node. To accomplish this, it is necessary to get a new ultrasound image of node, analyze it and perform simulation according to obtained data [11].

4 The general scheme of the simulation of RFA procedure

The developed technique of the computer simulation of radiofrequency ablation of the thyroid lobe is represented in diagram (fig. 6). The tracing of cross-sections of thyroid lobe was performed to determine the spatial position of the segmented region. After that the description of contours has been completed. Position of the scanning plane and

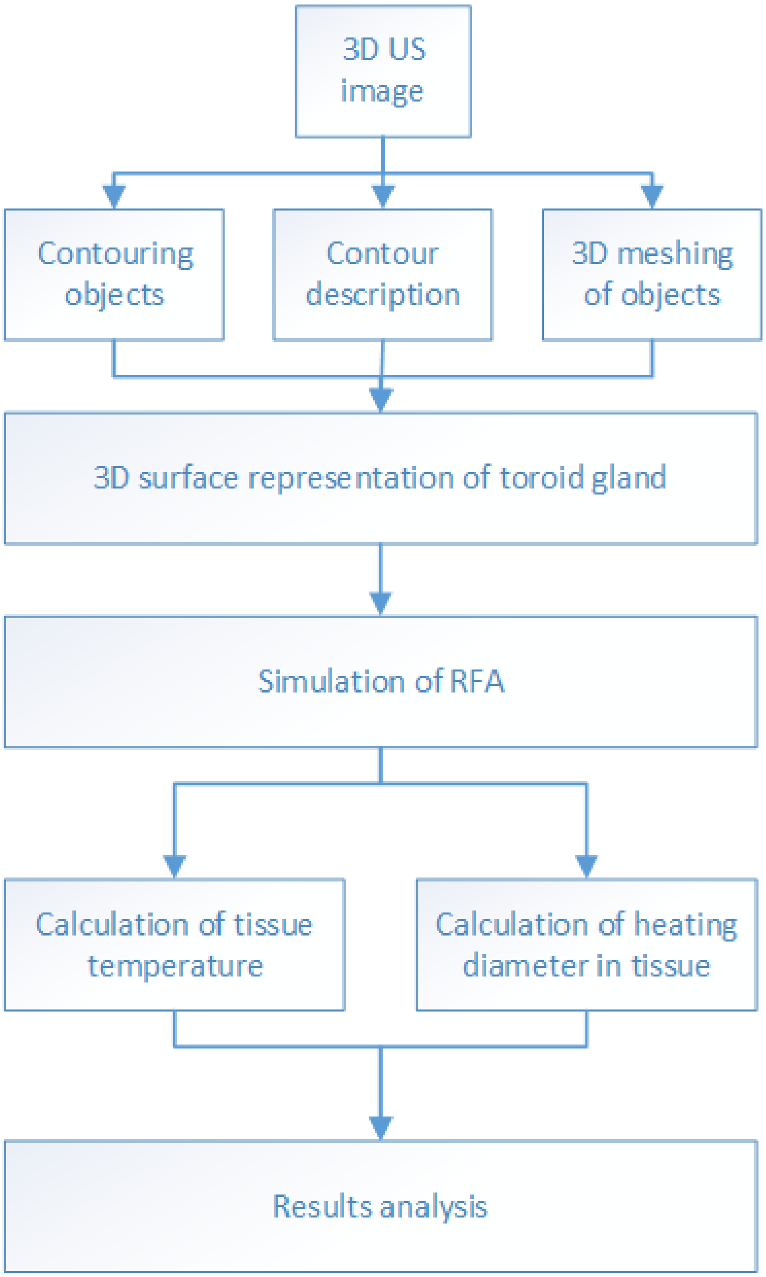


Figure 6: Temperature distribution during RF ablation within 20 s

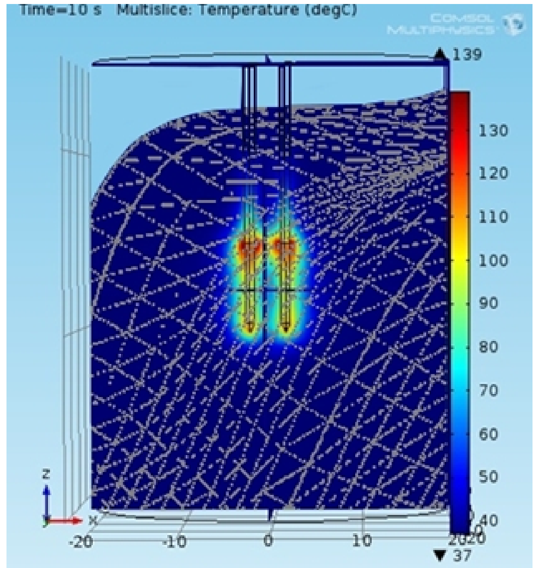


Figure 7: Simulation of temperature changing in tissue

position of the boundary points were defined for this purpose. Then the one-parameter interpolation and approximation splines were constructed according to points of the contour tracings. The form of selection has been described more accurately because of this.

Surface in the vector representation was obtained as a result. It can be converted into a format supported by simulation package. The computer simulation of RFA procedure was constructed on the basis of the three-dimensional surface. This simulation allows determining the optimal parameters of heating tissue: electrode voltage, the duration of the procedure and the size of the source of destruction corresponding to these parameters.

The automated constructing technique of RFA simulation procedure of thyroid lobe was obtained as a result(fig. 7).

5 Conclusion

The proposed technique of simulation would allow pretreatment identifying the zone of thermal damage with consideration with tumor geometry (fig. 7). The obtained simulation takes into account the shape of investigated thyroid lobe and time-temperature changes in electrical properties of tissue. Therefore, it provides more accurate information about the process of destruction of the tissue during the RFA procedure. Clarification of the form affects the simulation result by the finite element method and facilitates the analysis of temperature changes in the given volume.

The simulation results correlate with the results of the practical experiment. It proves the possibility of the practical application of this simulation for the planning of RFA. This technique can be used for the individual approach to the surgical planning. It can significantly reduce the risks and help to determine sequence of actions for the best quality of the operation.

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