Ultrafast 1D approach for phase or frequency mapping for MRI-based temperature measurement

N. McDannold[1], N. Chen[1], K. Oshio[1], K. Hynynen[1], R. V. Mulkern[2]

[1]Radiology, Harvard Medical School/Brigham and Women's Hospital, Boston, MA, United States, [2]Radiology, Harvard Medical School/Children's Hospital, Boston, MA, United States

Purpose: To establish an ultrafast MRI-based temperature monitoring method for moving organs including the heart and for rapid ultrasound exposures.

Methods: A slice selective 90-180 pair was used to solicit an echo from a 4-5 mm² column (1-3). The spin echo was sampled with either 4 or 32 gradient echoes for water phase (4) or frequency mapping (via spectra (3)) along the column, respectively. The column was sampled at a rate of either 5 or 20 Hz. Temperature monitoring was tested in a gel phantom during focused ultrasound heating during 5-20 second sonications. Feasibility of the spectroscopically mapping the water frequency was tested in the beating human heart of a volunteer. All experiments were performed in a 1.5T clinical scanner (GE Healthcare, Milwaukee, WI).

Results: Focal heating along the ultrasound beam during a 20 s sonication with a temperature rise of 8°C was readily quantified using phase mapping at a column sample rate of 5 times/second. By using each echo of the acquisition (TE's from 30 to 96 ms, 3 ms spacing) as an individual temperature measurement, a sample rate of 333 Hz was possible for a period of approximately 66 ms during each column acquisition (Figure 1). The noise level was better than ±2°C for TE values 30 ms or greater. At a higher column sampling rate of 20 Hz, heating of 7°C during a 5 s sonication could be visualized, but with more noise (±6°C). It was possible to acquire the water frequency (measured with frequency mapping) in the beating heart muscle at a 5 Hz sampling rate during a breath hold. Periodic frequency shifts were evident.

Conclusions: We have demonstrated an ultrafast method for monitoring frequency or phase changes along selected columns, allowing for rapid temperature change estimates. The method is insensitive to motion outside of the column, potentially allowing for applications in the heart such as for monitoring during thermal generation of transmural myocardial lesions for the treatment of tachyarrhythmias. Measurements of the water frequency in the heart were encouraging, indicating that gating or triggering of the sequence could allow for stable measurements to permit temperature measurement with adequate accuracy for monitoring thermal ablation. Using lower flip angle RF pulses for column selection may allow for decreased T1 saturation which resulted in unacceptably high noise levels at the higher sampling rates of the columns. By using each gradient echo as a separate temperature measurement, it may be possible to monitor the focal heating produced by short (less than one second) ultrasound pulses.

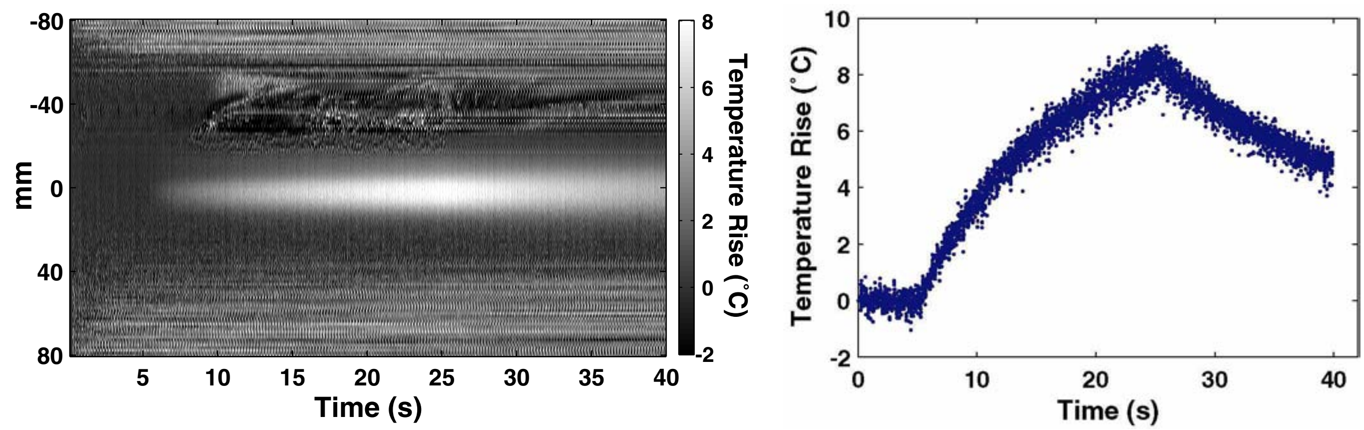

Figure 1: Left: Image showing 1D temperature measurements during a 20s sonication in a phantom. By acquiring 32 echoes and using TE values ≥ 30 ms, we achieved 4066 measurements in 40 s with a noise level less than ±2°C. Right: Plot of temperature rise vs. time at the focus.

References

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