MR-guided Laser Induced Thermal Therapy in Normal Canine Brain: Pre-clinical Device Evaluation

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Introduction

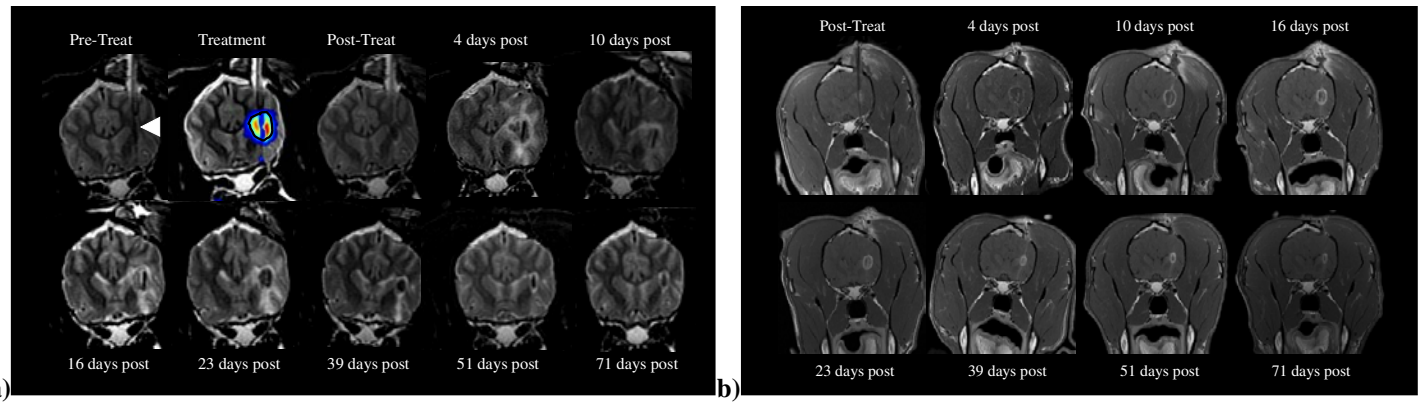
Due to the wealth of contrast mechanisms available for neuroimaging applications, MR image-guidance of interventional and intraoperative neurosurgical procedures is rapidly proving to be a potential method for both increasing the efficacy of these procedures as well as facilitating better outcomes. One particular benefit is that MR can provide a noninvasive measurement of the spatiotemporal temperature distribution using based on the temperature sensitivity of the water proton resonance frequency (PRF) shift [1]. This technique has been shown to non-invasively provide useful temperature feedback for control and dosimetry of thermal therapies in a variety of anatomical sites including the brain [2,3]. Using this MR temperature imaging (MRTI) feedback during minimally-invasive thermal ablative procedures facilitates a higher level of control than previously possible with rapid delivery of heat into a localized region of the brain, allowing much more aggressive and rapid heating techniques to be utilized safely in order to provide a highly conformal treatment. In this investigation, we finish a pre-clinical investigation of a diode laser ablation system's ability to safely and predictably ablate localized regions of normal brain tissue in a canine model using MRTI feedback to manually monitor and control the therapy in real-time. Serial MR imaging is used to follow the progression of damage normal brain tissue and results were verified with pathology.

Materials

Adult hound dogs (n=4) were anesthetized and a burr hole generated in the right parietal bone lateral to the sagittal suture and dorsal to the coronal suture (all animals in this study were handled in accordance to an Institutional Animal Care and Use Committee approved protocol). All imaging was performed on a 1.5T whole body MR scanner (EXCITE HD, GE Healthcare, Waukesha, WI) using an 8-channel, receive-only phased-array head coil (MRI Devices Corp, Gainesvill, FL). A 3D fast spoiled gradient-echo sequence was used to plan the fiber trajectory as well as verify the placement of a laser fiber into the frontal lobe of the brain. Final fiber positioning prior to treatment delivery was verified by a low power test pulse delivered under MRTI guidance. A 1-cm diffusing tip fiber encased in an actively cooled sheath (Biotex, Inc, Houston, TX) was used to deliver therapy. Real-time monitoring of the temperature changes was accomplished using a temperature sensitive echo-planar imaging sequence [5] in conjunction with parallel imaging [6] to obtain 5 planes of temperature images every 6 seconds. Temperature sensitive images were processed and displayed on a remote workstation to provide feedback during the procedure (Visualase®, BioTex, Inc, Houston, TX). Feedback included phase-difference images, an estimated region of coagulation based on an Arrhenius model of damage, and a magnitude image demonstrating anatomy. Control points placed by the user helped monitor the maximal heating near the laser as well as maximal heating near the edges of the lesion or near critical structures, with an option for automated reduction of the power if needed. During treatment, applied power was manually modulated (typically 6-15 W) by the user over time in order to obtain elliptical lesions of maximal dimension 1.5-2.0 cm along the fiber and 1.0-1.5 cm transverse to the fiber using the Arrhenius damage estimate from the MRTI feedback on the Visualase® system as a guide. Power was reduced when necessary to keep the temperature elevation near the fiber below 90ºC in order to prevent the possibility of charring the tissue and thereby ending the treatment. MR assessment of the treatment included T1-weighted pre- and post-contrast imaging, T2-weighted imaging with and without FLAIR, diffusion and perfusion imaging and susceptibility weighted imaging. Following treatment the animal was monitored for neurological deficits. Follow-up imaging occurred at 3-4 days post-therapy then at approximately weeks {1, 2, 3, 5, 7, 10}. Imaging ceased and the dog was sacrificed for pathological assessment of the lesion when changes in the damaged region slowed visibly on scans conducted at 3 week intervals.

Results

MR temperature imaging in the brain is extremely reliable and a much more accurate predictor of maximum lesion size (< 2 mm) as expressed in days 3-5 than other post-treatment imaging techniques applied immediately after treatment in this study. Lesion boundaries were extremely sharp with approximately CEM43>10 and T>47ºC correlating strongly with maximal lesion size as measured using post contrast T1-weighted images. Final measurements of lesion size from FLAIR and post-contrast T1-weighted images correlated well with observed pathological photographs of damage, depicting a thin (~2 mm) ring of edema surrounding the lesion. Edema and swelling of the region was not directly predictable from MRTI and tended to be more a function of lesion size and location.



a) b)

Figure 1: Typical results: (a) Longitudinal T2-weighted images of laser induced thermal therapy lesion in normal canine brain. Laser fiber (arrow on pre-treatment image) was positioned freehand using MR images for guidance. Typical laser induced lesion was generated measuring approximately 1.5-2.0 cm in maximum diameter using the Visualase® system to monitor the progression of the lesion during irradiation. The size of the lesion as estimated by thermal dosimetry from the real-time MR derived temperature images (black isodose line on Treatment image above) is a much better predictor of the maximum lesion size (visualized 4-days post-treatment) than T2-W or T1-W contrast enhanced (Figure 8 below) images taken after treatment. (b): Longitudinal T1-weighted contrast enhanced images of LITT lesion induced in normal canine brain. Resulting laser-induced lesions of the brain show a typical architecture with central necrosis surrounded by a rim of edema and eventually result in a cystic defect after resorptive and regenerative changes. Both T1 and T2 images taken prior to sacrifice correlate well with pathology photographs.

Conclusions

MR-guided laser induced thermal therapy in brain can be performed safely and with a fair degree of control when using MR temperature imaging guidance, despite the rapid heat deposition associated with the technique. MRTI is a good predictor of the maximal lesion size, allowing the power and time parameters to be made flexible in maintaining the conformality and safety of the treatment.

References

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