High Spatio-temporal Resolution Breast Dynamic Contrast Enhanced MRI at 3T

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Purpose: Dynamic-contrast enhanced (DCE) MRI is the primary approach for clinical breast imaging but is beset by the need for both high spatial and high temporal resolution [1], often resulting in suboptimal compromises. High temporal resolution is required for quantitative pharmacokinetic modeling whereas high spatial resolution is necessary for clear delineation of tumor morphology. We present clinical results from 20 patients of a new variable spatio-temporal resolution technique called DISCO that seamlessly switches between the high temporal and high spatial resolution modes. Bilateral coverage with 0.9x0.9x1.2 mm spatial resolution was achieved, with the two modes having a temporal resolution of ~9s and ~120s respectively.

Methods: DIfferential Subsampling with Cartesian Ordering (DISCO) uses variable density Cartesian undersampling [2] to generate a pseudo-random segmentation of k-space, resulting in an incoherent point spread function and dispersed artifacts. The central region A is fully sampled while the middle annulus B is under-sampled as B1, B2 and B3. C is the outermost annulus for high spatial resolution mode, with the k-space coverage (area) of AB approximately 1/6th of that of ABC. Following a full k-space pre-contrast acquisition (ABC) of ~120s, dynamic phases were acquired using an acquisition schedule of AB1AB2AB3… during and after injection of Gadolinium contrast as shown in Fig 1. To fill missing k-space points, keyhole was used for the outermost annulus (C) and nearest neighbor view sharing for the inner annuli (B regions), yielding 19-20 reconstructed dynamic phases with ~9s temporal resolution over 3 minutes. Following this, 4 high spatial resolution 120s datasets were acquired for the washout phase.

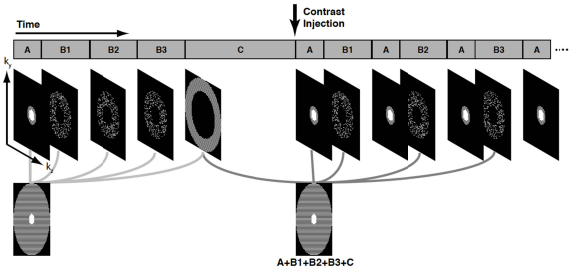

Figure 1. DISCO k-space segmentation and region scheduling showing the high spatial resolution and dynamic modes

Sequence-A dual-echo bipolar readout 3D SPGR sequence with a 2-point Dixon reconstruction algorithm [3] was used for fast, reliable water/fat separation, particularly useful at 3T where fat suppression schemes perform poorly due to B_1 and B_0 inhomogeneities. Following informed consent and under IRB guidelines, 20 patients with breast cancer were scanned on GE 3T Discovery 750 system using a vendor supplied 8-channel breast phased-array coil. Scan parameters- 3D axial bilateral slab, 24x29 cm FOV, 256x308x160 matrix, 1.2 mm section thickness, TR/TE1/TE2 4.6ms/1.3ms/2.4ms, flip angle 15º, ±167 KHz bandwidth, 1.6X ARC acceleration.

Analysis-The current clinical protocol at our institution uses a low spatial resolution, fully-sampled k-space acquisition for the dynamic phases. We compared 14 breast cancer patients scanned using this protocol to contrast-enhanced DISCO dynamic images obtained on 14 (out of 20 total) *different* breast cancer patients matched for age, tumor size and type, with the temporal resolution being ~9s for both. An expert breast radiologist blinded to the type of acquisition ranked images of each tumor according to perceived sharpness and detail from 1 = blurriest image to 28 = sharpest image. A Mann Whitney U test was used to determine statistical significance.

Results: Average ranking of DISCO cases (19.5) was significantly higher than the average ranking of the fully-sampled low spatial resolution cases (9.5) (Mann Whitney U test: Ua = 168, z = -3.19, two-tailed p = 0.0014). Figure 2 compares dynamic (a,c) and high spatial resolution phases (b,d) of the low spatial-resolution dynamic acquisition (left panel) with the proposed DISCO technique (right panel) on two *different* patients with invasive ductal carcinoma. Note the improved spatial resolution and absence of ringing artifacts in the DISCO images. Figure 3 shows 16 temporal phases of the same section acquired using DISCO on another patient with an invasive ductal carcinoma. The first precontrast phase and the last phase were high spatial resolution (120s per slab) while the intervening phases were high temporal resolution (~9s per slab). Figure 3b shows a representative section from the acquired axial slab illustrating the excellent spatial resolution and uniform fat suppression of the 3D SPGR-Dixon technique. Figure 3c shows the enhancement curves from two different regions inside the heterogeneously enhancing tumor (ROIs in Figure 3b) demonstrating the high temporal resolution of DISCO as well as the ability to seamlessly combine low and high spatial resolution data for post-processing.

Discussion: We have developed and tested a new robust sequence for variable spatio-temporal resolution DCE MRI and demonstrated it on patients with breast cancer. A near-isotropic 0.9x0.9x1.2 mm resolution was achieved for the high spatial resolution scans while the dynamic scans were of ~9s temporal resolution with ~2.5X reduction in spatial resolution. Using a "one-touch" technique, we eliminated delays in switching between acquisitions, patient movement due to perceived end of scan and potential quantification errors from different prescan parameters. DISCO dynamic images were significantly sharper than the low spatial resolution fully-sampled dynamic images with the tumor margins and spiculations more closely resembling the high spatial resolution images. There is still some residual blurring in rapidly enhancing masses due to signal discontinuities in outer k-space due to view sharing. Future investigations include replacing view sharing with a compressed sensing based reconstruction to further reduce the temporal footprint of the temporal phases and eliminate any blurring/ghosting artifacts.

References: 1. Kuhl et al. Radiol. 236:789–800 (2005) 2. Saranathan et al. Proc ISMRM p2941 (2011) 3. Ma et.al. MRM 52: 415-419 (2004)

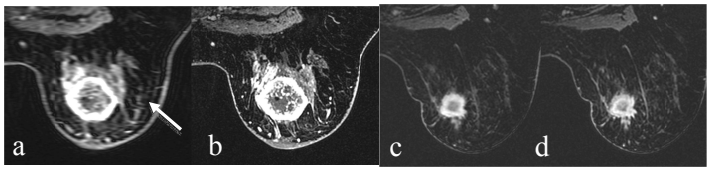

Fig 2. Dynamic (a,c) and high-resolution phases (b,d) obtained using the fully sampled low resolution sequence (left) and our proposed DISCO sequence (right) on two *different* patients with invasive ductal carcinoma. Note reduction of Gibb's ringing (arrows) and improvement of spatial resolution using the DISCO technique (a vs. c).

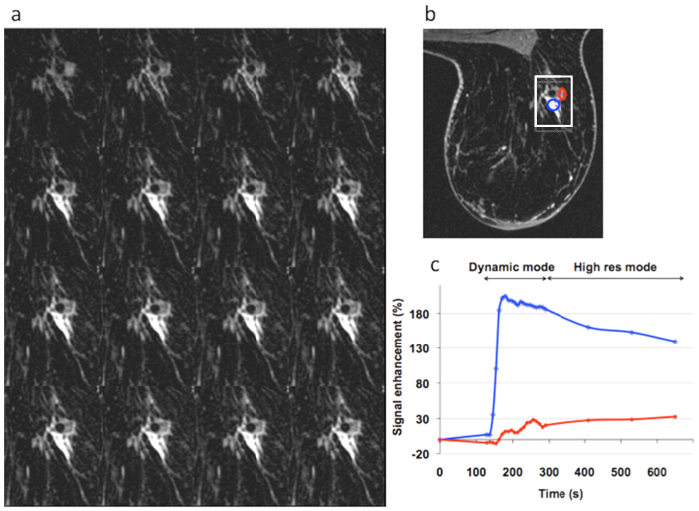

Fig 3. 16 phases through the tumor (zoom of white box in b) acquired on a patient with an invasive ductal carcinoma. The first phase and last phases are high spatial resolution and the middle 14 phases are high temporal resolution (~9s). An axial section is shown in (b) showing the ROIs and the corresponding uptake curves for the ROIs are plotted in (c). Note the non-uniform time scale illustrating the switch between dynamic and high spatial resolution modes.