Real-time 3D spiral MR thermometry

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Introduction & Purpose: Real time MR thermometry, usually based on the proton-resonance frequency shift, is a key aspect of MR-guided focused ultrasound procedures [1]. The desire to monitor the entire sonicated volume has led the field towards the development of rapid, 3D methods [2]; however, acquiring fully sampled 3D volumetric data to monitor heating is time consuming, and so fast methods must be developed in order to meet the spatial and temporal requirements for adequate monitoring of thermal therapy.

The data acquisition efficiency of spiral trajectories is higher than that of Cartesian scanning. Therefore, spiral trajectories are an attractive way to improve temporal resolution while maintaining spatial resolution in MR thermometry [3-5]. We have recently reported that a variation on the traditional spiral-out trajectory, called the redundant spiral-in/out trajectory, has certain advantages in terms of off-resonance performance [6]. We hypothesize this trajectory to also be advantageous for PRF thermometry. Here, we have implemented this –in/out trajectory, compared its performance in terms of the focal spot size and position shift versus a Cartesian and spiral-out acquisition, and have generated rapid 3D temperature maps using the method with a real-time reconstruction in a clinically-relevant experimental setup.

Methods: Focal spot evaluation experiments were performed in a gel phantom, using an MR-compatible FUS system (RK-100, FUS Instruments Inc., Toronto) in a 3T whole-body scanner (Siemens Trio). 2D temperature maps were acquired with a GRE sequence with TR/TE = 15/6 ms, FA = 25-degrees, FOV = 64 mm^2, matrix size 64 x 64. Spiral readout length was 1 ms. Spatial/temporal resolution for Cartesian imaging was 1x1x3 mm^3/960 ms vs 1x1x3 mm^3/720 ms for spiral imaging. The size and relative shift of the ultrasound hot spot was measured for all acquisitions.

We next implemented the redundant spiral-in/out sequence in a stack-of-spirals spoiled GRE sequence for rapid 3D imaging. The RTHawk (HeartVista, Inc.) platform was used for sequence design and real-time image reconstruction. The RTHawk system interfaces with a GE Discovery MR750T 3T scanner at the UVA Focused Ultrasound Center, where an Insightec ExAblate 650 focused ultrasound transducer was used to induce focal heating in a gelatin phantom. Sixteen 6 ms spiral interleaves were collected per partition, and 16 3D phase encoding partitions per volume were collected, for a total acquisition time per volume of 2.0 seconds. Spatial/temporal resolution was 2.9 x 2.9 x 2.5 mm^3/1.99 s.

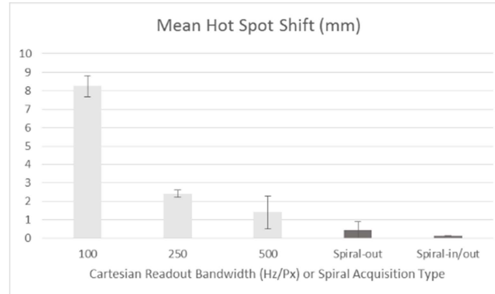


Fig 1. Focal spot shift measured between scans with switched readout / phase encoding directions. Low bandwidths are used to improve SNR in Cartesian imaging and in fast EPI methods, but result in greater shifts.

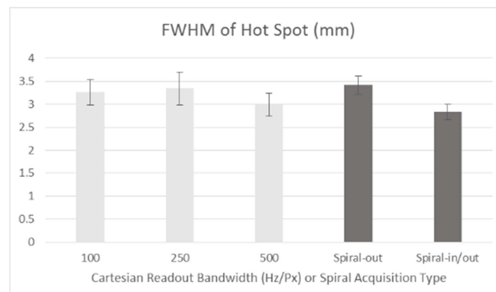
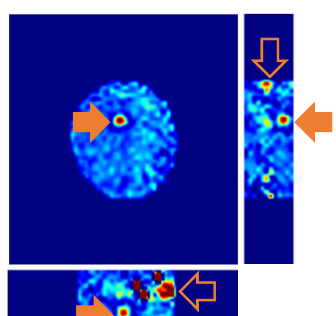


Fig 2. Full width at half maximum (FWHM) measurements of focal spot size at maximum temperature time point. Spiral-in/out recovers the slight blurring observed in the spiral-out images.

Results: Figure 1 shows that, using spiral readouts, temperature-induced phase does not cause a position shift of the ultrasound focal spot. In Figure 2, we show that the hot spot is better resolved when using the redundant in/out method, compared to spiral-out. Figure 3 shows one 3D temperature map obtained using the spiral-based method. Figure 4 shows the time-temperature plot of the hot spot induced by the FUS transducer array.

Conclusions: The efficiency of spiral readouts supports rapid generation of 3D temperature maps, with no shift of the focal spot. Sixteen slices are obtained every 2 seconds with no undersampling of the data. Because data is fully sampled, the reconstruction is easily performed in real-time at the scanner during sonication and does not rely on a model [7] to fill in missing data based on predicted temperature behavior.



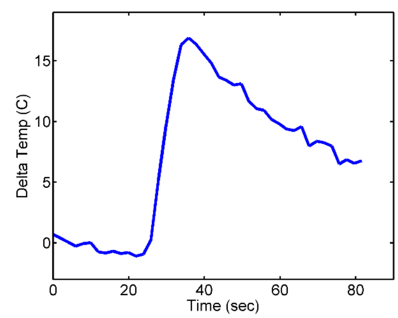


Fig 4. Time-temperature curve for heating experiment.

Fig 1. Phantom image at maximum temperature time point. Three-dimensional real-time thermometry resolves the hot spot in space (solid arrows) as well bubbles in the gelatin which are due to a manufacturing defect (open arrows). Background has been masked out of this figure.

References: [1] Rieke V, Butts Pauly K. JMRI 2008;27:376390. [2] Todd N, et al. MRM 2012;67:724-730. [3] Stafford, et al. MRM 2000; 43:909-912. [4] Josan, et al. ISMRM 20;1802. [5] Fielden, et al. ISMRM 22;2346. [6] Fielden, et al. MRM. 2014;doi:10.1002/mrm.25172. [7] Todd N, et al. MRM 2010;63:1269-1279.