Undersampled Variable-Density 3D Non-Cartesian Trajectories and L1-SPIRiT for Whole-Heart Coronary MR Angiography

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Introduction: 3D non-Cartesian MR imaging has been shown to successfully provide noninvasive visualization of coronary arteries [1]. In an effort to increase spatial resolution while maintaining a scan time under 10 min, non-Cartesian imaging can be combined with L1 iterative self-consistent parallel imaging reconstruction (L1-SPIRiT) [2]. L1-SPIRiT requires fully sampled calibration data near the *k*-space origin, but rather than acquiring a separate low-resolution reference scan, variable-density non-Cartesian 3D trajectories can be designed to fully sample an inner portion of *k*-space while undersampling the outer portion of *k*-space. In this work, three trajectories, anisotropic 3D projection reconstruction (3DPR) [3], variable-density (VD) 3D cones [4], and FLORET [5] are examined with an in vivo scan comparison between VD and uniform 3D cones.

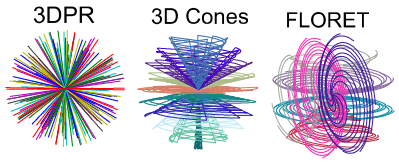

Figure 1: 3D non-Cartesian trajectories.

Trajectory	3DPR	3D Cones	FLORET
FOV (cm³)	28×24×14	28×28×14	28×28×28
Readouts required (full)	62,670	18,005	19,998
Readouts used (undersampled)	9,172	9,180	9,376

Table 1: Trajectory parameters

Methods: The trajectories shown in Fig. 1 and listed in Table 1, were designed for a 10 min scan time (~500 heartbeats) to image a 14 cm slab at 1 mm^3 resolution. Fig. 2 shows the sampling density given by the inter-readout spacing vs trajectory distance from the origin for the trajectories. Sample weighting for image reconstruction was calculated using a GPU implementation of the iterative sample weighting method [6].

Phantom and in vivo experiments ran on a 1.5 T GE Signa Exite scanner with an 8-channel cardiac array coil. Phantom scans were run with an SPGR sequence with TE/TR = 0.57/12 ms, flip angle = 20 ˚. In-vivo scans were run using a free-breathing whole heart ATR-SSFP sequence [1] with 2 cardiac phases at 87 ms/phase. Both the original 3D cones and the VD version were scanned for comparison. Scan times were about 10 min for the volunteer with a 50 BPM average heart rate.

To process the large undersampled data sets, a multi-threaded C++ L1-SPIRiT implementation with the FISTA [7] solver was written and ran for 10 iterations per echo. Processing time was approximately 40 seconds per iteration on a system with dual 2.6 GHz CPU Xeon x5650 CPUS.

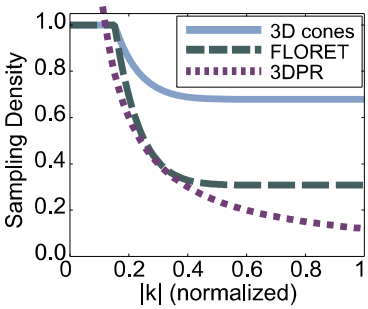

Figure 2: Trajectory sampling densities. Fully sampled when 1. Value is inversely proportional to the encoded FOV.

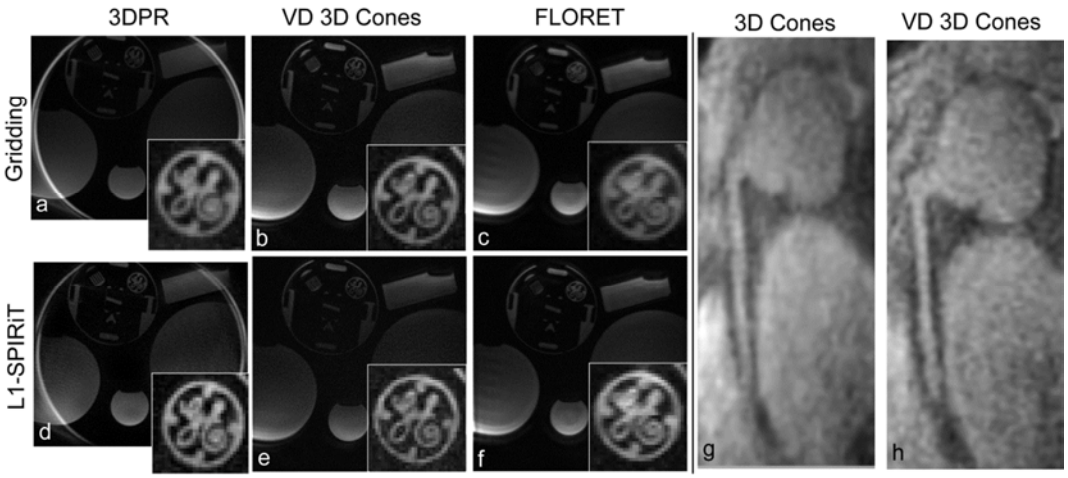

Figure 3: Reconstructed images with gridding (a-c,g) and L1-SPIRiT (b-f,h) for 3DPR (a,d), VD 3D cones (b,e,h), FLORET (c,f), and 3D cones (g). In-vivo scans at 1.2×1.2×1.25 mm³ (g) and 1 mm³ resolution.

Results: As shown in Fig. 3, the VD trajectory based images do not show large coherent aliasing artifacts due to the uniformly calculated sample weighting [8]. The ring seen for 3DPR is attributed to its spherical FOV. The intended resolution, however, is not achieved in the VD scans due to the undersampled periphery of *k*-space and sample weighting. L1-SPIRiT, recovers the resolution although, not as well for FLORET which has less uniform sampling at high spatial frequencies than the other trajectories. VD 3D cones and 3DPR show comparable results. For the in vivo scan, the higher resolution VD scan with L1-SPIRiT more clearly depicts the right coronary artery.

Conclusions: Using multiple VD trajectories and L1-SPIRiT, without increasing scan time, we were able to produce high resolution images without large aliasing artifacts. In vivo, this produced a sharper view of the RCA. Future work includes improving the SNR of the undersampled images, further investigating the ideal trajectory for L1-SPIRiT, and optimizing the L1/L2 solving algorithms for L1-SPIRiT.

References: [1] Wu, HH, et al., MRM early view, 2012. [2] Lustig, M, et al., Proc. 17th ISMRM p. 379, 2009. [3] Larson, PEZ et al., TMI 27:47-57, 2008 [4] Addy, NO, et al., Proc. 20th ISMRM p. 4178, 2012. [5] Pipe, JG, et al., MRM 66 :1303-11 [6] Johnson, KO, et al., MRM 61:439-47, 2009. [7] Beck, A, et al., SIAM J. Imaging Sci., 2:183-202, 2009. [8] Pipe, JG, MRM 43:867-75, 2000.