EVALUATION OF PARALLEL RECONSTRUCTION TECHNIQUES FOR FIRST-PASS PERFUSION IMAGING USING SPIRAL TRAJECTORIES

Yang Yang[1], Xiao Chen[1], Xue Feng[1], Meihan Wang[1], Frederick Epstein[1,2], Craig Meyer[1,2], and Micheal Salerno[2,3]
[1]*Biomedical Engineering, University of Virginia, Charlottesville, VA, United States,* [2]*Radiology, University of Virginia, Charlottesville, VA, United States,* [3]*Medicine, University of Virginia, Charlottesville, VA, United States*

Introduction: First-pass perfusion imaging using cardiac magnetic resonance (CMR) has become clinically applicable as an important tool for diagnosing coronary artery disease. Although spiral trajectories have multiple attractive features for this application including isotropic resolution, high acquisition efficiency, and robustness to motion, there has been limited application of spiral trajectories to first-pass perfusion CMR because of potential off-resonance artifacts. We have recently demonstrated that high quality first-pass images can be acquired with optimized spiral pulse sequences [1]. This sequence is capable of imaging 3 short axis slices of the heart at heart-rates up to 110 BPM without parallel imaging. Given the high SNR of this sequence, we hypothesize that spatial or temporal parallel imaging at rate 2x-4x should produce images with adequate SNR and image quality to enable full coverage of the left ventricle with high temporal resolution. We sought to compare three state of-the art non-Cartesian parallel reconstruction techniques: spiral partially parallel imaging with localized sensitivities (PILS) [2], iterative self-consistent parallel imaging reconstruction from arbitrary k-space (SPIRiT) [3] and Compressed Sensing (CS) [4] for first-pass perfusion myocardial perfusion imaging with spiral trajectories.

Methods: In order to evaluate parallel reconstruction methods we down-sampled raw data from clinical spiral first-pass perfusion scans to achieve acceleration rates of 2x and 4x. Spiral perfusion images were acquired on a 1.5T clinical scanner (Magnetom Avanto, Siemens Healthcare) during injection of 0.1 mmol/kg of Gd-DTPA. Pulse sequence parameters included: TE 1.0 ms TR 11ms, FOV 320mm^2, resolution 2.2mm^2, 8 interleaves and readout duration 8.1ms. Images were acquired typically using 5 coil channels. To simulate 2x acceleration, raw data from interleaves [1,3,5,7] and [2,4,6,8] were used in an alternating fashion at different imaging time points. For 4x acceleration, raw data from interleaves [1,5],[2,6],[3,7],[4,8] were used in a sequential fashion at different time points. Images were reconstructed using 3 different strategies: spiral PILS, SPIRiT and CS. For Spiral PILS, data from each coil was reconstructed using the standard Kaiser-Bessel gridding algorithm. A Gaussian window mask is used to determine the location of the coil sensitivities then the mask is applied to the image from each coil to suppress the aliasing and the composite image is reconstructed using sum of squares. For SPIRiT the central 10% of the fully sampled trajectory is used for auto-calibration of the SPiRIT operator. Reconstruction parameters included: Calibration matrix size 35 by 35, kernel size 5 by 5, weighting factor for the calibration consistency term of 10. SPIRiT reconstruction was performed using a conjugate-gradient algorithm, and yields the coil-by-coil image most consistent with both the collected data and the calibration data in the least squares sense. For CS reconstruction, we used a finite-difference in time (total variation in time) as the sparsifying operator. CS reconstruction involves an optimization between a data fidelity term that quantifies the misfit between the estimated image series and the acquired data and an L1 constrained cost function that enforces sparsity of the solution. For non-Cartesian reconstruction, the data-fidelity term utilizes the non-uniform FFT (NUFFT) [5] to reconstruct the undersampled spiral data. A steepest descent algorithm is used to solve the optimization problem. All of the reconstructions were implemented in Matlab.

Results: Figure 1 shows fully-sampled image (a) as well as the 2× and 4× accelerated reconstruction images by Spiral PILS (b,e), SPiRIT (c,f) and CS (d,g) respectively from one subject during the myocardial enhancement phase of enhancement. The fully-sampled image (a) from all 8 interleaves was used as the reference technique to determine the performance of different reconstruction methods. Figure 1b, c, d show the spiral PILS, SPIRiT and CS results at rate 2x acceleration. All three methods work well at rate 2x and visually produce nearly identical image quality as the fully sampled images with a slight reduction in SNR. Figure 1e to 1g show the 4× accelerated reconstruction images from the same three techniques respectively. For this dataset, Spiral PILs and SPiRIT have significant residual aliasing, whereas the CS technique has good image quality.

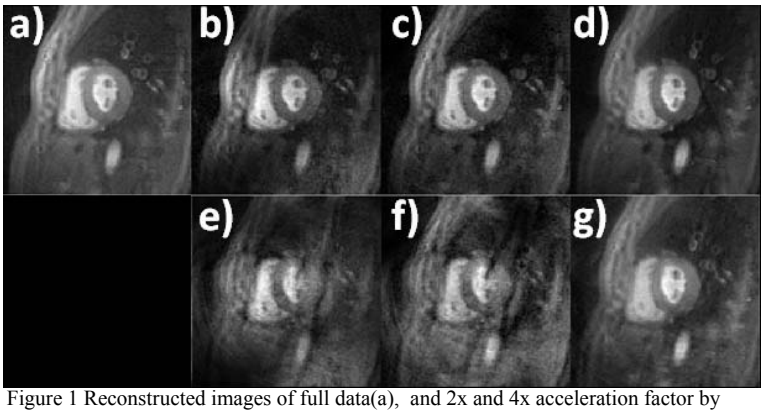

Figure 1 Reconstructed images of full data(a), and 2x and 4x acceleration factor by spiral PILS (b,e) , SPIRiT (c,f) and CS (d,g)

Discussion: At the lower acceleration factor (2x), each of the three parallel reconstruction methods resulted in good image quality, which demonstrates the feasibility of spiral parallel techniques for the first-pass myocardial perfusion imaging even with only 5 coil elements active. Among these three techniques, Spiral PILS is the easiest to implement and requires the least computation time and could easily be used as the online reconstruction method. However, the spiral PILS reconstruction is dependent on the size of localized sensitivity of the RF coils and the location of the heart relative to the coil elements. Therefore PILS may not be compatible with high acceleration factors. As for the SPIRiT and CS, these two methods treat the reconstruction as optimization problem per se, and as such have inherent advantages for higher acceleration rates when the constraints are well defined. In our experiment, the SPIRiT appears to fail for 4x reconstruction, but this is likely due to limitation of the available data which was collected with 5 coils rather than an inherent issue with the SPIRiT technique. We expect that SPIRiT reconstruction should be achievable at rate 4 or even rate 8 with more coil elements. Furthermore SPIRiT can also be combined with L-1 regularization (similar to the constraint in CS), which exploits the sparsity of the temporal information in a domain such as finite time difference resulting in the possibility of higher acceleration factors. From our experiments, spiral perfusion images reconstructed with CS with finite-difference in time have similar SNR and image quality to the fully sampled images at rate 4 and may have a SNR advantage compared to other parallel imaging techniques.

Conclusion: We demonstrate the successful application of the spiral PILS, SPIRiT and CS reconstruction techniques for the first-pass myocardial perfusion imaging at acceleration factors 2 and 4. Further development of an optimal spiral trajectory for parallel data acquisition and more coil elements should enable whole heart coverage with high temporal resolution for first pass adenosine stress CMR using parallel spiral pulse sequences.

Reference:

[1] Salerno et al. MRM 65:1602-1610(2011)
[2] Hu et al. Proc. ISMRM 2006:371
[3] Lustig et al. MRM 64:457-471(2010)
[4] Lustig et al. MRM 58:1182-1195(2007)
[5] Fessler et al. IEEE-TSP 51:560-574(2003)

Acknowledgements: Research Support from Siemens Healthcare, AHA 10SDG2650038