Spatial and Temporal Behaviors in Rapid DCE MRI with and without Compressed Sensing

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Introduction: High spatio-temporal resolution is desirable for a number of dynamic contrast enhanced (DCE) MRI applications. Many k-space data sharing schemes have been developed to improve both spatial and temporal resolution [1-4], but those methods inherently increase temporal footprints, resulting in temporal blurring at some or all-spatial frequencies. A new Compressed Sensing (CS) reconstruction algorithm, called Location Constrained Approximate Message Passing (LCAMP), has been developed [5] to improve reconstruction accuracy and temporal fidelity by avoiding any temporal data sharing when the location of significant (or non-zero) sparse coefficients is provided. In this work, we extend the LCAMP algorithm to the dynamic data sets acquired by DISCO (DIfferential Subsampling with Cartesian Ordering) [6], and evaluate spatial and temporal behaviors of DISCO and LCAMP in a total of 12 DCE MRI patients.

Methods: DISCO employs variable density Cartesian undersampling to generate a pseudo-random distribution of k-space [6]. Fig 1a illustrates the individual subsampled regions in k_y-k_z-t. Elliptical k_y-k_z is segmented into two annular regions (A and B), where B is subsampled by a factor of 3 (B1, B2 and B3). DISCO combines the individual subsampled regions (A+B1+B2+B3) so that the combined one becomes regularly undersampled parallel imaging k-space data (Fig 1b). Note that the temporal footprint is 3 times longer than the original temporal resolution, and the pseudo-random k-space contribution in high frequency k-space can cause temporal blurring.

In contrast, LCAMP uses only a minimal set of subsampled regions (A+Bn; n = 1, 2 and 3) and reconstructs the true time frames by a serial combination of parallel imaging (ARC) and LCAMP (Fig 1c). LCAMP modifies the approximate message passing (AMP) algorithm [7] by replacing the soft-thresholding with a location constraint to achieve both accurate and fast reconstruction. The location constraint is estimated by locating significant wavelet coefficients of the DISCO (A+B1+B2+B3) images, assuming structural information does not change between DISCO and LCAMP. By using a smaller number of regions, LCAMP improves the temporal footprint at the expense of possible residual CS reconstruction artifacts.

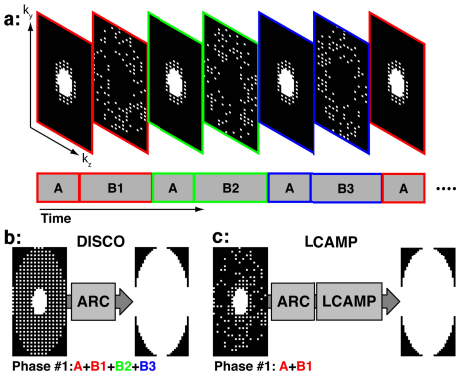

Fig 1: *(a) DISCO sampling patterns (k_y-k_z-t), (b) DISCO, and (c) LCAMP reconstruction methods.*

Imaging experiments were performed on 3.0T GE MR750 systems. A 3D SPGR sequence with a dual-echo bipolar readout was used for multiphasic gadolinium contrast imaging in 12 patients (3 breast, 2 kidney and 7 liver). Individual in- and out-of-phase images were reconstructed using DISCO and LCAMP, and a 2-point Dixon fat-water separation algorithm was applied to generate fat and water only images [8]. We also applied other CS methods including AMP [7] and L1-SPIRiT [9] without the location constraint as a comparison.

Results and Discussion: Fig 2 shows an example of liver imaging. 7 temporal phases were acquired with a temporal resolution of 4s in a 28s breath-hold (acquisition matrix=260×202×120). The parallel imaging factor was 2×2 (k_y×k_z) using a 32-channel torso array coil, and the net acceleration factor was 11.6. Slight spatial blurring can be seen in LCAMP, mainly due to wavelet denoising, but both images have retained similar diagnostic detectability of multiple carcinoid liver metastases (the red arrows). Examining the temporal resolution, early rim enhancement of aortic signal can be observed in DISCO due to longer temporal footprints (the yellow arrow). Both AMP and L1-SPIRiT were not successful due to the high acceleration factor and non-ideal undersampling pattern (images not shown here).

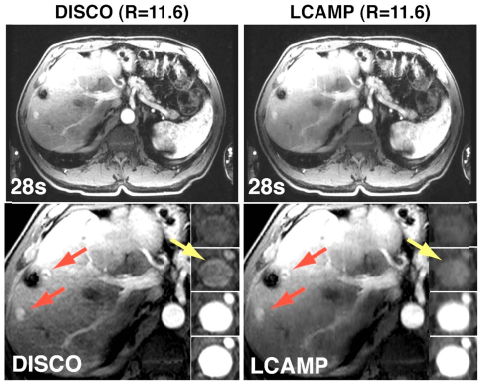

Fig 2: *Liver imaging using DISCO and LCAMP.*

Fig 3 shows an example of DISCO and LCAMP in renal function quantitation. 72 temporal phases were acquired with the respiratory-triggered version of DISCO (temporal resolution ~8s and acquisition matrix=208×162×38). The parallel imaging factor was 2×1 (k_y×k_z) using a 16-channel torso array coil, and the net acceleration factor was 6.1. Premature signal enhancement in the arterial (the yellow arrow) and cortical (the red arrow) edge has been observed in DISCO (Fig 3b), which resulted in lower and smoothed relative arterial signal (Fig 3c). This alteration adversely affected the estimation of regional Patlak numbers (ml/min/ml) (Fig 3d).

LCAMP successfully reconstructed all 12 cases without any manual reconstruction adjustments. We consistently observed similar differences between DISCO and LCAMP reconstruction (LCAMP had a better temporal footprint with a trade-off of a minor spatial resolution loss). This improved temporal footprint can be even more beneficial when pharmacokinetic and semi-quantitative parameters are estimated.

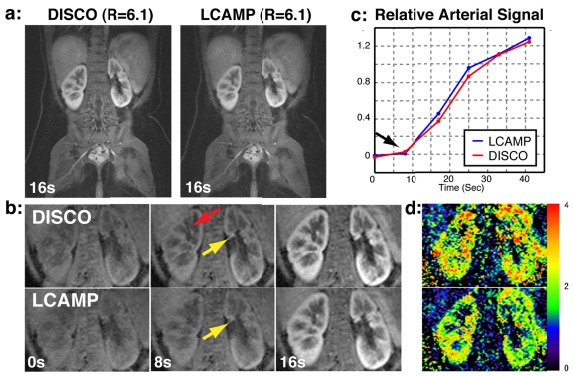

Fig 3: *(a) MR urography using DISCO and LCAMP, (b) zoomed-in dynamic kidney images, (c) relative arterial signal, and (d) regional Patlak maps.*

Conclusion: High spatial and temporal resolution is required for quantitative DCE MRI. We have shown that a temporal footprint of the view sharing method can be improved by reconstructing the individual subsampled k-space (R=11.6) using a novel CS reconstruction while maintaining excellent image quality.

References: [1] Korosec et al. MRM. 36:345-51, [2] J Du et al. JMRI 20:894-900 (2004), [3] A Madhuranthakam et al. MRM 51: 568-576 (2004), [4] Mistretta et al. MRM 55:30-40 (2006), [5] Sung et al. ISMRM p72 (2011), [6] Saranathan et al. ISMRM p2941 (2011), [7] Donoho et al., PNAS 106:18914 (2009), [8] Ma et al. MRM 52:415-419 (2004), [9] Lustig et al. MRM 64:457-471 (2010)