TMAP @ IFE - A Framework for Guiding and Monitoring Thermal Ablations

E. Rothgang[1,2], W. D. Gilson[2], J. Roland[3], J. Hornegger[1], and C. H. Lorenz[2]
[1]Pattern Recognition Lab, Department of Computer Science, University of Erlangen-Nuremberg, Erlangen, Germany, [2]Center for Applied Medical Imaging, Siemens Corporation, Corporate Research, Baltimore, MD, United States, [3]Siemens Healthcare, Erlangen, Germany

Introduction

In interventional oncology, thermal ablations are increasingly used for minimally invasive local treatment of solid malignancies, supplementing systemic treatment strategies such as chemotherapy and immunotherapy. The goal of all thermal ablation procedures is to cause cell death of disease tissue while sparing adjacent healthy tissue. Continuous thermometry allowing real-time assessment of thermal damage is the key to therapeutic efficiency and safety of such procedures. MRI is well-suited for non-invasively measuring the spatial and temporal distribution of temperature and its changes in vivo as several MR parameters are sensitive to temperature. To support the translation of MR thermometry to a clinical setting, we have developed an intuitive application for monitoring thermal treatment independent of heating source with real-time, multiplanar MRI.

Methods

The presented thermotherapy guidance tool, referred to as TMAP, was implemented in C++ within the eXtensible Imaging Platform [2] and integrated into the Interactive Front End (IFE) [1], a prototype for advanced visualization and real-time parameter control of image acquisition. Seamless integration with the IFE supports the thermal ablation workflow from placing the ablation device to online monitoring of the progress of ablation. The full application runs on an independent PC connected to the standard Siemens MR scanner network via Ethernet and receives magnitude and phase images acquired by the MR system in real-time. The user interface is duplicated to a MR compatible console inside the magnet room with an integrated mouse and/or displayed on a projection screen in the scanner room.

In our system, we used the temperature dependence of the proton resonance frequency (PRF) for spatial and temporal temperature measurements during the intervention. The PRF shift method [3] is currently the most widely used MR thermometry method at mid and high field. The TMAP tool has been developed to be compatible with gradient echo, single shot EPI and segmented EPI PRF sequences. To provide an intuitive and clear user interface, the presented TMAP application features visualization of up to three multiplanar slices during the thermal ablation. Anatomical (magnitude) and thermal (phase-based) images can be visualized either separately or fused, with flexibility to change the visualization mode interactively during the thermal ablation procedure. In line with the IFE, the application provides visualization of imaging slices in individual 2D views, as well as in a 3D graphic which gives information about the orientation of the slices in 3D space.

Systematic on-line quality control features were developed to ensure the reliability of the displayed temperature maps. A three-pronged approach to maintain measurement quality was used. First, an assumption was made that the standard deviation of the temperature measurement in an unheated region can be used to track the quality of the measurements. As such, TMAP was designed to monitor this value in a user-defined region of interest (ROI) and to give feedback to the physician when it exceeds a predefined value. Second, real-time motion monitoring was implemented by evaluating normalized mutual information (NMI) in sequential images throughout the image acquisition. In addition, users can view the difference images between the current and baseline magnitude image to individually evaluate effects. Further, if desired, users are allowed to select a threshold value with respect to the NMI index to remove outliers from the thermal dose calculation.

In order to quantitatively assess the progress of ongoing thermal damage, the system supports both the display of thermal damage based on CEM 43 (cumulative equivalent minutes at 43°C) or the Arrhenius model [4]. In addition, the temperature/ thermal dose over time can be monitored for selected points. The physician can, for example, place one seed point inside the ablation zone, one in the safety margin, and one in the non-heated region.

Results

To date, the TMAP application has been used for thermal monitoring of HIFU procedures in meat samples (Fig. 1) and in healthy volunteers without heating (Fig. 2). The figures illustrate the advanced visualization capabilities of the thermotherapy guidance tool, e.g. various viewing modes, simultaneous and consistent windowing of magnitude and thermal image and very flexible, user-definable temperature scales. The system was also validated using temperature images acquired during an MR-guided laser-induced thermal ablation in the liver (Fig. 3).

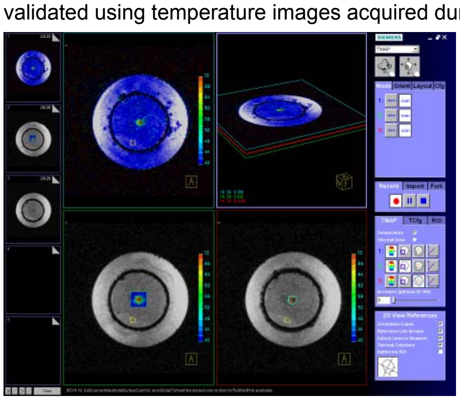

Figure 1: Cross-sectional images of a meat sample (inner circle) heated with HIFU. Basic functionality is shown including temperature overlay, region of interest selection and isotherms.

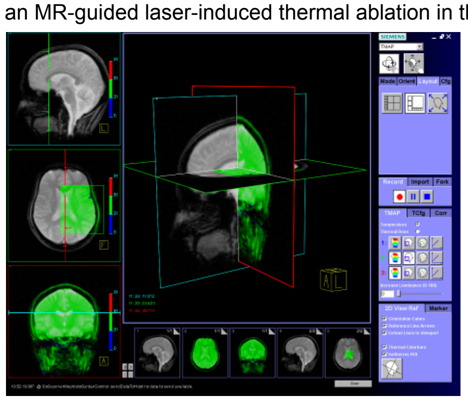

Figure 2: Volunteer brain scan with no heat applied. The 3D view (freely rotatable) to highlight the ability to visualize the temperature distribution in 3D.

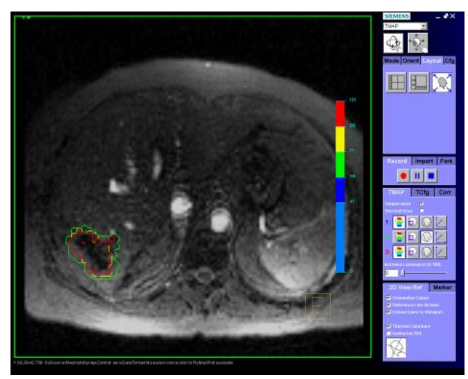

Figure 3: Laser induced thermal therapy in the posterior right lobe of a human liver. A full screen layout is shown for one 2D slice, and isotherms are displayed in the ablation zone

Discussion and conclusion

We have created a promising new system to guide and monitor thermal ablations independent of the type of heating source. Along with various tools for on-line assessment of data quality and the completeness of the ablation, our system has the potential to provide enhanced visualization capabilities for efficient use by the physician during thermal ablations combined with integration with the IFE to fully support the thermal ablation workflow.

[1] Lorenz et al., Proc. ISMRM, p. 2170, 2005.
[2] Paladini et al., Proc SPIE, 717108, 2009.
[3] Ishihara et al., MRM, vol. 34, pp. 814-823, 1995.
[4] Pearce et al., Proc SPIE, vol. 7181, 718104, 2009.