Laser Interstitial Thermo Therapy (LITT) for Prostate Cancer: Animal Model, Numerical Simulation of Temperature and Damage Distribution

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Background: Laser Interstitial Thermotherapy (LITT)

- Minimally invasive thermal technique
- Addressed to coagulate deep and solid tumors
- Tested in various tumors: breast, brain, kidney, Liver, and recently for low risk prostate cancer
Applications of LITT in the Unit 703

- In liver metastases (guidance with real-time MR images) 

- Development of new diffusing fibers used for LITT method 
  (patent pending No. 08008613.5)

- Pro-LITT project: Development of a protocol on a pre-clinical model of *prostate cancer* using LITT method
Objective

- Heat extent in prostate tissues
- Volume of necrosis estimated after prostate thermal laser treatment
Material and Methods: Experimental model (1/3)

Copenhagen rat
Material and Methods: Experimental model (2/3)

- Diode laser unit (Pharaon 980, Osyris)
  Wave length of 980 nm
- Diffusing fiber:
  (10 mm, d = 500 µm)
- Maximal power output 5 W
- Diffusion time = 75 s
- Maximum temperature measured = 155°C
MR images performed after 48h
Material and Methods: Simulation model (1/4)

- COMSOL Multiphysics 4.0

1 – Geometry: Dimensions

- Tissues (70 mm × 70 mm × 20 mm)
- Fiber (L=10.0 mm, d=500 µm)
Material and Methods: Simulation model (2/4)

2 – Heat distribution

\[ C_p \cdot \frac{\partial T}{\partial t} - \nabla \cdot (k \cdot \nabla T) = w_b \cdot C_p \cdot [T_b - T] + Q_{\text{met}} + Q_{\text{ext}} \]
Material and Methods: Simulation model (3/4)

3 – Thermal damage

\[ \Omega(r, \tau) = A_f \int_0^\tau \exp \left( \frac{-E_a}{RT(r,t)} \right) \, dt \]

Activation energy

Frequency factor

Universal gas constant

\[ \Omega(r, \tau) \begin{cases} 1 & (100\% \text{ destroyed tissues}) \\ 0 & (100\% \text{ healthy tissues}) \end{cases} \]
Material and Methods: Simulation model (4/4)

Physical parameters of the rat used in numerical simulation:

<table>
<thead>
<tr>
<th>$\lambda = 980\ nm$</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C\ (J.g^{-1}.{\circ}K^{-1})$</td>
<td>4.20</td>
</tr>
<tr>
<td>Thermal coefficients</td>
<td>$\rho\ (g.mm^{-3})$</td>
<td>$0.999 \times 10^{-3}$</td>
</tr>
<tr>
<td></td>
<td>$h\ (W.mm^{-1}.{\circ}K^{-1})$</td>
<td>$5.52 \times 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>$w_b\ (ml.g^{-1}.min^{-1})$</td>
<td>0.10</td>
</tr>
<tr>
<td>Tissue Damage Coefficients</td>
<td>$A_f\ (s^{-1})$</td>
<td>$1.50 \times 10^{101}$</td>
</tr>
<tr>
<td></td>
<td>$E_a\ (J.mole^{-1})$</td>
<td>$6.33 \times 10^{5}$</td>
</tr>
<tr>
<td></td>
<td>$R\ (J.mole^{-1}.{\circ}K^{-1})$</td>
<td>3.41847</td>
</tr>
</tbody>
</table>

Results

1 – Heat distribution
Results

2 – Thermal damage

Volume of region damaged at 50 °C after 75 sec
## Results

<table>
<thead>
<tr>
<th></th>
<th>Experiment</th>
<th>Simulation</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum heat diffused</strong></td>
<td>155°C</td>
<td>156.6°C</td>
<td>≈ 1%</td>
</tr>
<tr>
<td><strong>Volume of thermal damage</strong></td>
<td>0.98 ± 0.05 cm³</td>
<td>1.00 cm³ when T=50°C,</td>
<td>&lt; 1%</td>
</tr>
</tbody>
</table>
Conclusions

- LITT treatment of prostate cancer is a promising method

- The heat extent in tissues and thermal damage can be estimated by simulation

- Results presented from simulation are in good agreement with the experimental results

- This therapy needs further evaluation and understanding of the heat extent in tissues to become a surgical method applied in a routine hospitalization²
THANK YOU
QUESTIONS ?