VD k-t acquisition for accelerating temperature imaging

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Introduction

Real-time temperature imaging is critical in MR guided HIFU (High Intensity Focused Ultrasound) treatment. In thermal ablation using HIFU, energy deposition would vary, and temperature may increase very fast first, followed by a stage where temperature is kept relatively constant (Fig 1). Real time temperature imaging with suboptimal temporal resolution may fail to capture the peak temperature (Fig 1a) and result in tissue charring. Temporal resolution can be improved through various methods (e.g., reduced TR/matrix size, parallel imaging, etc.), which would reduce image SNR, or spatial resolution. In this abstract, we propose an acceleration scheme that can be adapted to the temporal resolution needed without significantly compromising image SNR or spatial resolution.

Methods

Theory The k-space is divided into several segments in the phase encoding (PE) direction. In each segment, one out of A_i lines is acquired (A_i = acceleration factor in segment i). A_i is gradually increased from segments near the k-space center to segments farther away from it (Fig 2a). Along the temporal axis, the total acquired lines will be adaptively changed according to the temperature evolution rate by adjusting the width and/or acceleration factor of each segment in order to achieve the desired temporal resolution. The k-space lines are sampled in an interleaved manner along the temporal direction (Fig 2b). Two reconstruction algorithms are used: echo sharing and iterative *k-t* BLAST/*k-t* SENSE [1] (Fig 3). By inheriting data from several adjacent frames, echo sharing provides instant updates of temperature maps and shows temperature changes that can be used to adaptively adjust the temporal resolution of the temperature maps subsequently sampled. Iterative *k-t* BLAST/*k-t* SENSE provides a more accurate reconstruction of the temperature map and can be used for thermal dose calculation in Regions of Interest (ROI).

Experiment An experiment was carried out to evaluate this adaptive accelerating algorithm. A piece of bovine liver, immersed in water, was heated for about 30 seconds and then cooled down freely on a MR guided HIFU system (MR scanner: Symphony, Siemens, Germany; HIFU: HAIFU, Chong Qing, China). During the heating process, the tissue temperature around the ultrasound focus was recorded by both an optic-fiber thermometer (sampling rate: 1Hz) and MR temperature imaging using PRF (GRE; TR/TE= 70ms/5.6ms; flip angle=30°, image matrix 256*256). Using the model proposed in [2], the change of spatial-temporal temperature distribution over time was synthesized in the following way. First, one magnitude image was extracted as a reference image (Fig 4). Second, the temperatures measured by the optic-fiber were interpolated to simulate a higher temporal resolution (i.e., sampling rate goes from 1Hz to 1/TR). Third, using the fiber-optic as the focus for HIFU heating, temperature distribution around it was calculated according to [2] using the interpolated temperature readings from the optic-fiber. The images were then transformed to k-space for resampling by the algorithm described above. During simulation, a denser k-space sampling scheme was used at the start to better track the temperature change around the focus. The sampling scheme was then adjusted to achieve desirable temporal resolution in subsequent frames (like Fig 2b). The temperature change rate can be calculated by echo sharing when k-space was sparsely acquired. The temporal resolution has been improved by 2 times compared to that without acceleration when temperature change rate >3°C/sec (Fig 5, shading area).

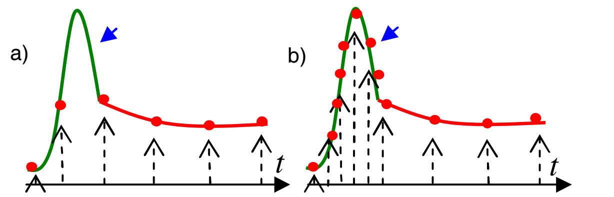

Fig 1. Typical temperature evolution curve with (a) uniform temporal resolution; (b) variable temporal resolution sampling

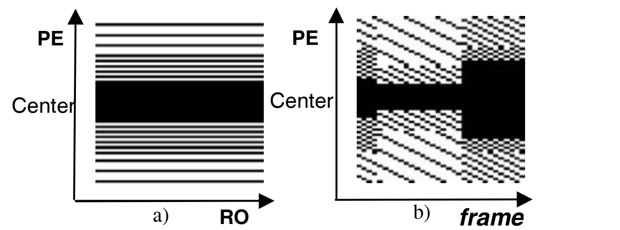

Fig 2. (a) sampling pattern in k-space, (b) along temporal axis. The acquisition pattern here is roughly corresponding to the desired temporal resolution in Fig 1b. Temporal resolution $\propto$ 1/ (measured phase encoding lines)

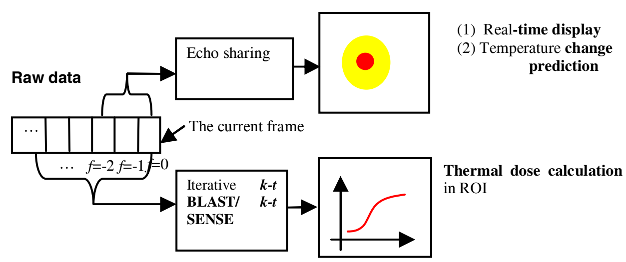

Fig 3. The reconstruction strategy

Results

With a uniform sampling scheme, the temperature peak was lost (Fig 5a, image sampling rate =0.055Hz). However, the peak was successfully captured with a minor error of 4°C by the adaptively variable density (VD) k-t acquisition (Fig 5b, image sampling rate =0.17Hz around the peak). The acceleration can be slowed down when temperature is being kept constant.

Discussion

By efficiently exploiting the correlation in both k-t spaces, iterative k-t reconstruction provides a more accurate calculation of temperature maps. However, its calculation would take a relatively long time than echo sharing method and is not suitable for real time updating.

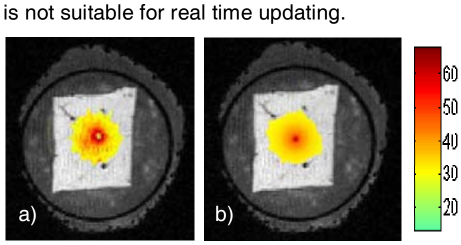

Fig 4. Temperature map around the ultrasound focus overlaid onto the reference magnitude image; (a) measured temperature map; (b) simulated map

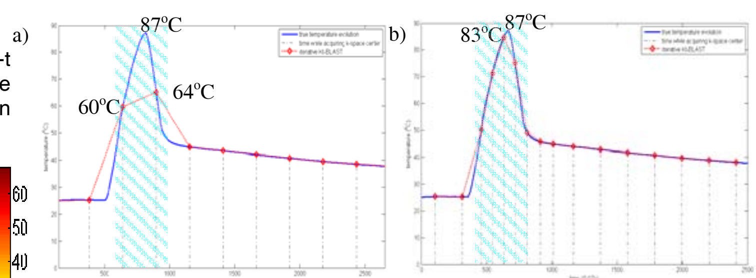

Fig 5. Blue line was temperature evolution measured by optic-fiber thermometer, red dots were several discrete values measured by MR temperature imaging simulation in the focus. (a) without acceleration; (b) adaptively variable density k-t acquisition.

References

[1]. Tsao J et al. Magn Reson Med. 2003 Nov; 50(5):1031-42.   [2]. Chung YC et al. Proc. ISMRM 1998, p.2000;