Fast Dynamic Whole-Brain-Coverage MR Thermometry Using Simultaneous Multi-slice Echo Planar Imaging for MR-guided Focused Ultrasound

Feiyu Chen[1], Kangrong Zhu[2], Urvi Vyas[3], Rachelle Bitton[3], Karen Ying[4], John M Pauly[2], and Kim Butts Pauly[3]

[1]*Center for Biomedical Imaging Research, Department of Biomedical Engineering, Tsinghua University, Beijing, China,* [2]*Department of Electrical Engineering, Stanford University, Stanford, California, United States,* [3]*Department of Radiology, Stanford University, Stanford, California, United States,* [4]*Department of Engineering Physics, Tsinghua University, Beijing, China*

Target audience: Radiologists and MR scientists working on MR-guided Focused Ultrasound Surgery (MRgFUS) treatments of the brain.

Purpose: MRgFUS is a very promising technique for treating diseases such as brain tumor, brain tremor and neuropathic pain. Single slice spoiled gradient echo (SPGR) sequence is currently used to monitor the temperature of the heating target. However, it is necessary to monitor the temperature of the whole brain to detect undesired heating caused away from the target due to ultrasound reflection, refraction and standing waves [1]. In this work, we develop a simultaneous multi-slice excitation and reconstruction framework for whole-brain-coverage temperature measurement. This approach provides high temporal resolution, high spatial resolution and good temperature measurement accuracy for MRgFUS treatment of the brain.

Methods: The blipped-CAIPI sequence [2] was implemented to conduct simultaneous multi-slice echo planar imaging (EPI) during the High Intensity Focused Ultrasound (HIFU)-heating experiments. Data were acquired with 3× slice-acceleration and 2× in-plane acceleration. A FOV/3 shift along the phase encoding direction was applied to adjacent simultaneous slices. Coil images of each individual slice were reconstructed using the GRAPPA/SENSE combination [3] algorithm. The phase of all coil images of a slice were combined to generate one phase image for that slice [4]. The phase images were used by the proton resonance frequency (PRF) shift method [5] to calculate the temperature maps. Ex-vivo HIFU-heating experiment was performed to test the feasibility and accuracy of this method. A porcine tissue composed of muscle and fat was heated using an InSightec ExAblate 2000 (InSightec Ltd, Haifa, Israel) HIFU conformal bone system, and scanned in a GE Signa Excite 3T scanner (GE Healthcare, Waukeshaw, WI) with a 32-channel head coil (Nova Medical, Wilmington, MA). The acoustic power of heating was 63.7 watts and the heating duration was 20 seconds. For comparison, the SPGR sequence was used in a repeated heating process at a different heating target. Imaging parameters for the simultaneous multi-slice EPI sequence were: TR = 2000ms, TE = 41ms, flip angle = 77°, BW = 250 kHz, acquisition matrix size = 128×128, FOV = 180 mm × 180 mm, slice thickness = 2 mm, number of slices after reconstruction = 45. Thus, the volume size was 180 mm × 180 mm × 90 mm. Imaging parameters for SPGR were: TR = 14.5ms, TE = 7.2ms, flip angle = 30°, BW = 5.7 kHz, acquisition matrix size = 128×128, FOV = 180 mm × 180 mm.

Results: Temperature maps in Fig.1 show the distribution of temperature for the heating target and its surrounding area from 3 orthogonal views. The intersections of the red dashed lines show the location of the heating target in the whole volume. The temperature evolution curve of simultaneous multi-slice EPI agrees well with SPGR (Fig.2) during the HIFU-heating and cooling down process. According to the temporal standard deviation maps in Fig.3, simultaneous multi-slice EPI provides good temperature accuracy for the whole tissue. The temperature uncertainty is 0.39°C for this method and 0.37°C for SPGR, based on an average of the temporal standard deviation in the unheated area.

Discussion: Fig.1 shows that simultaneous multi-slice EPI can provide volumetric temperature distribution with an update rate of 2 seconds/frame and a volume size of 180 mm × 180 mm × 90 mm during MRgFUS treatment. The agreement of two temperature evolution curves also demonstrates the feasibility of this method for monitoring acute change of temperature (Fig.2). Geometric distortion caused by the EPI acquisition can be seen in Fig.3 (a). The edges of the tissue show larger temperature uncertainty with an absolute value of about 1°C in both sequences.

Conclusion: We validate the feasibility of simultaneous multi-slice EPI to monitor the volumetric temperature of the target tissue with high temperature accuracy during MRgFUS treatment. The average uncertainty of the measured temperature is less than 0.4°C for an ex-vivo porcine tissue. This approach allows researchers to monitor the temperature of the whole brain, especially the brain surface and scalp. It can be used to prevent undesired heating during MRgFUS treatment of the brain.

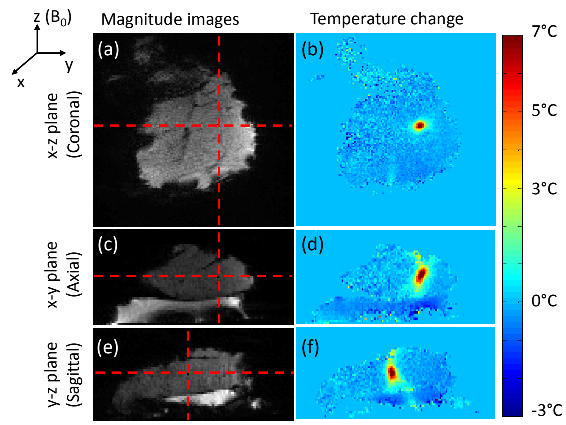

Fig.1 *(a, c, e): Three orthogonal views of the porcine tissue and the location of the heating target (intersections of the red dashed lines). (b, d, f): corresponding temperature maps 30 seconds after the heating experiment began, showing the heating target and its surrounding temperature distribution.*

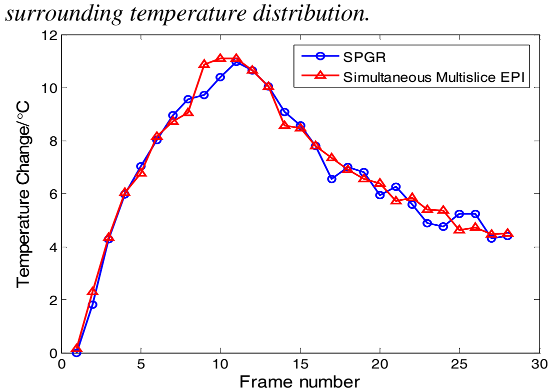

Fig.2 *Comparison of SPGR (blue circles) and the simultaneous multi-slice EPI method (red triangles) for temperature measurement of the heating target (1 pixel) with a temporal resolution of 2 seconds/frame.*

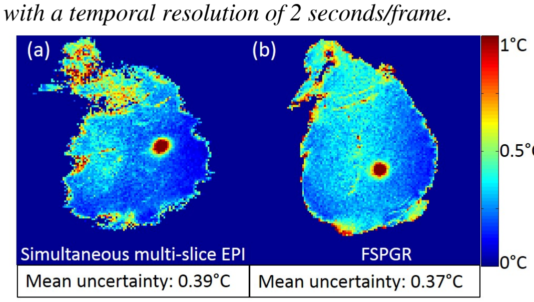

Fig.3 *Comparison of the temperature uncertainty using SPGR and simultaneous multi-slice EPI for the slice containing the heating target. The arrows point to the heating targets. The temperature uncertainty measured from unheated areas is 0.39°C for the simultaneous multi-slice EPI method and 0.37°C for SPGR.*

References:

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