IMPROVED SPIRAL FIRST-PASS PERFUSION IMAGING WITH MOTION-CORRECTED COMPRESSED SENSING

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TARGET AUDIENCE: Clinicians and researchers interested in robust whole heart coverage first pass myocardial perfusion imaging with motion compensation.

INTRODUCTION: First-pass perfusion imaging using cardiac magnetic resonance (CMR) has become clinically applicable as an important tool for diagnosing coronary artery disease. However, most clinical techniques are limited in spatial coverage. While compressed-sensing (CS)[1] and parallel imaging (PI)[2] techniques hold promise for highly accelerated perfusion imaging with whole heart coverage, CS techniques suffer from temporal blurring artifacts in the presence of respiratory motion which is inevitable in clinical breath-hold perfusion scans. Spiral pulse sequences have multiple advantages for myocardial perfusion imaging including high acquisition efficiency, high signal to noise (SNR), robustness to motion, and a relatively incoherent aliasing pattern which is advantageous for CS. Thus, we developed a multi-slice 2D whole heart coverage spiral first-pass perfusion sequence combined with motion-correction technique to better assess myocardial perfusion.

METHODS: Twelve subjects were recruited from the clinical site under normal rest perfusion using the previous accelerated 4x spiral perfusion sequence with whole heart coverage[3]. The sequence parameters included: 2 variable density interleaves, 6.1ms readout per interleaf, TE 1.0 ms, TR 18ms, SRT 80ms, FA 45°, FOV 340mm^2, in-plane resolution of ~2mm, slice thickness 8mm, 6 ~ 10 slices to cover the whole heart. All perfusion images were acquired on a 1.5T Siemens Avanto scanner during injection of 0.1mmol/kg of Gd-DTPA. Perfusion images were reconstructed using an iterative conjugate gradient algorithm incorporating the motion correction into modeling.

$$\arg\min_{x^*} \left\| F_u \cdot \psi^{-1} x^* - y \right\|^2 + \lambda_1 \left\| (G - I)\psi^{-1} x^* \right\|^2 + \lambda_2 \left\| \nabla_t x^* \right\|_1 \quad x \xrightarrow[\psi^{-1}]{\psi} x^*$$

where F_u is the NUFFT operator to convert the spiral k-space to image-space, ψ is the non-rigid forward registration using ANTs[4], ψ^{-1} is the ANTs backward registration operator, G is the SPIRiT calibration operator, ∇_t is the finite time difference as the sparsifying operator, x is the solution of images with motion, x^* is the solution of aligned images. Thus, we are solving the optimization problem including a data fidelity term, SPIRIT calibration consistency term and an L1-finite difference in time as the sparsifying transform in the registered images domain. By iterative solving this equation, we obtain the aligned perfusion images directly enabling quantitative analysis of perfusion on a pixel-wise basis without any additional image registration. Reconstruction and analysis of perfusion images were performed in MATLAB.

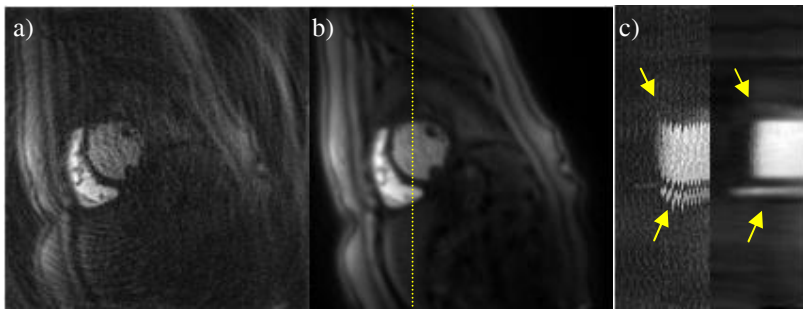

Figure 1. Perfusion images of direct recon with zero pad (a), proposed motion correction (b) and the temporal profile along dashed line for both perfusion images series(c).

RESULTS: Figure 1 shows perfusion images reconstructed with zero filling (a) and proposed motion corrected reconstruction method (b). The combination of PI and CS successfully removes the aliasing and generates images with high SNR. The temporal profile along the dashed line in Fig. 1 from the zero-padded direct reconstruction demonstrates strong respiratory motion whereas the proposed motion-corrected reconstruction successfully eliminates the respiratory motion resulting in a motion-free perfusion dataset. Figure 2 demonstrates whole heart coverage with 8 slices of perfusion images from one subject.

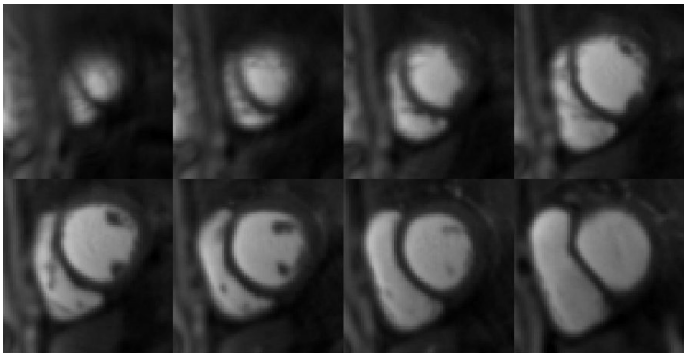

Figure 2. Whole heart coverage 8 slices perfusion images

DISCUSSION: Our proposed method incorporates a non-rigid registration operator directly into the reconstruction model and thus the output of the reconstruction is the series of motion-free perfusion images. The motion correction improves sparsity of the L1 finite-difference term and reduces temporal blurring artifacts resulting from violation of the piecewise smooth assumption in the setting of significant respiratory motion. While current motion compensated reconstruction techniques attempt to model the motion and then correct the image distortion resulting from the motion, our technique operates in the motion-corrected image domain. As such, no further image registration is required prior to pixel-wise quantification of myocardial perfusion. One potential limitation of incorporating the registration into iterative reconstruction is that multiple interpolation steps can result in some spatial blurring, but by carefully selecting the registration parameters, this effect could be mitigated.

CONCLUSION: We demonstrated the successful application of whole ventricular coverage spiral first pass perfusion imaging using non-rigid ANTs registration to perform robust CS even in the setting of significant respiratory motion. Further validation will be required in patients undergoing vasodilator stress CMR.

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