A motion-robust sequence for combined thermometry and T2-mapping to guide and assess tissue damage during thermal therapies

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Target audience: Clinical researchers involved in MR-guided thermal ablation work.

Purpose: There is currently no completely-satisfactory way of detecting tissue damage as it occurs during MR-guided Focused Ultrasound (FUS) surgery. The current standard involves calculating the temperature dose (TD) and selecting a threshold beyond which damage is assumed to have occurred. Although very useful, TD measurements have notable drawbacks: 1) damage is inferred indirectly rather than seen directly in the images, and 2) the entire thermal history of each volume of tissue is needed toward TD calculations. Especially in abdominal organs where motion is problematic, capturing the thermal history of any given piece of moving tissue can be a challenge, and errors readily propagate to all future TD measurements. As tissue damage is believed to be associated with changes in T2[1], damage could possibly prove visible on a frame-by-frame basis if real-time T2 maps were available. A dual-pathway (PSIF-FISP) thermometry sequence was employed here to provide time-resolved measurements of both temperature and T2 simultaneously. It was tested both with and without motion, during heating experiments.

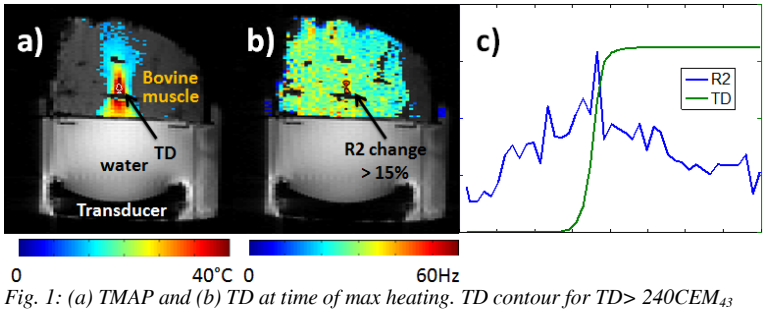

Fig. 1: (a) TMAP and (b) TD at time of max heating. TD contour for TD> 240CEM$_{43}$ and R2 contour for change > 15%. (c) Temporal evolution of TD and R2 during heating experiment.

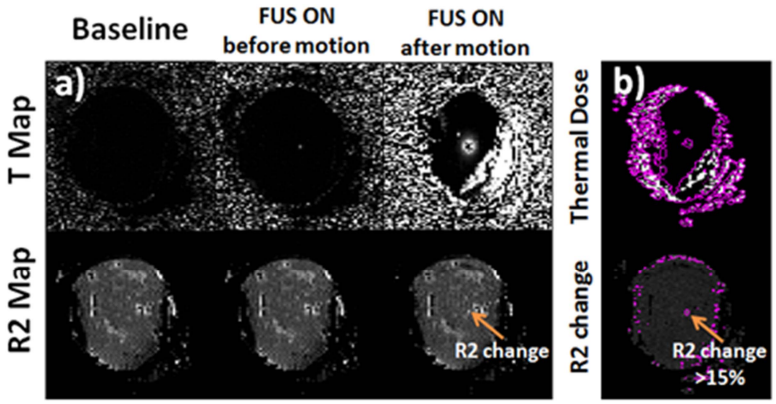

Fig. 2: (a) TMAP (top) and R2 map (bottom) at different time points. (b) The pink contours show TD above 240CEM$_{43}$ (top) and R2 changes above 15% (bottom).

Methods: A dual-pathway sequence[2] sampling PSIF-FISP echoes on odd TRs and reversed-order FISP-PSIF echoes on even TRs was implemented on a 3T GE scanner. This sequence was used to monitor T2 changes during FUS heating of *ex vivo* degassed bovine muscle (36/59 W for 60 sec in the sagittal/coronal plane). An 8-channel receive-only head coil was used with imaging parameters: TR=14.5 ms, flip angle=25°, FOV=19.2cm, 5mm slices, 128×128, BW=±61.3 kHz, TE_{PSIF1}/TE_{FISP1}=2.2/9.5 ms for odd TRs and TE_{FISP2}/TE_{PSIF2}=2.2/9.5 ms in even TRs. R2 and R2′ maps are calculated from the magnitude images from different pathways[3]. Scanning was continuous for 180 sec, including a 30 sec baseline, 60 sec of FUS heating and 90 sec of cooling. The MR table began to move 7 seconds after the FUS was turned and continued moving back and forth throughout the scan. The table was programmed to move in a direction outward from iso-center for 30 mm, to stop for 6 sec and then move back again toward iso-center. Thermal dose (TD) calculations were performed, and a TD of 240 CEM$_{43}$ (cumulative equivalent minutes at 43°C) was used as a threshold to signify damage.

Results: A temperature map (TMAP) and an R2 map at the time of maximum heating were overlaid on magnitude images and shown in Fig. 1a and b. Fatty tissues in bovine muscle were masked out. The pink contour shown in Fig. 1a marks the region where TD exceeded 240 CEM$_{43}$ while the black contour in Fig. 1b marks the region where R2 has changed by more than 15% as compared to baseline. The mean T2 value in a 7×7 region around the heating focus in a baseline time frame was 43±8 ms, which is consistent with the 47 ms value expected for muscle. Normalized TD and R2 changes over time are shown in Fig. 1c for a 3×1 ROI at the focus. Note that the result shows R2 at its maximum when the TD reaches the damage threshold. Results of heating experiments with the table moving are shown in Fig. 2. In Fig. 2a, the TMAPs and R2 maps (top and bottom rows respectively) are shown at baseline, at a time of heating without any motion, and at a time of heating with motion. Note that the phase-based TMAP may become erratic when motion occurs while the magnitude-based R2 map remains more stable. The size of the lesion is only a few voxels in the middle of the R2 map (third column), making it difficult to see. An R2 difference is shown in Fig. 2b (bottom) with contour overlay of regions exceeding 15% change. The change can be clearly seen in the difference map as opposed to the TD map where it is obscured by motion effects (comparing top and bottom parts of Fig. 2b).

Discussion: T2 mapping is often used to verify tissue damage after thermal ablation. However, the typically-poor temporal resolution (~ minutes) of T2 mapping sequences prevent this from being used in real-time to monitor thermal therapies. A dual-pathway sequence provides a novel strategy to map T2 on the order of seconds while also measuring temperature, and can be used to monitor treatments in real time. A major advantage of using T2 (or R2) maps instead of TD for tissue damage detection is its relative insensitivity to motion. T2 mapping is performed here on a frame-by-frame basis and does not depend on heating history. While TD values may well become unreliable whenever motion occurs, R2 measurements are more likely to remain stable. How well R2 changes may correlate with lesion formation and with tissue damage remains, however, a largely unanswered question at this point.

Conclusion: A multi-pathway sequence can be used to measure T2 on a frame-by-frame basis while also measuring temperature information. Changes in T2 (and R2) might prove a relatively motion-robust way of detecting tissue damage in real-time.

References: 1. Anzai et al, JMRI 1:553(1991). 2. Madore et al, MRM 66:658(2011). 3. Mei et al. ISMRM 2013:5251. Support from grants R01CA149342, P41EB015898 and R01EB010195 is acknowledged.