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

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Introduction

- Cancer causes significant human deaths and is increasing due to increase in life expectancy and lifestyle.

- Radiofrequency ablation (RFA) 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 ablation procedure planning and simulation.
RF Ablation

- Radio frequency ablation utilizes ac current and induces heat into the tissue by conversion of electrical energy into thermal energy.

- Temperature control of the tissue is critical for safe and efficient treatment.

- Simulations to plan a safe procedure.

Picture from: http://www.surgery.usc.edu/divisions/hep/radiofrequencyablation.html
Governing Equation

• The RF electrical conduction of the tissue is governed by the Laplace’s equation

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

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

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

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

which \( V \) is electrical potential. \( Q_m \) 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.
Design and Simulation

- 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.

Picture from http://www.cool-tiprf.com/electrodes.html
DoE Design and Simulation

• A frequency dependent electrical and Transient thermal simulation was performed.
• 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
• DoE: Input energy, time duration, Angle, Distance between electrode, exposure length
Electro Thermal Properties of Liver

- RF ablation system operates at a frequency range of around 500 kHz.
- The Cool-tip™ RF Ablation Systems operating frequency is 480 kHz.
- The electrical properties of the tissue depend on the composition and structure and are dispersive.

<table>
<thead>
<tr>
<th>Liver Property</th>
<th>Symbol</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative permittivity</td>
<td>$\varepsilon_r$ (500 kHz)</td>
<td>c</td>
<td>2770</td>
</tr>
<tr>
<td>Dielectric conductivity</td>
<td>$\sigma$ (500 kHz)</td>
<td>S/m</td>
<td>0.36</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>$k$</td>
<td>W/mK</td>
<td>0.512</td>
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<tr>
<td>Blood perfusion coefficient</td>
<td>$\omega_b$</td>
<td>1/s</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Electro thermal properties of liver tissue at 500 kHz
Results and Discussion

- The coupled electro thermal performance results are reported.
- Input energy, time duration, exposure length were investigated.
- The heating performance results of single probe.
- The temperature distribution and electrical potential distribution are highlighted.

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

Iso surface distribution for a temp of 333 oK at a frequency of 480 kHz and 100 W output.
Results and Discussion

- **3D Model**: Twin electrode configuration
- **Parameters**: Input energy, time duration, Angle, Distance between electrode, exposure length
- **Output**: Temperature distribution

![Typical electrical potential distribution contour plots](image1)

![Typical temperature distribution contour plots](image2)

![Typical 50°C Temperature isosurfaces plots](image3)
Conclusion

• A brief about Radiofrequency ablation, an interventional technique for cancer treatment was given.

• Coupled electrothermal simulation methodology

• A typical single and twin electrode parallel configuration for cancer ablation was investigated.

• The simulation results showcased the modeling capability and advantages of coupled electrothermal simulation for planning optimal and safe RF ablation