Accelerated 3D radial short echo-time MRI of the knee using compressed sensing

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Introduction: Concurrent Dephasing and excitation (CODE) is a is a 3D highly asymmetric radial echo MR imaging technique which allows for fast, short T_2 sensitive MR imaging with reduced motion artifacts and reduced signal dynamic range (1). Compressed sensing (CS) has been demonstrated as a viable technique to accelerate MR acquisition (2) and we demonstrate its utility to speed up CODE acquisitions of the human knee. The CODE MRI volume data is sparse in the total variation transform domain and the artifacts would be incoherent in this domain. It is important to use a 3 dimensional total variation (TV) transform to exploit the sparsity in all the 3 dimensions and hence is used in the reconstruction. The functional used to solve for the best estimate of the image is given by equation below where *m* is the desired CODE MR volume, *y* is the measured data, F_u is the undersampled Fourier operator and λ_{TV} is the regularization parameter,

$$argmin_m ||F_u m - y||_2^2 + \lambda_{TV}\, TV_{3D}(m) \qquad \{1\}$$

Methods: The demonstration of CS CODE MRI was performed through the reconstruction on 5 human knee MRI volumes. The MRI protocol was approved by the Institution Review Board of the university. All data were acquired on a Siemens 3.0T Magnetom Trio. For the *in vivo* data, the TR was 3.4ms and nominal flip angle of 5, number of projections was 128,000 (100,000 in one case) and the FOV was chosen to cover the knee and acquired using a transceive knee coil. Four data sets had matrix sizes of 256 x 256 x 256 while one of them had dimensions of 379 x379 x 379.. The acquired k-space was gridded to Cartesian k-space as in (10) and Fourier transformed with density compensation to obtain the full k-space reconstruction. For CS reconstruction, the acquired data was undersampled through retaining projections randomly and the k-space was gridded as in the prior case and Fourier transformed with density compensation (*zfwdc)* and normalized. This served as the initial estimate of the volume which was iteratively reconstructed using a custom implementation of a nonlinear conjugate gradient algorithm to solve {1} using a value of 0.005 for $\lambda_{TV.}$ This value was fixed for all reconstructions of the knee data sets. This was done to ensure consistency in comparative analyses. Error quantification was performed by computing the root-mean-square-error (RMSE) weighted by the number of voxels in each data set, for each acceleration factor of the pooled in *vivo* data. The compressed sensing reconstruction was performed for acceleration factors of 2, 3, 4 and 5X. For solving {1}, a total of 16 iterations were used. All implementations were performed using MATLAB, (Mathworks, Inc., MA.)

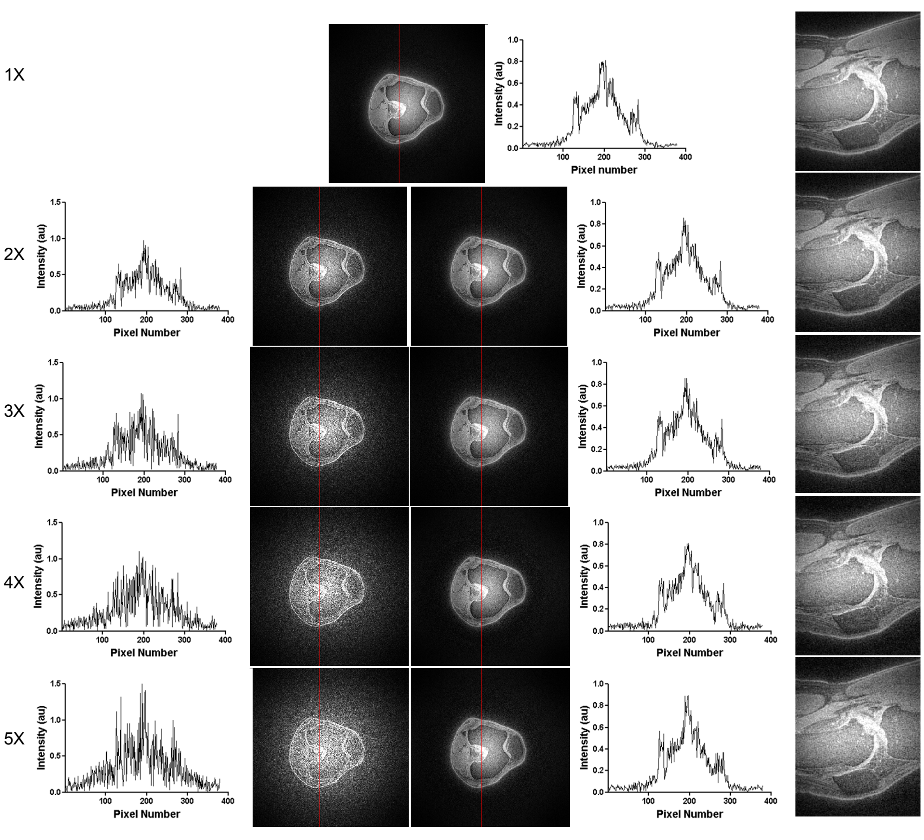

***Figure 1:** Line intensity profile of a symmetrical feature in an axial slice shown in the top panel (a) the zfwdc images for the accelerations shown and (b) the corresponding reconstructions and the plot of line intensities adjacent to the images (c) A magnified view of the original and reconstructed images of the center slice in the sagittal plane.*

Results: Figure 1 shows the CS CODE MRI results for a representative human knee. The image panels show the effect of iterative reconstruction for the CS CODE data. The original reconstruction (1X) using the full k-space data can be seen at the top of the panel. The first column of images shows the *zfwdc* images for acceleration factors of 2, 3, 4 and 5 while the second column depicts the corresponding CS reconstructions. It can be seen that the *zfwdc* images (a) contain incoherent noise significantly denoised by the reconstruction resulting in (b). A line intensity profile from the image shown by the red line on the image is shown in the graph adjacent to it to demonstrate the effect of CS reconstructions. Figure 1(c) shows magnified images of the central slice in the sagittal plane to evaluate reconstruction of fine structures important in musculoskeletal studies. Figure 2 shows the RMSE values for the accelerations chosen for reconstruction and is less than 0.02 for 5X as well.

Conclusion and future work: The application of CS to accelerate CODE MRI of the knee has been demonstrated on 5 *in vivo* data sets with 5 fold acceleration and reduction in noise while maintaining low reconstruction error as indicated by computed RMSE values. It can also be noticed that these fine details in the image related to the medial meniscus have been faithfully reproduced even at 5X.A potential application of a faster CODE would be the dynamic imaging of the knee (4) and T_2 exchange based contrast agents (5) within acceptable acquisition times.

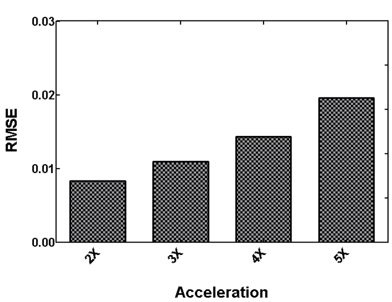

***Figure 2:** Voxel weighted RMSE values for the reconstructions of the 5 knee data sets over acceleration factors of 2, 3, 4 and 5X as compared to 1X*

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