Motion Robust Abdominal Imaging with Complementary Poisson-disc Sampling and Retrospectively Reduced View-sharing

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INTRODUCTION: In dynamic imaging, the exact severity and characteristics of motion and signal intensity changes are often not known *a priori*. To address this problem, sampling strategies must judiciously allocate redundancy to ensure image quality. Pseudorandom k_y-k_z-t sampling trajectories provide robustness to motion and signal intensity changes.[1-4] Many trajectories acquire a central *k*-space region and interleave subsets of outer regions, allowing dynamic phases to be reconstructed with view-sharing (VS). To reduce the temporal footprint retrospectively, compressed sensing (CS) reconstruction techniques have been applied to data from reduced VS schemes.[5-8] To allow accurate CS reconstruction, complementary Poisson-disc (CPD) sampling was proposed as a method of segmenting regions of *k*-space into subsets that approximate Poisson-disc sampling. Like DISCO[1] and TWIST[2] trajectories, CPD is also pseudorandom, but g-factor is lower in reconstruction from reduced VS data. In this work, we extended CPD and considered scenarios where the time and duration of data corruption is not known *a priori* and thus, neither is the optimal temporal footprint. We apply the trajectory for abdominal imaging with variable breath holding and dynamic contrast-enhanced (DCE) MRI and use CS parallel imaging reconstruction with reduced VS to mitigate motion artifacts.

METHODS: The CPD trajectory was implemented by iteratively adding samples at random to one of N subsets (B_1-B_N) of an annular outer k-space region B at *k*-space locations not yet in B_1-B_N and at minimum distance in *k*-*t* space to other samples. Much like golden angle[9] sampling, these criteria guarantee that samples from any possible time and temporal footprint approximate Poisson-disc sampling. For abdominal imaging, a central k-space region A and one of B_1-B_4 segmented from a 2x2 autocalibrating parallel imaging (acPI) pattern (to enable product acPI reconstruction) over an annular region were acquired with each temporal phase (Fig. 1).

Liver images were acquired with a GE 3.0T MRI scanner (MR750, GE Healthcare) with a 3D SPGR two-point Dixon sequence[1] from patients and healthy volunteers after informed consent. Subjects were asked to exhale starting mid-way through the breath-hold period. In one case, the subject initiated the breath hold mid-way through the scan. Scan parameters: TE1/TE2/TR = 1.2/2.2/3.9ms, 260×202×71 matrix, 3 mm slice thickness. Reduced VS schemes were also compared in DCE-MRI in patients referred for liver evaluation after Gadolinium contrast injection.

Temporal phases were acquired with ~4.5 second temporal resolution, and VS images were reconstructed from $B_1AB_2B_3B_4$ data, a 16 second temporal footprint. Reduced VS schemes used B_1AB_2 and AB_2 data reconstructed with l_1-ESPIRiT[10] for joint CS parallel imaging, and the former was reconstructed with ESPIRiT without l_1-wavelet regularization to evaluate contributions from CS and parallel imaging.

RESULTS AND DISCUSSION: In Fig. 2, images reconstructed from B_1AB_2 data within the breath hold period show reduced motion artifacts compared to VS images. Prior to breath hold loss, image quality from l_1-ESPIRiT reconstructions from B_1AB_2 data and acPI reconstructions from VS data were comparable despite static image content, indicating that reduced VS could be used throughout the scan without introducing noticeable artifacts. ESPIRiT reconstructions better preserved small structures and reduced noise with l_1-wavelet regularization for CS. Images from AB_2 data showed reduced motion artifact but blurring due to high under-sampling in the B region (R=16) and could be used when BH is lost very early or initiated late. Fig. 3 shows an example where VS images were corrupted by motion in the A region due to latency in breathholding and motion-free images recovered from AB_2 data. Fig. 4 shows an example from a DCE-MRI post-contrast phase with BH loss, where motion artifact in VS images is mitigated using B_1AB_2 data.

CONCLUSION: We have proposed a sampling and reconstruction method for robust imaging where motion severity and characteristics are not known *a priori*, such as with delayed or poor breath holds. Like golden angle approaches for radial MRI, a temporally constrained CPD approach ensures that reduced VS data from any of several time frames and temporal footprints chosen retrospectively can be effectively reconstructed with CS and/or parallel imaging.

REFERENCES: [1] Saranathan *et al.* JMRI 2012; 35:1484-92 [2] Song *et al.* MRM 2009; 61:1242–48; [3] Gdaniec MRM 2013 [4] Gdaniec N ISMRM 2014. [5] Levine E *et al.* ISMRM 2014. [6] Levine E *et al.* ISMRM 2014. [7] Rapacchi S *et al.* MRM 2013. [8] Rapacchi S *et al.* ISMRM 2014. [9] Winkelmann S TMI 2007. [10] Uecker M *et al.* MRM 2013

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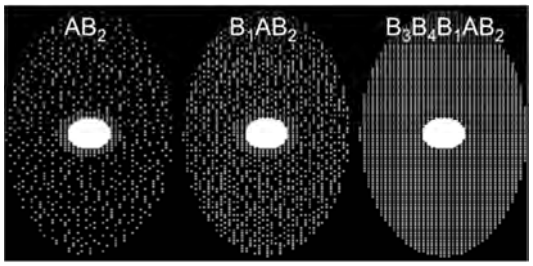

Figure 1: Composite sampling patterns from the CPD trajectory used for abdominal acquisitions.

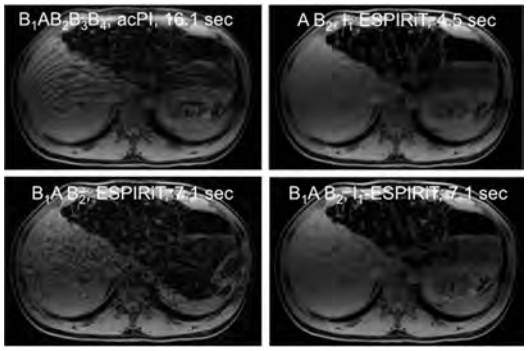

Figure 2: Liver images from a healthy subject with BH loss reconstructed from VS data show motion artifacts, mitigated with shorter temporal footprints. ESPIRiT reconstructions with B_1AB_2 better delineate small structures and reduce noise with CS (l_1-ESPIRiT). Images from AB_2 data show blurring due to high under-sampling in the B region.

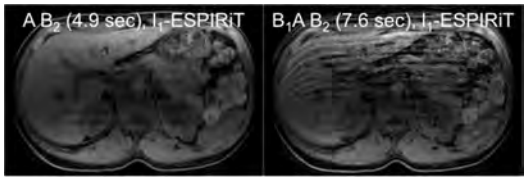

Figure 3: Liver images from a healthy subject with delayed BH show motion artifact even from B_1AB_2 data but not in images from AB_2 data due to the shorter temporal footprint.

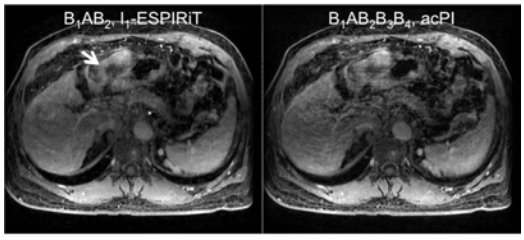

Figure 4: Images from a 62 year old cirrhotic patient with BH loss in the post-contrast DCE phase show motion artifact in images from $B_1AB_2B_3B_4$ (fully VS) data but not in images from B_1AB_2 data.