Differential Subsampling with Cartesian Ordering (DISCO): a novel k-space ordering scheme for dynamic MRI

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Purpose: Dynamic contrast enhanced MRI (DCEMRI) and MR angiography (MRA) are both beset by the conflicting requirements of spatial and temporal resolution. Various schemes have been proposed and evaluated for high spatio-temporal resolution MR imaging [1-4]. They all incorporate combinations of partial Fourier imaging, sub-sampling, view sharing and parallel imaging to effect acceleration. The underlying k-space sampling scheme in these methods is generally Cartesian, radial or “radial-like”. We propose DISCO (**DI**fferential **S**ubsampling with **C**artesian **O**rdering), a flexible k-space segmentation scheme that minimizes sensitivity to eddy currents and motion for dynamic imaging while dispersing artifacts and residual ghosting and demonstrate its use in first pass contrast enhanced liver imaging.

Methods: For time-resolved imaging, DISCO employs a variable density undersampling scheme to generate a pseudo-random distribution of peripheral k-space points. Elliptical ky-kz space is segmented into N annular regions and each region *i* is subsampled by a factor of *i* with the central region being fully sampled and the outer regions being progressively undersampled. Note that k-space points are still confined to a Cartesian grid [3] retaining the advantages of Cartesian image reconstruction. Temporal footprint was minimized by zero filling or view sharing the undersampled views. DISCO can also be used in non-time resolved imaging to impart motion robustness. Here, all k-space points are acquired but the order of acquisition of the outer k-space sub-regions are scrambled, resulting in dispersal of residual artifacts. Since each sub-region is elliptically ordered, eddy current artifacts present in random sampling are avoided while still imparting a degree of stochasticity.

<u>Experiments</u>- MATLAB simulations were used to compute the Point Spread Function (PSF) of sub-sampled CAPR and DISCO trajectories. DISCO and CAPR k-space segmentation were incorporated into a dual-echo bipolar readout 3D SPGR sequence with a 2-point Dixon fat-water separation algorithm [5]. Imaging parameters were as follows: 15° flip, ±167 kHz bandwidth, TR/TE_1/TE_2 4/1.2/2.4 ms, 256x192 matrix, 26-35 cm FOV, 3-4 mm thick, 48-60 slices, self-calibrated hybrid space parallel imaging with a 2.5x1 acceleration. For first pass Gadolinium contrast imaging, 3-5 phases were acquired with a temporal resolution of 5-7s. After obtaining informed consent, subjects were imaged on a GE 3T MR750 system (GE Healthcare, Waukesha, WI) using an 8-channel torso array coil. In order to evaluate DISCO’s robustness to motion, subjects were asked to hold their breath for the first 5-7s of a non-time resolved scan and then breathe normally for the remaining duration.

Results: Figure 1 compares PSFs obtained from MATLAB simulations of CAPR and DISCO k-space segmentation schemes for the same total number of sampled points. Note the significant dispersal of ghosting energy in DISCO (D) compared to that of CAPR (C) due to the pseudo-random nature of sampling in DISCO. Figure 2 compares corresponding sections from a peak contrast multiphasic DISCO scan and a post-contrast CAPR scan on a patient with ascites and portal venous hypertension. The image sharpness and reduced artifacts in the DISCO scan (A) can be easily discerned. Figure 3A-B demonstrates the motion robustness of the DISCO scheme by comparing sections from a fully breath-held scan (A) with a scan where the subject started to breathe after 7s (B). Total scan duration was 20s. Note the dispersal of ghosting artifacts in (B) as predicted by the PSF (Fig 1D).

Discussion: We have demonstrated the robustness of the DISCO segmentation scheme in first pass dynamic imaging as well as in motion insensitive imaging. CAPR segments k-space into radial sectors and hence artifacts from motion and signal discontinuities (in-flow of contrast agent, for example) are smeared out similar to that of radial undersampling in the form of streaks. DISCO, due its pseudo random nature, disperses artifacts much better than coherent undersampling schemes. Further acceleration with reduction of temporal footprint can be achieved in DISCO with minimal ghosting by zero filling the unsampled views**.** In sparse imaging cases like MRA, we expect DISCO to be significantly better than CAPR when zero filling.

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] Ma et al. MRM. 52:415-419 (2004)

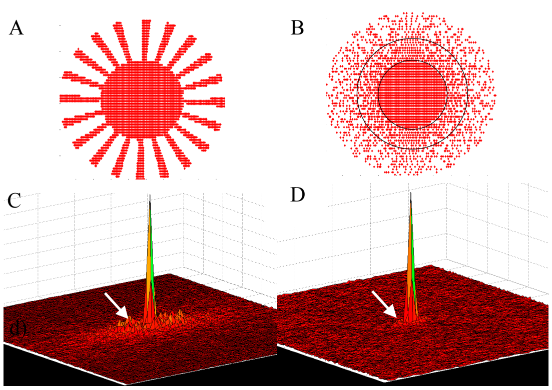

Figure 1. k_y-k_z segmentation schemes for CAPR (A) and DISCO (B) and the corresponding point spread functions (C-D). Note that the PSF for DISCO (D) shows significantly reduced artifacts around the main lobe and periphery compared to that of CAPR (C)

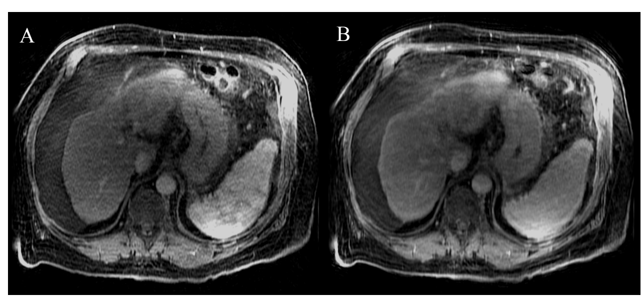

Figure 2. Corresponding sections from a peak contrast multi-phase DISCO scan (A) and a post-contrast CAPR scan (B) on a patient with ascites and portal venous hypertension reconstructed by zero-filling the unsampled points. Note the improved resolution and reduced blurring in (A) compared to (B) as predicted by the PSFs.

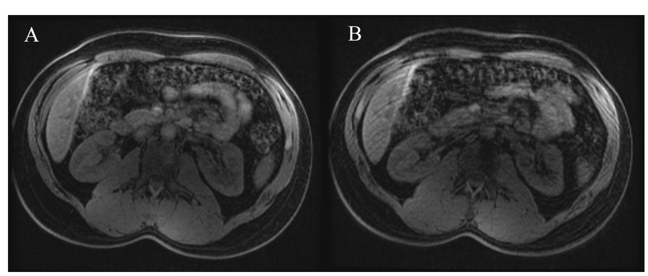

Figure 3. Comparison of a fully breath-held DISCO scan (A) with a scan where the subject started to breathe after 7s (B). Note the dispersal of ghosting artifacts in (B) as predicted by the PSF demonstrating DISCO’s modest immunity to motion.