Real-time MR Thermometry Feedback Control for Prostate Hyperthermia with a Commercial HIFU System

Eugene Ozhinsky[1], Vasant A. Salgaonkar[2], Chris J. Diederich[2], and Viola Rieke[1]

[1]*Radiology and Biomedical Imaging, University of California San Francisco, San Francisco, CA, United States,* [2]*Radiation Oncology, University of California San Francisco, San Francisco, CA, United States*

Target Audience: Researchers and clinicians interested in thermal therapy

Purpose: Hyperthermia (40-45°C, 30-60 min) has been combined successfully with several cancer treatment modalities, such as radiation, chemotherapy and drug delivery. Clinical studies have demonstrated feasibility of safe application of prostate hyperthermia with endorectal ultrasound applicators. Previously, the possibility of hyperthermia therapy using a commercially available MR-guided High-Intensity Focused Ultrasound (HIFU) system for prostate ablation was investigated in simulations and phantom experiments (1,2). The goal of this project was to develop a real-time MR-thermometry feedback control for prostate HT with the InSightec prostate transducer and measure its performance in ex-vivo muscle and in in-vivo animal model.

Methods: The real-time thermometry application was developed for the RTHawk real-time MRI system (Heartvista, Inc., Menlo Park, CA), connected to a 3T MR scanner (GE Healthcare, Waukesha, WI) and the ExAblate 2100 prostate array (InSightec, Haifa, Israel). The application included an SPGR pulse sequence (TE = 13.4 ms, FOV = 28-32 cm, 3 s/slice), a real-time PRFS thermometry reconstruction pipeline and a custom interface for data visualization and prescription (fig.1). The system provided for interleaved simultaneous acquisition of multiple slices at different orientations. Temperature measurement was implemented using a user-adjustable elliptical ROI and served as an input to a PI feedback controller module. The controller automatically adjusted the ultrasound transducer duty cycle using a signal generator (Agilent, Santa Clara, CA), controlled via an Ethernet interface.

Three HT beamforming and control patterns were implemented on the ExAblate 2100 prostate phased array ablation system (1): sharp 4-point focus pattern (Focal dist. = 30 mm, foci: 0.5 cm apart), mild 4-point focus (focal dist. = 40 mm, foci: 1 cm apart), and cylindrically diverging (ROC: 40 mm). Max. electrical power was 10 W; target temperature increase: 6 and 8°C.

The HT technique was validated in phantom (2 experiments), ex-vivo muscle tissue (2 experiments) and in-vivo in one live pig (6 experiments), where the prostate endorectal transducer was placed on the inner thigh of the animal.

Results and Discussion: The experiments demonstrated that MR thermometry feedback control allowed to sustain the therapeutic temperature rises (4-8°C) for long durations (>15 min) in large contiguous volumes in-vivo (fig. 2-3). Table 1 shows the spatial distributions of the heated regions at steady state for the three sonication patterns. This demonstrates the feasibility of using the commercially-available InSightec prostate transducer with real-time MR thermometry feedback control for hyperthermia therapy.

ΔT (°C)	4	6
Sharp 4-pt Focus	4 x 2.1 x 1.8	3.3 x 1.1 x 1.0
Mild 4-pt Focus	3.1 x 2.6 x 2.7	2.7 x 1.8 x 1.7
Cylindrically Diverging	5.4 x 4.5 x 3.25	3.8 x 3.2 x 1.5

Table 1. Steady state spatial distributions (depth x width x length, cm) for the three beamforming patters at 4° and 6°C

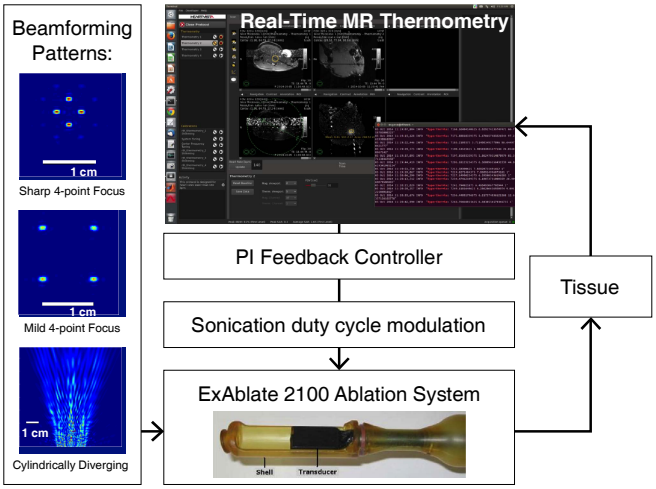

Fig. 1. Real-time MR thermometry feedback control

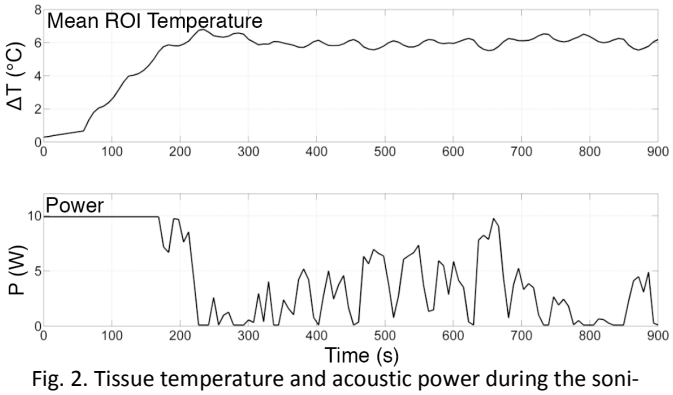

Fig. 2. Tissue temperature and acoustic power during the sonication with mild 4-point pattern

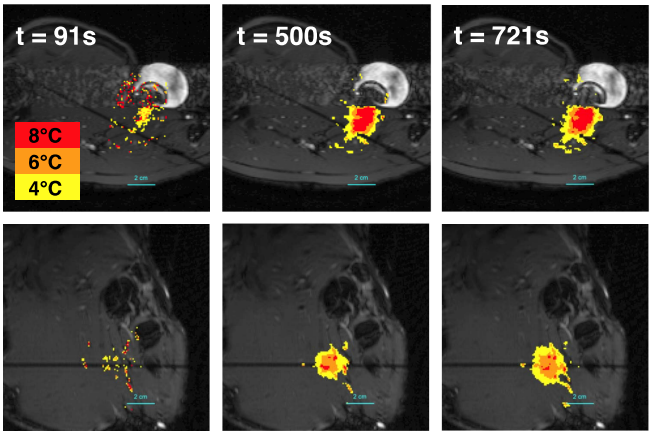

Fig. 3. Axial and sagittal oblique images with temperature map overlays during the MR HT animal experiment

References and Acknowledgements:

1. Salgaonkar VA, et al. Med Phys. 2014 Mar;41(3):033301
2. Ozhinsky E, et al. Proc 22nd ISMRM 2014: 7667

This study was supported by grants from FUS foundation and NIH (R01CA122276, R01CA111981, R00HL097030).