An In Vivo Study on Fast PRF Temperature Imaging based on Compressed Sensing: An Alternative Approach to Monitor RF Safety?

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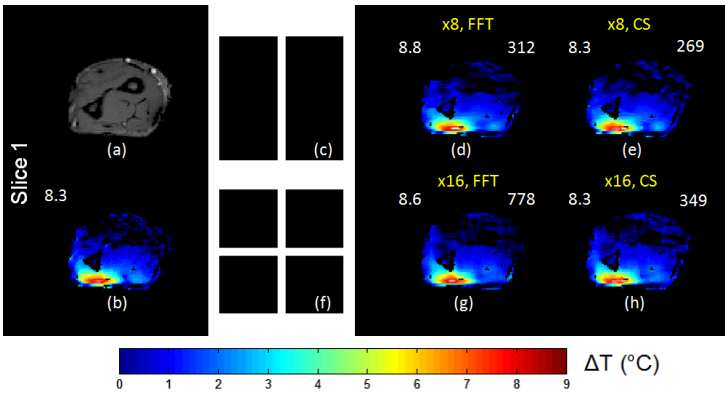
Introduction: To prevent adverse effects from RF heating on MRI, the IEC has established guidelines on the maximum temperature to be reached in any part of the body, as well as a maximum core body temperature [1]. Because temperature is not typically measured in experiment or predicted in practice, guidelines for maximum specific absorption rate (SAR) are also given. Current methods used to ensure safety in real time are almost exclusively based on SAR. There are significant challenges to predicting a SAR distribution in each patient, position, and transmit coil accurately. In addition, while SAR serves as the origin of RF heating, it is temperature increases that ultimately cause tissue damage. Such temperature increases result from a number of additional factors besides SAR. These factors, including patient specific tissue characteristics, are hard to accurately model or measure. If it could be performed rapidly and accurately, direct monitoring of temperature increase could serve as a potential alternative to ensure RF safety. Such an approach requires a fast, accurate, and non-invasive temperature mapping method. The proton resonance frequency (PRF) shift MR temperature imaging method accelerated by advanced acquisition strategies, parallel imaging, and/or compressed sensing could, in principle, measure temperature change very rapidly, accurately and can be unobtrusively integrated with many imaging protocols. This abstract is intended to evaluate the feasibility and effectiveness of a proposed phase-constrained compressed sensing approach for MR PRF temperature imaging [2] by analyzing different *in vivo* heating patterns using two different Cartesian under-sampling trajectories.

Theory: Our proposed fast PRF temperature imaging strategy begins with a fully-sampled baseline GRE image acquired before running any sequence with a significant expected temperature increase (e.g. fast spin-echo). During temperature monitoring, under-sampled images are acquired and phase-difference images are reconstructed based on compressed sensing. Such an imaging strategy is based on the fact that the distribution of temperature increase should be generally smooth with piece-wise local variations in accordance with bioheat equations considering thermal conduction. This important feature serves as a good basis for a reconstruction algorithm based on the principles of compressed sensing [3]. Because the temperature increase measured by PRF temperature mapping method is proportional to the phase shift between the contrast image and the baseline image, a cost function can be designed: $\min_u \left\{ \left| angle\left(\frac{u}{u_0}\right) \right| + \alpha * TV\left(angle\left(\frac{u}{u_0}\right) \right) \right\},\ s.t.\ F_u u = b\ \&\ F_u u_0 = b_0$. Here, u_0 denotes fully sampled baseline GRE image with its k-space data b_0, u the under-sampled contrast GRE image to be reconstructed with its k-space data b, and F_u the Fourier under-sampling operator. The Iterative Reweighted Least Squares (IRLS) method [4] is utilized to solve the CS minimization problem by reformulating the cost function into $\min_u \sum_{i=1}^{N} w_i (u_i - u_{i0})^2,\ s.t.\ E(u - u_0) = b - b_0$, with the reweighting coefficient $w_i = \frac{\left| angle\left(\frac{u_i}{u_{i0}}\right) \right| + \alpha * TV\left(angle\left(\frac{u_i}{u_{i0}}\right) \right)}{|u_i - u_{i0}|}$. For each IRLS iteration, the conjugate gradient algorithm is used to solve for u, and the reweighting coefficient is updated for another IRLS iteration until u converges to an optimal value.

Method: To evaluate the reconstruction accuracy of the proposed temperature mapping scheme *in vivo*, data from a human forearm RF heating experiment (single channel, multi-slice, Cartesian, GRE, TR/TE=100/10ms, image resolution=128x128, [5]) was used for this study. The data was retrospectively under-sampled on the Cartesian grid using two under-sampling schemes that both focused mainly on data sampling at the middle of k-space: 1) a 1D Gaussian under-sampling mask and 2) a 2D cross "propeller". The under-sampled phase contrast images were reconstructed by two different strategies: 1) using traditional 2D FFT with zero filling, and 2) using the compressed sensing method described above. The imaging time required would be 1.6s for the 8x data and 800ms for the 16x data, which could be interleaved into a fast spin echo sequence, for example. For both cases, the temperature increase images were created and compared to the fully-sampled reference images. The reconstruction accuracy was evaluated by comparing the L2 temperature error as well as the peak temperature change values.

Results and Discussion: Results from two arbitrarily chosen slices are shown here with peak temperature values and L2 errors (Fig.1&2). They demonstrate the good accuracy of the reconstruction method even at very high accelerations. The proposed strategy is especially good at reconstructing high temperature peaks. The results from the cross "propeller" under-sampling trajectory demonstrated improved reconstruction accuracy (Fig.1&2 (g)~(h)), suggesting better reconstruction results by using non-Cartesian radial or propeller sampling schemes. Thus we believe that direct temperature measurement during high SAR scans may be feasible and may result in a change in how MR RF safety is regulated. It is also expected that the proposed method can be utilized for applications with more dramatic temperature changes such as MRI-guided-ablation.



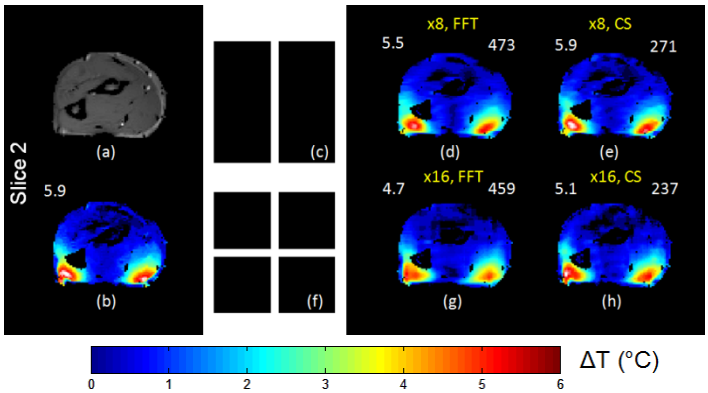


Figure 1 (left) & Figure 2 (right). Temperature change image results from two slices. Shown here are: (a) anatomical image, (b) fully-sampled temperature change image, (c) 1D undersampling mask and its corresponding undersampled images reconstructed by FFT (d), and by proposed method (e), and (f) 2D undersampling mask and its corresponding undersampled images reconstructed by FFT (g), and by the proposed method (h). The peak temperature values are written on the upper-left corner of each image and the l2 errors on the upper-right.

References: [1] IEC 60601-2-33, 2005 [2] Cao *et al*., ISMRM 2011, p2842 [3] Lustig *et al*., MRM 2007, 58(6):1182-1195 [4] Chartrand and Yin, ICASSP 2008 [5] Oh *et al*., ISMRM 2011, p3863

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