Reference-based realtime temperature and damage estimate maps for monitoring laser ablation of hepatic tumors under MRI

Anil Shetty[1], Hiroumi Kitajima[2,3], Tracy E. Powell[2,3], Michael A. Bowen[2,3], and Sherif Nour[2,3]

[1]*Visualase Inc, Houston, Texas, United States,* [2]*Department of Radiology and Imaging Sciences, Emory University Hospital, Atlanta, Georgia, United States,* [3]*Interventional MRI Program, Emory University Hospital, Atlanta, Georgia, United States*

Introduction & Purpose:

Laser-induced interstitial thermotherapy (LITT) is a minimally invasive ablative therapy, the heat induced coagulative effects of which lead to tumour destruction in solid organs. MR temperature imaging (MRTI) has been utilized to monitor laser ablation in the brain and prostate [1,2]. Ablative techniques like radiofrequency and microwave have been in use for hepatic tumors, but none have temperature monitoring capabilities due to interference in MR environment. Vogl et al; used lasers but without MRTI. This ability is crucial to perform targeted ablations near critical structures and evaluate coverage of large lesions. The purpose of the current study is to evaluate the feasibility of using real-time MR temperature imaging for laser ablation of hepatic tumors and to understand of use of post-MR imaging for confirmation of ablation coverage of targeted lesion.

Patients & Methods:

Laser ablations were performed in single or multiple tumors in 25 patients. The thermal monitoring was done with the Visualase Thermal Therapy System (Visualase, Inc., Houston, TX), which comprised a computer workstation, a 30 W 980 nm diode laser, a cooling pump, and a (disposable) laser applicator set. A 600 um (micrometers) core silica fiberoptic with a cylindrical diffusing tip housed within a 1.85 mm diameter saline-cooled polycarbonate cooling catheter [3,4] was inserted. A titanium stiffener was used to stiffen the laser catheter and visualize the trajectory in real-time. After reaching the target, the stiffener was replaced with the fiberoptic laser fiber. MR imaging with TRUFISP sequence was used to locate, adjust, and confirm the laser fiber tip position. When the fiber position was deemed satisfactory on MR imaging, further confirmation was added by applying a test dose of laser energy (30 seconds at 9 W) to verify the actual location of the ablation. During the temperature imaging, the anesthesia team would do a breath-hold for the duration of laser exposure. The average single laser exposure was 27W for 2 min. In larger lesions, multiple laser placements with multiple ablations per set were required. The workstation used an Ethernet connection to connect to the clinical MR scanner (Siemens Espree, Germany) and retrieved reconstructed images from the scanner as soon as they are available. Reference based proton resonance frequency (PRF) method was used for non-invasive MRI thermometry [5]. Extracted thermal data produce color-coded ''thermal'' and ''damage'' images based on an Arrhenius rate process model [6] which were displayed on the workstation. The damage image accounted for the cumulative effects of the time-temperature history of each voxel in the image. In addition to this visualization, the user interface allowed the association of prescribed ''limit temperatures'' to specific target points on the image. If during treatment, the computed temperature at one of these targets exceeded the associated limit temperature, a signal was sent to automatically deactivate the laser. These ''limit points'' were established by ''clicking'' on the images and could be moved in real-time during the therapy. The monitoring could be done in single plane or multiple parallel or orthogonal planes if required. Post-ablation scans consisted of TSE-T2, GRE-T2, FLAIR, DWI/ADC, and pre- and post-gadolinium VIBE. These were evaluated for size of thermal lesions and coverage of the targeted lesion.

Results:

The average damage area for single fiber was 666.4 sq.mm for 2 min ablation, 1111.6 sq.mm for multiple single exposures with pullbacks and 1875.4 sq.mm for simultaneous use of 2 fibers for 2 minute ablation cycle. The real time temperature monitoring with safety limits enabled tumor ablation near critical structures like the heart, gall bladder and hepatic vessels. Due to these safety features , no complications occurred that required the procedure to be aborted, Image acquisition at rate of 5 sec/image with breath hold enabled robust temperature monitoring and reproducible damage maps, without need for motion correction algorithms. Ablations near interfaces like lung-liver and near cardiac motion caused artifacts which affected the temperature monitoring. Thermal ablation zones demonstrated hypointense signal on T2-weighted imaging sequences, surrounded by a thin hyperintense rim. T2 imaging was a very effective tool to evaluate coverage of targeted lesion and aided in decision making of repeat ablations and repositioning of fiber. After completion of all ablations, gadolinium was administrated and a thin rim of enhancement around the ablation zone corresponding to the changes seen on T2WIs.

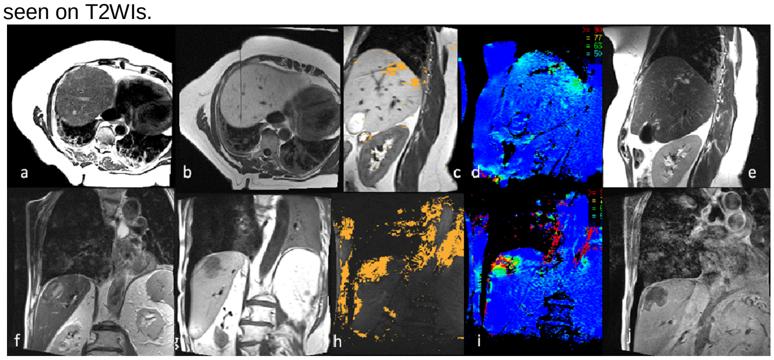

Figure 1: The top row demonstrates various stages during a single fiber ablation while the lower panel shows a simultaneous 2 fiber ablation . The targeted tumor is seen in a) and f) , fiber placement in b) and g), damage prediction in c) and h), temperature imaging in d) and i) and post imaging in e) and j).

Conclusions:

This report demonstrated the feasibility of percutaneous laser ablation for hepatic tumors with real-time MRI monitoring within a dedicated "interventional MRI" suite. The online temperature feedback was robust and damage predictions were reproducible, thus allowed creation of large ablation volumes with an excellent safety profile. The real-time monitoring, along with automatic shutoff mechanism with triggering of safety limits, protected adjacent critical structures. Advantages of using MR guided laser ablation include ability to ablate lesions which are in locations that are difficult to access and ability to ablate lesions which are only conspicuous on certain MR weighted sequences . Treatment success can be acutely evaluated with post-ablation T2 wt imaging, and treatment plan altered immediately on that feedback.

References

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