Electro Thermal Performance Prediction of Radio Frequency Ablation System for Efficient Cancer Treatment

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Abstract: Cancer causes significant human deaths and is increasing due to increase in life expectancy and lifestyle. Radiofrequency ablation is an encouraging procedure for cancer treatment. The objective of this paper is to demonstrate the multiphysics simulation methodology and COMSOL capability for the radio frequency (RF) ablation procedure planning and simulation. This report briefly summarizes the problem description, governing equations, modeling methodology, assumptions, simulation results and discussion related to the thermal performance prediction of radio frequency ablation on a homogeneous tissue model. The electromagnetic interaction with biological tissue and thermal ablation coupling are highlighted. Effects of single electrode and two electrode energized simultaneously at parallel angles are investigated and reported. The main problem addressed in this paper is the prediction of temperature distribution of biological tissue due to Radio frequency energy of electrodes placed at various interval, angle, power and exposure time. This is critical to estimate and monitor the procedure to ablate only the defective tissues as identified by the physician. The simulation potential for the development safe procedure planning and protocol is highlighted.

Keywords: Cancer treatment, cancer ablation, RF heating, Electromagnetic heating, bio heating, coupled heat transfer, liver tissue, ablation.

1.0 Introduction

Radiofrequency ablation is an interventional technique, which is increasingly used for cancer treatment [1-5]. The COMSOL simulation capability for the coupled electromagnetic and heat transfer capability is leveraged for efficient planning of the procedure for ablation. A typical single and twin electrode parallel configuration for cancer ablation is investigated. The numerical simulation was performed by an equivalent electrical potential as prescribed by the manufacturers and is applied to the electrode. Coupled RF and thermal simulation is then performed with appropriate boundary, mesh conditions to predict the transient temperature built-up. The transient performance was predicted for the given exposure time. The contour plot of electrical potential and temperature distribution for the given probe configuration is reported.

The objective of this paper is to demonstrate the multiphysics simulation methodology and capability for the radio frequency (RF) ablation procedure. This paper briefly summarizes the problem description, governing equation, modeling methodology, assumptions, simulation results and discussion related to the thermal performance prediction of cool tip radio frequency ablation. The electromagnetic interaction with biological tissue and thermal ablation coupling are highlighted.

The main problem addressed in this report is the prediction of temperature distribution of biological tissue due to Radio frequency ablation. The overall objective of thermal distribution prediction is to be consistent with manufactures specification for a given ablation system. Radiation frequency ablation for Covidien Cool-tip Single and Twin configuration is considered for this coupled electro thermal investigations.

2.0 Governing Equations

Radio frequency ablation utilizes ac current and induces heat into the tissue by conversion of electrical energy into thermal energy. The radio frequency electrical conduction of the tissue is governed by the Laplace's equation in a quasistatic electrical conduction model, in which V is electrical potential.

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} = 0$$

The heat transfer in the tissue is governed by the Bio heat equation,

$$\nabla \cdot k\nabla T + \dot{q} + Q_m - Q_p = \rho_t c$$

Q_m and Q_p represent the metabolic heat generation and the heat loss due to blood perfusion. T, is the temperature, k is, the thermal conductivity. The source term in the bio heat equation is related to the electrical potential as follows.

$$q = \mathbf{j} \cdot \mathbf{E} = \frac{1}{\sigma}\left[\left(\frac{\partial V}{\partial x}\right)^2 + \left(\frac{\partial V}{\partial y}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2\right]$$

The temperature distribution in the tissue due to the propagation of radiofrequency electrical energy is obtained by solving the above coupled equations. The coupled electrical conduction and heat transfer is a predefined multiphysics solution in COMSOL with Heat transfer and Radio frequency module, which is used for solving the above coupled problem.

Radiation frequency ablation system operates at a frequency range of around 500 kHz. The Cool-tip™ RF Ablation Systems operating frequency is 480 kHz [1]. The electrical properties of the tissue depend on the composition and structure and are dispersive. The electrical properties of the tissue for the given frequency determine the joule heating and temperature distribution. Accurate properties are critical for the prediction of temperature distribution. The properties published elsewhere for liver tissue at 500 kHz is used in this simulation.

Table 1: Electro thermal properties of liver Tissue at 500 kHz

Liver Property	Symbol	Unit	Value
Relative permittivity	εr (500 kHz)	c	2770
Dielectric conductivity	σ (500 kHz)	S/m	0.36
Thermal conductivity	k	W/mK	0.512
Blood perfusion coefficient	ωb	1/s	0.017

3.0. Simulation methodology

Cool-tip™ RF Electrode Kits, Single model ACT1530 with length of 150mm and an exposure of 30 mm is modeled. Liver tissue 3D volume of around 120 mm deep axisymmetric segment was modeled with appropriate boundary conditions. The electrode center of the exposure is positioned at the center of the Liver tissue Volume. A frequency of 480 kHz at 100 Watts energy output of the electrode is considered. Appropriate boundary conditions and mesh convergence investigations were performed prior to the coupled electromagnetic and thermal simulation. A frequency dependent electrical and steady state thermal simulation was performed. The thermal and electrical field potential results were post processed. The single and twin electrode configuration was used to evaluate the heating performance. An equivalent electrical potential as prescribed by the manufacturers is applied to the probe. Coupled RF and thermal simulation is then performed with appropriate boundary, mesh conditions to predict the transient temperature built-up. The transient performance was predicted for a time of about 12 minutes. The simulation methodology along with parametric modeling capability of COMSOL can be used for further optimization and post processing.

4.0 Results and Discussion

The heating performance results of single and twin probes are shown in this section. The coupled electrothermal performance results are reported. The temperature distribution and electrical potential distribution are highlighted. Figure 1 to 3 shows the temperature distribution for the single electrode configuration at 100 W power rating. Figure 3 shows the iso surface distribution.

Figure 4 to 7 shows the typical contour plot of electrical potential and temperature distribution for a twin probe parallel configuration for 100 W power setting.

The main objective of this investigation is to highlight the multiphysics simulation capability for optimization of ablation procedure. These results show good agreement with previous investigations and published results [2-5]. The results can be further post processed for export of iso-surface and other contour temperature data for further processing. The base model can then be extended for various manufacturers, transient condition, frequency intervals, multiple probes and other ablation systems. The simulation methodology and results thus can be used for planning the RF ablation procedure.

Figure 1. Typical Temperature distribution for a frequency of 480 kHz at 100 W output.

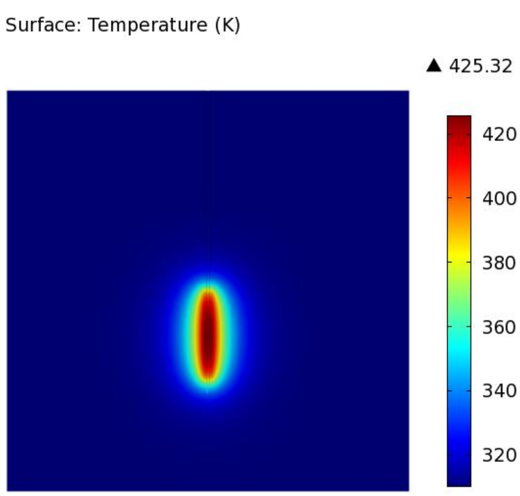


Figure 2. Typical continuous (left) and contour bands (right) of Temperature distribution.

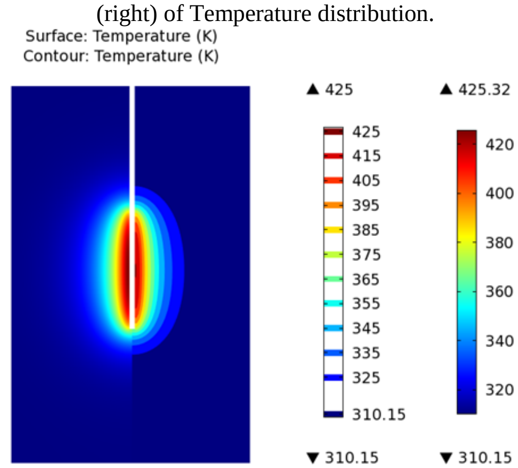


Figure 3. Iso surface distribution for a temperature of 333 oK at a frequency of 480 kHz and 100 W output.

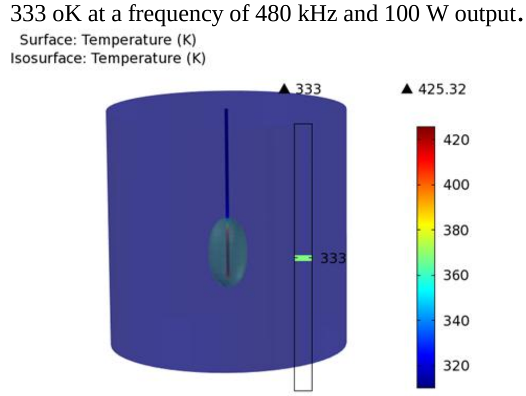


Figure 4 Typical electrical potential distribution for the twin probe configuration

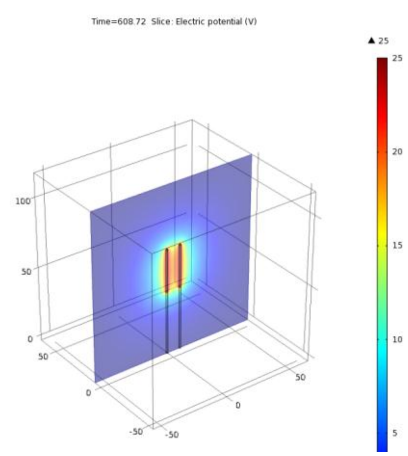


Figure 5 Typical temperature distribution contour plots for the twin probe configuration

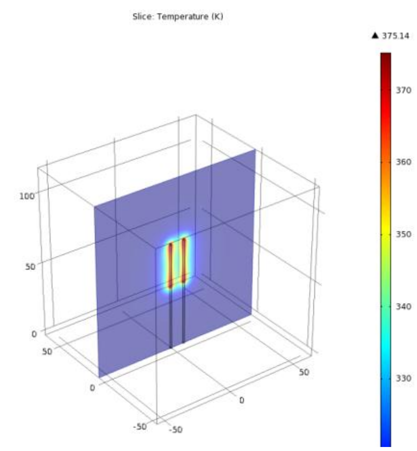
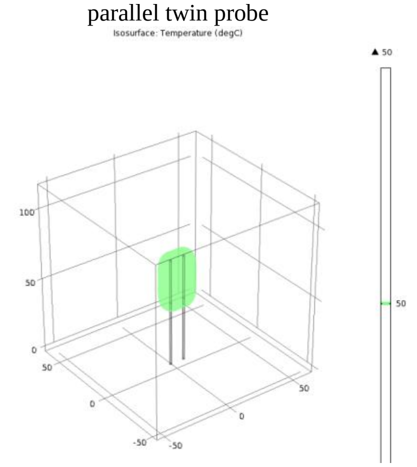


Figure 7 Typical 50oC Temperature isosurfaces for a parallel twin probe



5.0 Conclusions

A brief about Radiofrequency ablation, an interventional technique for cancer treatment was given. . The COMSOL simulation capability for the coupled electromagnetic and heat transfer capability was leveraged for efficient planning of the procedure for ablation. The problem description, governing equation, modeling methodology, material properties, assumptions, simulation results and discussion related to the thermal performance prediction of cool tip radio frequency ablation was given. The electromagnetic interaction with biological tissue and thermal ablation coupling were highlighted. A typical single and twin electrode parallel configuration for cancer ablation was investigated. Coupled electrothermal simulation was performed with appropriate boundary, mesh conditions to predict the transient temperature built-up. The contour plot of electrical potential and temperature distribution for the given probe configuration was reported. The simulation results showcased the modeling capability and advantages of coupled electrothermal simulation for planning optimal and safe RF ablation

6.0 References

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7. Acknowledgements

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