3-D MR Temperature Imaging with Model Predictive Filtering Reconstruction

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INTRODUCTION:

Proper monitoring of thermal therapies, such as high intensity focused ultrasound (HIFU) surgery where small tissue volumes are heated rapidly, requires temperature imaging with high spatial and temporal resolution. We feel that the goal of MR thermometry should be to provide accurate temperature maps with 1mm^3 isotropic spatial resolution and 1 second temporal resolution. 3-D imaging will be necessary to achieve the spatial resolution goal, but comes with a heavy penalty in scan time. To overcome the problem of lengthy imaging time, we propose using a 3-D gradient echo sequence that undersamples k-space and employs a model predictive filtering (MPF) algorithm for reconstructing the proton resonance frequency (PRF) based temperature maps. Here we compare our undersampled 3-D MPF technique with the traditional fully sampled 2-D PRF technique.

METHODS:

The Model Predictive Filtering Reconstruction Algorithm. The MPF reconstruction algorithm requires a site-specific model of the tissue's thermal response. This model is identified before the treatment using a low power sonication, fully sampled 2-D PRF temperature maps, information about the tissue properties, and the Pennes bioheat equation[1]. The 2-D model is interpolated in the slice direction using a Gaussian fit to create the 3-D model. The MPF reconstruction is a recursive multi-step process. Starting with a temperature distribution at time point (n), the identified model is used to predict a new temperature distribution at time (n+1). Next, a complex image for time (n+1) is created by using the magnitude of the image at time (n) and computing the phase, ϕ_{n+1}, according to[2]: $\phi_{n+1} = \phi_n + \gamma B_0 \alpha T_E (T_{n+1} - T_n)$, where α=-0.01ppm/°C is the chemical shift coefficient[3]. This complex image is then projected into k-space where any phase encode lines that were acquired at time (n+1) are inserted. This data-updated k-space is then projected back into image space and a new temperature distribution for time (n+1) is calculated using the phase of the updated image.

HIFU heating Experiments and MR Image Acquisition. Nine HIFU heating experiments were performed on an *ex vivo* tissue sample using a 256-element MRI-compatible phased array ultrasound transducer (IGT, Bordeaux, France). The first heating run was used for model identification. To be able to compare the 2 methods, the remaining 8 runs were all done with the exact same ultrasound parameters (36W of power for 58.1 seconds) and alternately scanned with the fully sampled 2-D sequence and the undersampled 3-D sequence. All MR imaging was performed on a Siemens TIM Trio 3T scanner. The fully sampled 2-D imaging parameters were: 8ms TE, 65ms TR, 2.0x2.0x4.0mm^3 resolution, 128x128 imaging matrix, 5 slices acquired in 8.3 seconds. The undersampled 3-D imaging parameters were: 8ms TE, 25ms TR, 2.0x2.0x2.0mm^3 resolution, 128x128x24 imaging matrix, undersampling factors of 4.6 in the Ky direction and 2.6 in the Kz direction, 16 slices acquired in 6.4 seconds.

RESULTS:

Temperature maps created from the model only, from fully sampled 2-D imaging with the traditional PRF method, and from undersampled 3-D imaging with MPF reconstruction are shown in Figure 1. For both methods, a mean and standard deviation of the temperatures were calculated for each time point over each set of 4 runs- comparison temperature plots of one voxel are shown in Figure 2A. The small error bars indicate good heating repeatability and the temperature curves of the two methods match quite well. The temperature difference (2D full data – 3D MPF) was also calculated over a 29x14x3 voxel ROI in time frames that fell within 1 second of one another (the different sampling rates meant only 12 time frames satisfied this criterion). The mean and standard deviation of this difference is shown in Figure 2B. A histogram of all of the differences is shown in Figure 3.

DISCUSSION:

The MPF algorithm can reconstruct temperature maps from undersampled 3-D data that are as accurate as those produced from traditional 2-D PRF imaging without sacrificing scan time. The 3-D imaging provides better spatial resolution and greater volume coverage in the slice direction. The chosen parameters provided 2mm^3 / 6sec resolution. Combining the undersampled 3-D MPF technique with a segmented EPI read out and 2-D RF excitation should place the goal of 1mm^3 / 1sec resolution within reach.

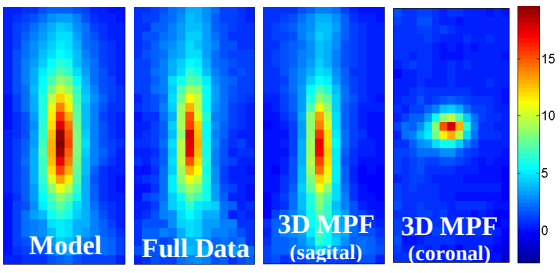

Fig 1. Temperature maps produced using the model only, fully sampled 2-D imaging, and undersampled 3-D imaging with MPF reconstruction. 3-D imaging provides good resolution in the slice direction, as shown in the coronal image.

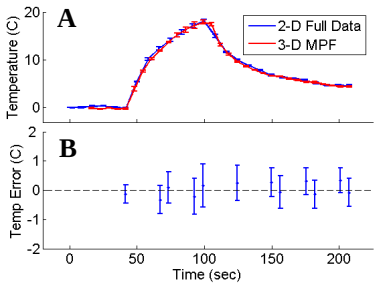

Fig 2. A: Mean and STD of the temperature of one voxel over the 4 runs for each technique. B: Mean and STD of the difference between the 2-D full data and 3-D MPF temperatures.

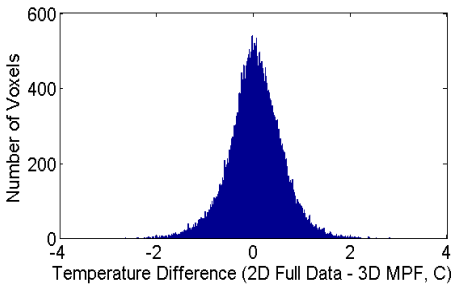

Fig 3. Histogram of the temperature difference between the two methods over a 29x14x3 voxel ROI, 12 time frames and all 4 heating runs.

REFERENCES: 1. RB Roemer et al, Int J Radiat Oncol Bio 1985 11(8) 2. J DePoorter et al. MRM 1995 33(1), p.74-81. 3. JC Hindman, J. Chem Phys, 1966, 44(12)

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