Magnetic resonance guided laser thermal therapy with finite element simulation for treatment planning

A. Elliott[1], A. M. Shetty[1], R. McNichols[2], D. Fuentes[1], J. D. Hazle[1], and R. J. Stafford[1]

[1]Imaging Physics, M.D. Anderson Cancer Center, Houston, Texas, United States, [2]Biotex Inc., Houston, Texas, United States

Introduction:

Image-guided laser induced thermal therapy using actively cooled applicators provides a potentially minimally invasive alternative to conventional surgical interventions in regions such as the brain [1]. Active cooling allows for more controlled heating of tissue, this in turn helps eliminate tissue charring. In the brain, MRI provides a method by which to effectively plan, monitor and follow-up treatments with imaging results and FDA approved MR-guided laser therapy systems are already in use [2]. Real-time MR temperature imaging in conjunction with appropriate dose models can provide a method for controlling and predicting outcomes. In order to optimize the safety and efficiency of these procedures, rapid and accurate prospective 3D treatment planning could assist in the optimal placement of the laser applicator in the patient given the target size and location, surrounding critical structures and equipment capabilities. In this work, we evaluate the finite element solution of the bio-heat equation to predict the thermal distribution *in vivo* for ablation of normal brain tissue in a canine model using a commercially available MR-guided laser ablation system. Lesions of varying sizes were generated in the dogs using several treatment régimes and the spatiotemporal temperature measured by MR temperature imaging; these were modeled using a commercial finite element program (COMSOL Multiphysics® Burlington, MA 01803).

Methods:

A total of six dogs were used in the study which was carried out according to institutional protocol. MRI temperature imaging was carried out using a 1.5T MRI (ExciteHD®, General Electric, Milwaukee, WI). MR temperature imaging was performed using a 5-slice 8-shot 2D EPI sequence (FA= 60°, FOV= 20x20cm, slice thickness 4.0mm, encoding matrix of 256x128, TR/TE=544/20 ms with 5 sec per update). In the operating room, applicators were placed through a small burr hole and secured to the head using a skull bolt based on previously acquired planning images. After transfer to the MR suite, final position of the laser catheter determined based on planning images. Laser powers and exposure times were varied in order to effect different sized lesions. T2-weighted images of the treatment region were segmented to separate brain, muscle and cranial fluid. These were imported into Comsol, meshed and given values for their respective physical quantities of density, specific heat, perfusion etc. Finite element processing used a triangular mesh with the size of each triangle being on the order of millimeters. We accounted for perfusion in the brain only because no other tissue was heated. For speed, the elongated laser diffuse source was simulated as a series of point sources and the optical diffusion approximation (ODA) applied to the region. The effect of the laser cooling fiber was simulated using the region of the applicator as seen on the MRI held at the constant temperature of the reservoir as a first order approximation.

Results:

Figure 1 shows the MRTI derived temperature measurements at the end of therapy superimposed onto the magnitude image for one subject. The maximum temperature change was 97.7°C. Figure 2 shows the corresponding finite element image. The positioning of the source in relation to surrounding anatomy greatly impacted the symmetry of heating from the laser catheter. Accurate estimates for brain perfusion were taken from [3]. The dashed line in figures 1 and 2 indicates where data was taken for comparison in figure 3. Figure 3 shows a profile of the finite element simulation superimposed over the experimental results; the average difference between the distributions for the model and experiment was 8%. The discrepancy was primarily in the region of the boundary condition of the applicator, where a very sharp gradient in temperature occurs.

Conclusions:

We have shown promising results that a simple finite element model of Pennes bioheat equation with the ODA approximation for photon propagation is sufficient for a first order approximation in predicting the heating associated with laser heating in the brain. Modeling of both the spatial distribution and maximum temperature reached was reasonable indicating that such techniques might be adapted to rapid treatment planning. While live MR temperature imaging does provide real-time control, prospective 3D treatment planning is still required to increase efficacy and minimize the need for multiple applicator placements.

References:

1. R. McNichols *et. al.* Int. J. Hyperthermia Vol. 20, No. 1 page 45-56 (2004)
2. A. Carpentier *et. al.* Neurosurgery Vol. 63 Supp.1, ON21-ON29 (2008)
3. C. Kennedy *et. al.* J. Neurochem. Vol. 19 page 2423-2433 (1972)

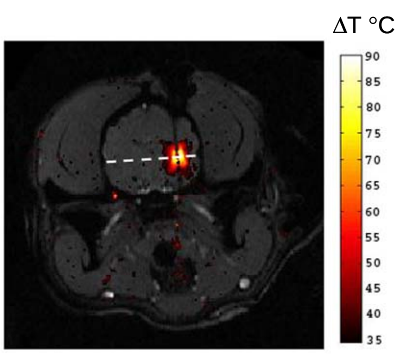

Figure 1: MRI of dog brain showing thermal distribution overlaid on magnitude image. Dashed line indicates where data was taken from for figure 3.

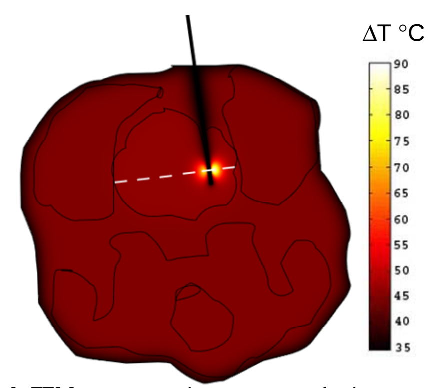

Figure 2: FEM temperature image generated using the geometry of dog brain as seen in figure 1. Dashed line indicates where data was taken from for figure 3.

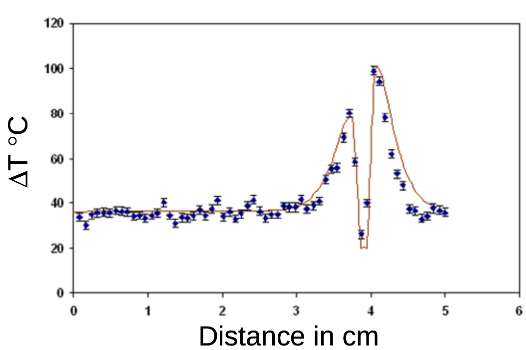

Figure 3: Comparison of profile data from experimental and FEM calculations. Base temperature was 35°C and the average discrepancy between FEM and experiment was 8%.