Abstract: Due to the restriction of the number of probes that a patient can tolerate and the inaccurate information provided by the invasive temperature measurements, which provide information only at discrete points, a mathematical model simulation is more effective to help physicians in planning their thermal treatment doses. This simulation will maximize therapeutic effects while minimizing side effects. Prior to the treatment, it will provide a precise idea of the predicted reaction depending on selected doses; so new treatment strategies can be proposed and evaluated.

The objective of this study is to simulate the Laser Interstitial Thermal Therapy in Treatment (LITT) of brain tumors. The thermal effect of the laser during coagulation lasts around one second and its temperature is between 50 and 90°C. LITT has the following results; the desiccation and retraction of the tissue to destroy tumor phenomena.

Keywords: Laser Interstitial Thermal Therapy in Treatment, thermal damage, brain cancer, bioheat transfer simulation.

1. Introduction

COMSOL Multiphysics Simulation Software will be used to simulate the mathematical model which includes thermal conduction (based on either Fourier’s law or modified Fourier’s law), constant blood perfusion and evaporation as a boundary condition. The Heat Transfer Module will be used with a material library model for brain and probe solid materials. The Brain material with tumors will be defined with their density, conductivity, specific heat, diffusivity, relative permittivity, relative permeability and electrical conductivity values. A new material Laser delivery probe will also be defined as source energy.

Expected results are thermal distribution throughout the biological tissues during the heating and temperature distribution. We will also compare thermal conduction results on Fourier’s law vs. modified Fourier’s law. An expected result is the estimation of the volume of tissues damaged during the treatment.

Furthermore predicting the result of the laser interstitial thermal therapy in treatment of brain cancer depending on scenarios discussed between physicians and patients will improve the health care system by providing a personalized and focused treatment. Using the laser energy source, light is emitted from a diffusive tip of an optical fiber probe that is inserted into the center of a brain tumor.

Using COMSOL v5.1, we build apps for physicians’ use. Our COMSOL Multiphysics model is turned into an application with its own interface using the tools provided with the Application Builder desktop environment. Physicians will use their laptops or smart phones to access and run the application remotely.

2. Materials and Methods

2.1 Simulation model

A cylinder 2.54 cm radius by 2.54 cm thickness Brain tissue, as shows in Figure 1, is heated up to 10 seconds by a 5 W laser. The initial temperature of the brain tissues is considered 293.15 K. The tissue is modeled...
as a Cylinder of radius $r_{\text{pot}}$ and height thickness, 3D, Bioheat Transfer (ht), Time dependent of range (0,0.1,15) seconds. These values can be changed by the user of the model to simulate in real-time.

![Figure 1. A cylinder 2.54 cm radius by 2.54 cm thickness Brian tissue is heated up to 10 seconds by a 5 W laser.](image)

**2.2 Laser procedure**

The laser beam [6] is modeled as a heat source in the plane with Gaussian profile gp1 (figure 2). This model uses the built-in Gaussian Pulse functions, which enforces that the integral under the curve equals unity. The emissivity of the surface of the brain tissue is approximately 0.8. At the operating wavelength of the laser, it is assumed that absorptivity equals emissivity. The heat load due to the laser is multiplied by the emissivity.

![Figure 2. The Gaussian Pulse with location 0 and Standard deriation equal $r_{\text{spot}}$.](image)

The waveform function wv1 is a Triangle with Angular frequency and Phase equal 0 and the Amplitude equal 1.

We used from the COMSOL library, an analytic heat function hf is defined as following (figure 3):

$$hf(x,y,t) = P_{\text{laser}} \ast gp1(x - wv1(t)) \ast gp1(y)$$

Where $P_{\text{laser}}$ is the source power, $gp1$ is Gaussian pulse function, $wv1$ is the waveform function.

![Figure 3. Analytic heat function hf.](image)

**2.3 Modeling in COMSOL Multiphysics**

**2.3.1 Geometrical description of the model**

We will start with the thermal conduction using Fourier’s law for our first step of the simulation (results presented here) then upgrade to the modified Fourier’s law. We will then compare the results of these two simulations.

**2.3.2 Heat distribution**

The LITT of Brain Tumors was modeled by the bio-heat equation in a 3D geometric study, using the bioheat transfer application mode with time dependent COMSOL 5.1.
Table 1 describes the physical parameters used by our Comsol numerical simulation.

**Heat Equation**

\[
\rho C_p \frac{dT}{dt} + \rho C_p \mathbf{u} \cdot \nabla T + \nabla \mathbf{q} = Q + Q_{bio}
\]

\[
\mathbf{q} = -k \nabla T
\]

Where \( T \) is temperature (K), \( C_p \) is the heat capacity \( J/(kg*K) \), \( \rho \) is the density of the brain tissue \( (kg/m^3) \), and \( k \) is the thermal conductivity of brain tissue \( (W/(m*K)) \), \( Q \) is heat source, \( Q_{bio} \) is the perfusion and metabolic heat source.

**The Perfusion Equation**

\[
Q_{bio} = \rho_b C_s \omega_b (T_b - T) + Q_{met}
\]

Where \( Q_{bio} \) is the perfusion and metabolic heat source, \( \rho_b \) is the blood Density, \( C_s \) is Specific blood heat, \( Q_{met} \) is Metabolic heat source, \( \omega_b \) is Blood perfusion rate, \( T_b \) is the blood flow rate, \( T \) is time \( (s) \), \( Q_{met} \) is the metabolic heat source.

Table 1. Settings of Qbio parameters.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial blood temperature</td>
<td>310.15[K]</td>
</tr>
<tr>
<td>Specific heat, blood</td>
<td>3650[J/(kg*K)]</td>
</tr>
<tr>
<td>Blood perfusion rate</td>
<td>0.866[l/s]</td>
</tr>
<tr>
<td>Density, blood</td>
<td>1035 kg/m³</td>
</tr>
<tr>
<td>Metabolic heat source</td>
<td>0</td>
</tr>
</tbody>
</table>

We consider that the metabolic heat and external heat sources are negligible in respect to the laser inducted heat.

The initial temperature of the brain tissues was considered as \( T_0=293.15 \) K.

The thermo-optical parameters were considered constant during the thermal process.

2.3.3 **Mesh**

The brain tissue is meshed using a triangle swept mesh as shown in Figure 4.

Figure 4. Mesh of the model simulation.

2.3.4 **Thermal damage**

We used integrated Thermal damage function on the Heat Transfer Module. Simulation includes damage integral analysis from Energy absorption. The Parameters Frequency factor and Activation factor are defined in table 2. The damage is calculated from the Arrhenius law:

We used the following defined functions used on the COMSOL 5.1:

Fraction of necrotic tissue:

\[
\theta_d = \min(\max(0.1 - e^{-\alpha}), 1)
\]

Where \( \alpha \) is a Discontinuous Lagrange (constant) shape function (which describes the degree of tissue injury).
Table 2: The Physical parameters used in our COMSOL numerical simulation. (Thermal properties of brain from [9])

<table>
<thead>
<tr>
<th>Name</th>
<th>Expression</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_{mat}$</td>
<td>1[in]</td>
<td>0.0254 m</td>
<td>material inner radius</td>
</tr>
<tr>
<td>Thickness</td>
<td>25400[um]</td>
<td>0.0254 m</td>
<td>mat inner thickness</td>
</tr>
<tr>
<td>$r_{spot}$</td>
<td>8[mm]</td>
<td>0.008 m</td>
<td>Radius of laser spot size</td>
</tr>
<tr>
<td>$P_{laser}$</td>
<td>5[W]</td>
<td>5 W</td>
<td>Laser power</td>
</tr>
<tr>
<td>Period</td>
<td>10[s]</td>
<td>10 s</td>
<td>Time of laser to move back and forth</td>
</tr>
<tr>
<td>Emissivity</td>
<td>0.8</td>
<td>0.8</td>
<td>surface emissivity of mat1</td>
</tr>
<tr>
<td>Temp</td>
<td>310.15[K]</td>
<td>310.15 K</td>
<td>Initial Temperature</td>
</tr>
<tr>
<td>Heat Capacity</td>
<td>3636[J/(kg * K)]</td>
<td>3636[J/(kg * K)]</td>
<td>Brain Heat Capacity</td>
</tr>
<tr>
<td>Density</td>
<td>1050[kg/m^3]</td>
<td>1050[kg/m^3]</td>
<td>Brain Density</td>
</tr>
<tr>
<td>Thermal conductiviy</td>
<td>0.51[W/(m^2*K)]</td>
<td>0.51[W/(m^2*K)]</td>
<td>Brain Thermal conductiviy</td>
</tr>
<tr>
<td>A</td>
<td>7.39e39[1/s]</td>
<td>7.39e39</td>
<td>Frequency factor</td>
</tr>
<tr>
<td>dE</td>
<td>2.577e5[J/mol]</td>
<td>2.577e5</td>
<td>Activation energy</td>
</tr>
</tbody>
</table>

3. Simulation Results

During the simulation, the physician can play with the input values to Control the thermal ablation during a laser surgery/cancer treatment.

Figures 5 to 8 show the heat distribution during the simulation which will help physicians to predict and organize the treatment.

Figure 5. Temperature during 15 seconds at the Surface of the Brain Tissue.

Figure 6. Temperature during 15 seconds at the Surface of the Brain Tissue (Isothermal Contours (lt)).

Figure 7. Global Max/Min/Average Temperature (K) of the Tissue during 15 seconds.

Figure 8. Global Temperature difference (K) of the tissue during 15 seconds.
Such model shows also the impact of the thermal damaged tissues during the simulation.

Figures 9 to 11 show the fraction of the necrotic tissue, the degree of tissue injury.

4. Apps for physicians’ use

Using Comsol v5.3, we build apps for physicians’ use. Our COMSOL Multiphysics model is turned into an application with its own interface using the tools provided with the Application Builder desktop environment. Physicians will use their laptops or smart phones to access and run the application remotely (Figures 11 and 12).
5. Conclusion

Controlled thermal ablation is a big challenge during a laser surgery/cancer treatment. A tool to help physicians predict and organize the treatment will be helpful.

In this paper, we proposed a simulation model of the LITT with physicians’ interaction via Comsol Apps. Such model shows the impact of the heat distribution and thermal damage of the tissue during the simulation.

6. References

5. Comsol, Introduction to Comsol Multiphysics. 5.0 And Introduction to Application Builder, Comsol 5.1.