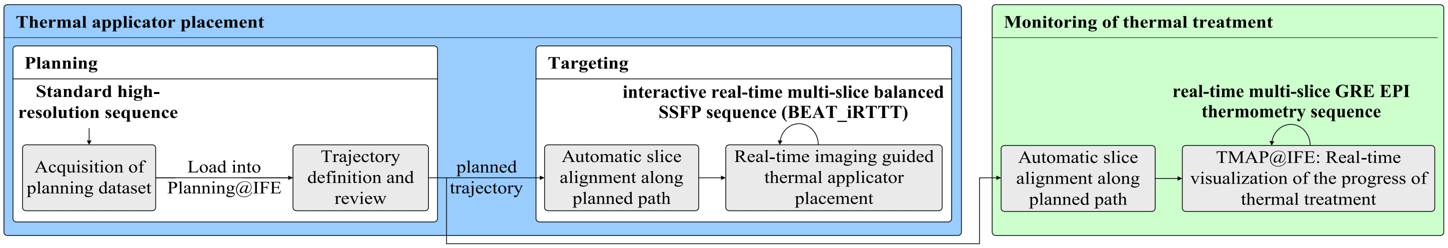
An Integrated System for MR-Guided Thermal Ablations: From Planning to Real-Time Temperature Monitoring

Eva Rothgang[1,2], Wesley D. Gilson[2,3], Li Pan[2,3], Jörg Roland[4], Klaus J. Kirchberg[2], Frank Wacker[3,5], Joachim Hornegger[1], and Christine H. Lorenz[2,3]
[1]Pattern Recognition Lab, Department of Computer Science, Friedrich-Alexander University, Erlangen, Germany, [2]Center for Applied Medical Imaging, Siemens Corporate Research, Baltimore, Maryland, United States, [3]Russell H. Morgan Department of Radiology and Radiological Science, Johns Hopkins University, Baltimore, Maryland, United States, [4]Siemens Healthcare, Erlangen, Germany, [5]Department of Radiology, Hannover Medical School, Hannover, Germany

Introduction: Thermal ablations, e.g. laser, radiofrequency and cryo [1-3], are increasingly being used for minimally invasive local treatment of solid malignancies. The goal of these procedures is to destroy the diseased tissue while sparing adjacent healthy structures. MRI provides two key advantages over other imaging modalities for guiding thermal ablations. First, its soft tissue contrast and multi-planar imaging capabilities allow to clearly visualize many solid tumors and further support accurate placement of the thermal applicator even into difficult locations. Second, MR can measure in real-time the spatial distribution of temperature changes in tissue. This information can then be used to estimate boundaries of irreversible tissue necrosis. The purpose of this study was to create methods to improve the entire thermal ablation workflow and to fully integrate them into one tool independent of the heating source used.

Methods: The thermal ablation workflow can be divided into two key steps (Fig. 1): 1) *thermal applicator placement* (planning and targeting) and 2) *online monitoring* of thermal treatment.



Thermal applicator placement

Planning

Standard high-resolution sequence

Acquisition of planning dataset

Load into Planning@IFE

Trajectory definition and review

planned trajectory

Targeting

interactive real-time multi-slice balanced SSFP sequence (BEAT_iRTTT)

Automatic slice alignment along planned path

Real-time imaging guided thermal applicator placement

Monitoring of thermal treatment

real-time multi-slice GRE EPI thermometry sequence

Automatic slice alignment along planned path

TMAP@IFE: Real-time visualization of the progress of thermal treatment

Figure 1*: Fully integrated system for MR-guided thermal ablations independent of the heating source used. Dedicated MRI pulse sequences are combined with visualization/analysis tools for trajectory planning, device placement, and advanced MR thermal mapping.*

Planning: An effective treatment begins by identifying the best locations for thermal applicator placement such that the ablation zone adequately covers the target tumor but spares healthy and/or critical structures. A planning application was developed that enables flexible visualization of a planning image dataset with multi-planar reformatting (MPR), maximum intensity projection, and volume rendering (Fig. 2a). A trajectory is defined by identifying the entry and target points in the MPR planes. Multiple trajectories can be planned in one session which is useful for thermal ablations of large lesions that require accurate placement of several applicators in a defined spatial relationship to each other. An automatic alignment strategy (Fig. 2a) was also developed to assist in reviewing the trajectory prior to applicator placement.

Targeting: Having defined the trajectory, targeting can be performed using real-time imaging with an interactive multi-slice, balanced SSFP sequence [4] (2-5 fps). The slices are automatically aligned with the following layout: two slices along the prescribed trajectory orthogonal to each other and a third slice orthogonal to the trajectory at the target location with the slices oriented as closely as possible to the principal patient axes. The overlaid path or slice saturation bands (Fig. 2b) can then be used to guide thermal applicator placement.

Monitoring: In this study, thermal treatment monitoring was performed based on the proton resonance frequency [5] using a multi-slice gradient echo EPI thermometry sequence (up to 5 fps) which supports the baseline subtraction approach and a reference-less approach [6]. The temperature imaging planes were automatically aligned with respect to the planned trajectory. Temperature visualization was improved by using a modified fusion method which combines anatomic images and temperature/thermal dose maps in the HSL color space [7]. Various monitoring tools (e.g. seed points to monitor temperature over time, difference image to detect motion and monitor ablation induced tissue changes) were also built into this application. The application supports continuous monitoring of three imaging planes to allow visualization of the ablation zone in 3D (Fig.3, upper right).

Implementation: These Planning, Targeting and Monitoring methods were fully integrated as modules in the Interactive Front End (IFE) [8] prototype, a real-time MR-scanner control interface.

Results: To date, 10 porcine studies have been performed to evaluate the prototype performance during laser ablation (Visualase, Inc), radio-frequency ablation (CelonPOWER, Olympus KeyMed) and cryoablation (Galil Medical). Figures 2 and 3 demonstrate the workflow steps within the prototype for a laser-induced thermal ablation in the liver. Figure 3 also highlights the importance of accurate and fast real-time temperature monitoring in multiple planes. The laser fiber was accidently moved during the procedure. The magnitude images did not reflect this, but local heating in the real-time temperature maps identified this problem instantly.

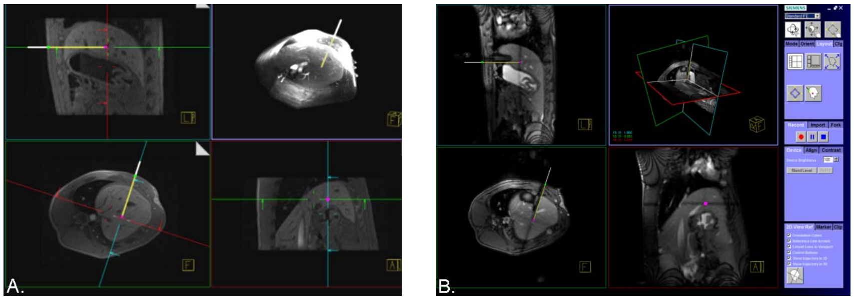


Figure 2: *(A)* ***Planning*** *– A trajectory (yellow line) is defined by placing an entry point (green) and a target point (magenta). Automatic slice alignment provides MPR views that allow to fly-through the planned path for review. (B)* ***Targeting*** *– Scan planes are automatically positioned with respect to the prescribed path and during real-time imaging generate slice saturation bands that are useful for needle placement.*

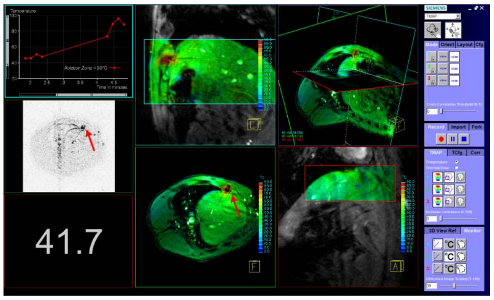


Figure 3: Monitoring *– Temperature maps are shown fused with anatomical images in three real-time slice planes. A graph of temperature over time for a selected seed point (left upper), the magnitude difference image (left middle), and the current seed point temperature (left lower) are displayed as additional monitoring strategies.*

In this example, the laser fiber is not visible in MR images once the introducing trocar is removed. However, real-time temperature images and the difference image show that laser fiber accidently moved (marked by arrows).

Conclusion: An integrated system that supports the entire MR-guided thermal ablation workflow from planning to applicator placement to real-time monitoring has been shown to be effective for guiding a variety of thermal ablation procedures. It is anticipated that these methods will be useful in making MR-guided thermal ablations more effective and efficient, and could facilitate more widespread clinical adoption of MR for guiding these procedures.

References: [1] Ahrar et al. Tech Vasc Interv Radiol, 2011. [2] Rempp et al. Cardiovasc Intervent Radiol, Jul 2011. [3] Morrison et al. JMRI, 2008. [4] Pan et al. ISMRM, 2011. [5] Ishihara et al. MRM, 1995. [6] Salomir et al. TMI, Sep 2011 [7] Rothgang et al. SPIE, 2010. [8] Lorenz et al. ISMRM, 2005.