Low-Resolution Cartesian Compressed Sensing MRI: Application to Dynamic Susceptibility MRI

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INTRODUCTION Dynamic susceptibility contrast (DSC) MRI is a highly sensitive approach for evaluating the hemodynamic status of normal and pathologic tissue (1). Since high temporal sampling requirements are needed to characterize the first pass of a contrast agent (CA) through tissue, most DSC-MRI studies employ low spatial resolution acquisition methods (e.g., echo planar imaging or FLASH). Compressed sensing (CS; 2,3) MRI (4) allows for dramatically improved spatial and temporal resolution and SNR by relaxing the Nyquist sampling criterion. In this work, we study the potential for CS MRI to improve the temporal resolution of Cartesian DSC-MRI without sacrificing accuracy of the derived cerebral blood flow (CBF), cerebral blood volume (CBV), and mean transit time (MTT). Since 2-D Cartesian scans can be partially sampled only in the phase encode direction, the ability of the scan to be accelerated with CS is limited. Furthermore, low-resolution data is less sparse in any representation, so L1 regularization is less effective. Thus we expect a more rapid decline in reconstruction quality with undersampling factor as spatial resolution decreases.

MATERIALS and METHODS DSC-MRI images were acquired using a gradient echo planar imaging sequence (TR = 1 sec, TE = 10 ms, 64 x 64 matrix, 35 mm^2 FOV). Sixty seconds into the acquisition an iron oxide contrast agent (6 mg / kg) was injected. The fully sampled scans were reconstructed with standard inverse Fourier methods. Three simulated CS scans were retrospectively generated by randomly discarding 25%, 35%, and 50% of the phase encode lines from the fully sampled data. This partial Fourier data was then reconstructed using a TV- and Haar wavelet-penalized, non-convex CS reconstruction. Standard CS reconstruction uses the L_1 norm of the sparse representations because it is a convex function, but non-convex norms are known to produce more accurate reconstructions (5). In this work, we use the $L_{1/2}$ norm, defined as the square of the sum of the square roots, as this norm reduced ghosting artifacts from missing phase encodes.

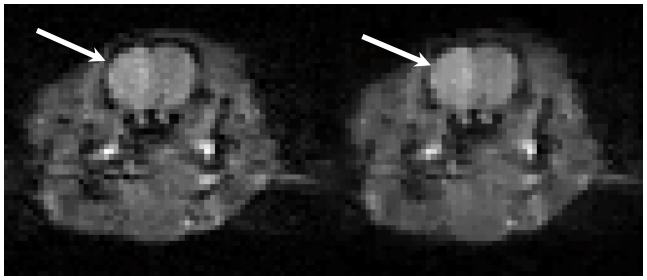

Figure 1: Visual comparison of a full reconstruction (left) and the 2x accelerated compressed sensing reconstruction (right) of GE-EPI data. The arrow shows the tumor.

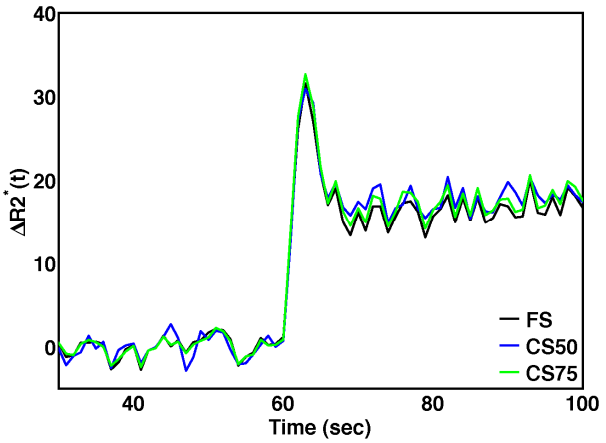

Figure 2: The fully sampled time course (black) is shown with two CS reconstructions (blue, green).

RESULTS Fig. 1 shows a comparison of images used in the DSC analysis. Even at the relatively low image resolution of 64 x 64, the image quality of the CS reconstruction is still excellent at 50% undersampling. Fig. 2 shows that the calculated time series is faithfully reproduced by the CS reconstruction. The ROI-averaged hemodynamic tissue parameters are also nearly identically retrieved with up to 2x acceleration. Table 1 shows the concordance correlation coefficients of the CBF, CBV, and MTT for normal tissue and tumor (the tumor is shown by the arrow in Fig. 1). Voxel-by-voxel agreement on CBF and CBV all the way down to the 2x accelerated scan is excellent, while the MTT values decline somewhat faster, perhaps because it is affected by the uncertainty in both the CBV and the CBF.

DISCUSSION Accelerating the DSC-MRI sequence by up to a factor of two with compressed sensing did not produce a significant change in predicted hemodynamic parameters within the tumor. This seems to be a viable method for either doubling the temporal or spatial resolution of the experiment without introducing systematic errors in the tissue parameters. Future studies will improve the derived DSC parameters by including voxel intensity changes as a function of time in the CS reconstruction to increase the fidelity of the time variation and push the technique to higher resolution by spreading the random phase encodes farther out in *k*-space.

Accel	Normal CBF	Tumor CBF	Normal CBV	Tumor CBV	Normal MTT	Tumor MTT
2x	0.87	0.94	0.85	0.87	0.59	0.96
1.5x	0.96	0.99	0.96	0.97	0.69	0.99
1.3x	0.99	0.99	0.99	0.99	0.94	0.99

Table 1: Concordance correlation coefficients of DSC parameters for three different CS-accelerated scans.

REFERENCES [1] Ostergaard L.; *Mag Res Imag* 2005;22:710-717, [2] Candes et al.; *IEEE Trans Inf Theory* 2006;52:489-509, [3] Donoho, D.; *IEEE Trans Inf Theory* 2006;52:1289-1306, [4] Lustig et al.; *Mag Res Med* 2007;58,1182-1195, [5] Chartrand, R.; *IEEE Sig Proc Lett* 2007;14:707-710.

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