Full coverage 3D temperature mapping for transcranial MRgHIFU applications

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INTRODUCTION:

Transcranial MR-guided high intensity focused ultrasound (MRgHIFU) applications are both very promising and very challenging. New techniques for focusing ultrasound through the skull[1] have made non-invasive heating in the brain possible, paving the way to clinical applications such as tumor ablation[2] and targeted drug delivery via blood-brain barrier opening[3]. However, high bone absorption can lead to undesirable heating outside of the focus and severe consequences if not properly monitored. To realize 3D MR thermometry over the entire volume of interest, we have developed an approach that combines a modified 3-D segmented EPI sequence with data undersampling and a constrained reconstruction method to provide temperature maps with good spatial resolution, large volume coverage, and high temporal resolution. Feasibility studies for the approach has been performed at the University of Utah and further testing will be carried out during transcranial HIFU applications at the Institut Langevin in Paris, France.

METHODS:

3D Sequence. The phase encoding order of a 3D segmented EPI sequence with N slices was modified such that an evenly undersampled k-space data set was acquired every 2*TR*N seconds. Imaging was performed on a Siemens 3T TIM Trio scanner with the following parameters: 192x108x27 imaging matrix; 1.5x2x3 mm resolution; 288x216x108 mm FOV; EPI factor 9; TR/TE = 32/9 ms; 10.5 s for fully sampled time frame, 1.8 s for 6X undersampled time frame.

Temporally Constrained Reconstruction (TCR). The TCR algorithm reconstructs artifact-free images from the undersampled k-space data by iteratively minimizing a cost function that consists of a data fidelity term and a constraint term[4]. The constraint term penalizes abrupt changes in time in the image, weighted by a spatially varying free parameter. Larger weights are applied outside of the focal zone where changes are not expected and the constraint is relaxed over the focal zone to allow for temperature-induced phase changes.

Experiments. The 3D sequence and TCR algorithm were tested during *in vivo* brain imaging and HIFU heating of a phantom. Brain imaging was performed without heating to test for stability. Two HIFU heating runs were done with identical ultrasound parameters, the first imaged with only 16 slices for 5.8 s/scan and the second imaged with the parameters described above. Transcranial HIFU heating was performed on cadaver heads by the medical team of the Institut Langevin in Paris with MR temperature monitoring on a 1.5T Philips Achieva scanner with a standard 3D FFE gradient echo sequence around the geometrical focus of the array: 120x51x5 imaging matrix; 1.5x1.8x3 mm resolution; 180x96x15 mm FOV; EPI factor 17; TR/TE = 103/40 ms; 1.8 s time frame.

RESULTS & CONCLUSIONS:

The *in vivo* brain images, corresponding temperature maps, and maps of the standard deviation of the temperature over time are shown in Figure 1, displaying three orthogonal slices through the 3D volume. All images have been zero-filled to 1 mm isotropic voxel spacing. The 3D temperature maps of HIFU heating of a phantom are shown in Figure 2. Figure 3 shows temperature plots from the two HIFU heating runs, reconstructed using the full data (A) and with the TCR algorithm at 6X data reduction factor (B). Figure 4 shows a temperature map during transcranial HIFU in a cadaver head obtained using conventional 3-D temperature imaging.

The new 3D thermometry approach demonstrates the ability to stably measure temperatures and accurately track HIFU heating with large coverage and high temporal resolution. Future tests will be performed with the sequence during transcranial HIFU heating.

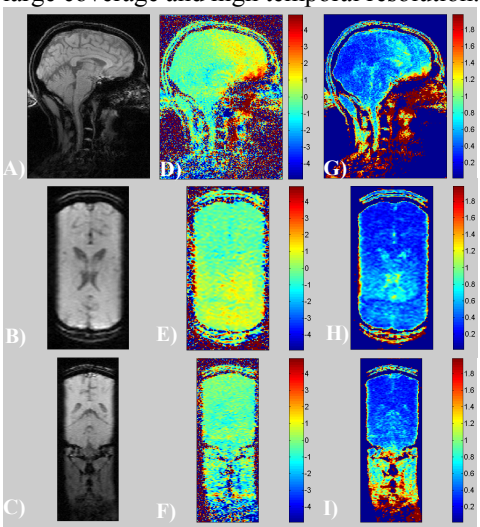

Fig 1. *In vivo* brain imaging. orthogonal views of the 3D volume (1.5x2x3 mm res, zero-filled to 1 mm isotropic spacing; 288x216x108 mm FOV). A) – C): Magnitude images. D) – F): Temp maps. G) – I): Map of STD of temps over time.

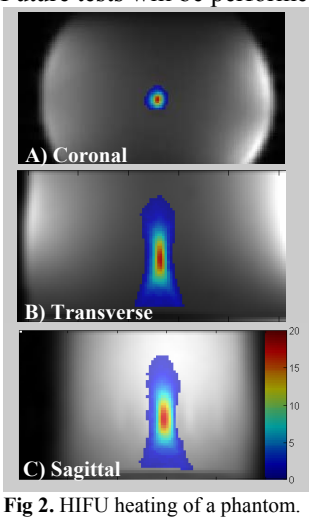

Fig 2. HIFU heating of a phantom. orthogonal views of the 3D volume temperature map overlaid on magnitude images (1.5x2x3 mm res, zero-filled to 1 mm isotropic spacing; 288x216x108 mm FOV).

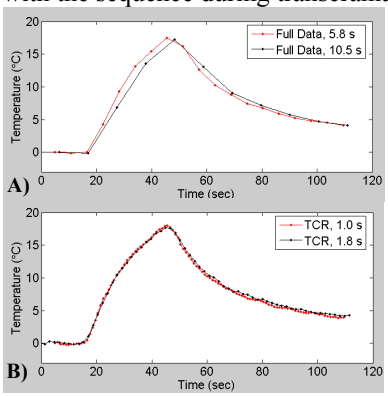

Fig 3. HIFU heating of a phantom. A) Temperature vs time curves for 2 separate identical HIFU heatings, one imaged at 5.8 s/scan and the other at 10.5 s/scan, each reconstructed using the full k-space data at each frame. Temporal averaging effects are seen in the 10.5 s/scan data. B) Same data reconstructed using TCR for temporal resolution gain of 6X. Temporal averaging effects no longer seen.

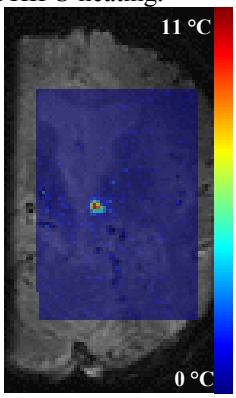

Fig 4. *In vivo* brain transcranial HIFU heating at Institut Langevin. 3D imaging1.5x1.8x3 mm res, 1.8 s/scan. The hotspot is well visualized, but the imaging volume is not large enough to detect inadvertent heating away from the focus.

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ACKNOWLEDGEMENTS: The Focused Ultrasound Surgery Foundation, The Margolis Foundation, Siemens Medical Solutions, NIH grants R01 CA87785, and R01 CA134599.