High Spatio-temporal Resolution Dixon Imaging Sequence for Multiphasic Contrast Enhanced Abdominal Imaging

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Purpose: High spatio-temporal resolution is essential in hepatobiliary imaging to characterize lesion morphology and to assess contrast uptake. In addition, late arterial phase imaging is critical for hypervascular tumors such as hepatocellular carcinoma (HCC) and neuroendocrine metastases. We demonstrate feasibility and clinical performance on 25 patients of a new high spatio-temporal resolution technique called DISCO (DIfferential Sub-sampling with Cartesian Ordering) that combines a dual-echo SPGR sequence with pseudo-random variable density k-space segmentation [1]. A high spatial resolution of 1.1x1.5x3 mm over 60 slices was routinely achieved with a temporal resolution of ~4 seconds, enabling clear delineation of angiographic, hepatic arterial, hepatic venous and portal venous phases.

Methods: DISCO uses a variable density Cartesian undersampling scheme to generate a pseudo-random distribution of k-space. Elliptical k_y-k_z is first sorted by k-space radius and segmented into N annular regions (A,B,C..). The central region A is fully sampled while the outer regions B, C are progressively under-sampled as B1, B2, C1, C2, C3 resulting in a point spread function and artifacts that are much less coherent than linear segmentation schemes. For this work, N=2 was used with the k-space segmentation scheme being depicted in Figure 1a. Note that k-space points are confined to a Cartesian grid [2], enabling an FFT-based image reconstruction. View sharing was restricted to within a breath-hold, minimizing motion mis-registration. A 2-point Dixon method [3] was used for robust fat suppression at 3T. **Experiments**- DISCO was incorporated into a dual-echo bipolar readout 3D SPGR sequence. Imaging parameters were as follows: 12° flip, ±167 kHz bandwidth, $TR/TE_1/TE_2$ 4.1/1.2/2.4 ms, 320x224 matrix, 30-35 cm FOV, 3 mm thick, 60 slices, ARC parallel imaging with 2x2 acceleration. After obtaining informed consent, 25 patients were imaged on a GE 3T MR750 system (GE Healthcare, Waukesha, WI) using the upper 20 elements of a 32-channel torso array coil optimized for high acceleration factors. For multiphasic gadolinium contrast imaging, 7 post-contrast phases were acquired with a temporal resolution of 4s in a ~28s breath-hold (Fig 1b). **Analysis**- In a preliminary image analysis on 11 consecutive patients, a 15s 3D LAVA FLEX scan with conventional parallel imaging acquired immediately after DISCO was used for comparing overall image quality, severity of artifacts, and quality of fat suppression, graded on a scale of 0-4 by consensus review of two radiologists. The number of angiographic and arterial temporal phases that were observable in the DISCO images were also recorded.

Results: There were no significant differences between DISCO and 3D LAVA FLEX ($p > 0.05$) for any of the scoring criteria. At least two angiographic phases and three arterial phases were captured in all 11 cases analyzed (mean # of angiographic & arterial phases identified- 1.9 ± 0.8 & 3.3 ± 1.5), attesting to the high temporal resolution of DISCO. As a representative example, eight temporal phases with ~4s temporal resolution obtained on a 67-year old male with two foci of likely HCC are shown in Figure 2. Precontrast fully sampled data was obtained in one 10s breath-hold (a), followed by a second 27s breath-hold of seven DISCO dynamic contrast enhanced phases (b-h) showing successive enhancement of arteries (black arrow), tumors (non-dashed and dashed white arrow), portal veins (solid blue arrow), and hepatic veins (thin long black arrow) following a single-dose gadoxetate injection. Note that tumors show hyper-enhancement on only two phases, mostly when the portal vein has its first blush of contrast (thin dashed black arrow in e) and by this time, contrast has already washed out from the hepatic arteries. Images from a 53-year old female with HCC are shown in Figure 3. A precontrast fully sampled phase (a) is followed by six DISCO dynamic contrast enhanced phases with ~4 s temporal resolution (b-g) showing an enhancing tumor (white arrow) and adjacent transient hepatic intensity difference (dashed white arrow) with a single-dose gadobenate injection. Note regions of hyper-enhancement of the tumor are rapidly reaching same signal intensity as background liver (black arrows in g). A fully sampled 3D LAVA FLEX image obtained in a third breath-hold a few seconds later (h) shows comparable image quality.

Discussion: We have demonstrated clinical feasibility of DISCO in **fast multi-phasic, whole-liver imaging** due to its high spatio-temporal resolution and excellent fat suppression. Angiographic and arterial phases were captured on all patients with an average of 2 and 3 temporal phases. Optimizing arterial phase timing for contrast-enhanced MRI can be challenging in hepatic MRI, particularly for lesions such as HCC, which are visualized briefly during the arterial phase. This is particularly relevant when using a contrast agent with a fast vascular clearance such as gadoxetate as illustrated in Figure 2, where the rapid contrast wash-in and wash-out has been effectively captured by DISCO. Future work includes combining DISCO with compressed sensing as the k-space trajectory is pseudo-random.

References: [1] Saranathan et al. Proc ISMRM p2941 (2011) [2] A Madhuranthakam et al. MRM 51: 568-576 (2004) [1] Ma et al. MRM. 52:415-419 (2004)

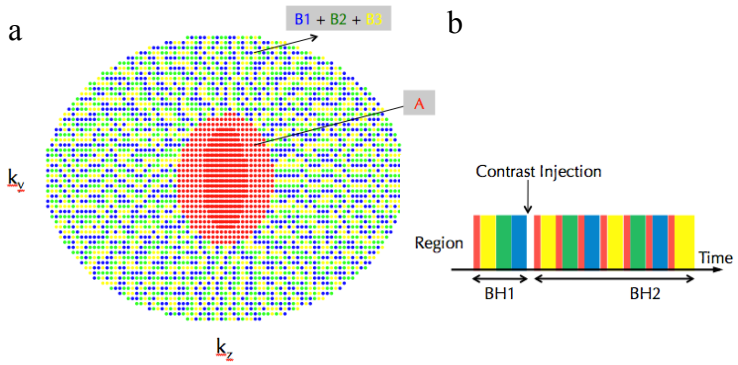

Figure 1. (Top) DISCO k-space segmentation scheme (a) and region schedule (b). The central A region is depicted in red and outer B sub-regions in blue,green and yellow. The innermost part of A is the calibration data for ARC parallel imaging .

Figure 2. (Right top) 8 phases of DISCO with ~4s temporal resolution on a patient with HCC. Precontrast (a) and post-contrast (b-h) show progressive enhancement and washout of hepatic artery (black arrow), portal vein (blue arrow), hepatic vein (long black arrow) and tumors (dashed and non-dashed white arrows).

Figure 3 (Right bottom) 7 phases of DISCO on a patient with HCC. Precontrast (a) and post-contrast (b-g) capture the rapid wash-in and washout of the hyper-enhancing tumor. (white arrow). Note regions of hyper-enhancement of the tumor are rapidly reaching same signal intensity as background liver (black arrows in g). A fully sampled 3D LAVA FLEX image is shown in (h) for comparison.

Figure 2

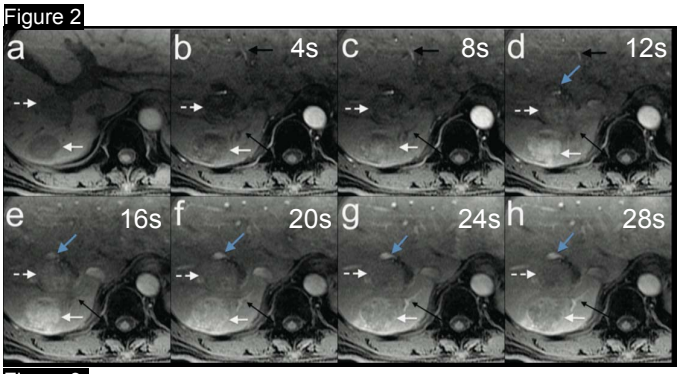

Figure 3