Prospectively Accelerated CMR First-pass Perfusion Imaging in Patients with Suspected Heart Disease

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Target audience: Researchers, cardiologists and radiologists interested in imaging cardiac perfusion

Purpose: First-pass cardiac perfusion MRI acquires a time series of images during the first passage of gadolinium through the heart. Fast imaging is needed to achieve high spatial resolution and coverage within a small acquisition window. Several compressed sensing (CS) methods have been proposed to accelerate cardiac perfusion imaging[1-3]. However, patient motion due to imperfect breathholding and other factors , leads to complicated imaging dynamics and, if left uncorrected, results in artifacts when using CS reconstruction. To address this issue, we recently developed a CS method termed Block LOw-rank Sparsity with Motion-guidance (BLOSM)[4] that exploits regional low-rank sparsity within motion-tracked blocks, and demonstrated the advantages of BLOSM using retrospectively-undersampled first-pass data. In the present study, we aimed to evaluate prospectively-accelerated BLOSM first-pass images in patients with suspected heart disease.

Methods: Data acquisition: Multi-slice 2D saturation-recovery Cartesian first-pass gadolinium-enhanced data were collected from patients on a 1.5T Avanto scanner (Siemens Healthcare, Erlangen, Germany) using the standard body phased-array RF coil. A variable-density k_y-t undersampling pattern following the Poisson disc distribution was implemented for CS acceleration, where the center k_y lines were fully sampled at all time points and the sampling density decreased towards the edges of k_y-space. Prospectively rate-4 (Pro R4) accelerated first-pass perfusion data were collected in 10 patients. Three short-axis slices with a saturation recovery time of 100ms were acquired per heartbeat for 50-70 heartbeats for each patient. At rate 4, the acquisition window for each slice was 96 ms. Other parameters included: spatial resolution=1.8-2.1×1.8-2.1mm^2, slice thickness=8mm, and repetition time=2.4ms. Prospectively rate-6 (Pro R6) accelerated data were also collected in 2 patients, where the acquisition window was further shortened to 64 ms per slice. To evaluate the CS methods at various acceleration rates, the rate-4 data were further retrospectively down-sampled to simulate rate-6 (Retro R6) and rate-8 (Retro R8) accelerations. Data reconstruction: the undersampled data were reconstructed using BLOSM and k-t SLR[2], a reference CS method that exploits global low-rank sparsity. The multi-channel data were combined using SENSE[5], where the sensitivity maps were calculated from temporally-averaged data. Both BLOSM and k-t SLR reconstructions were implemented using the same optimization algorithm and the reconstruction parameters were optimized for each method. Reconstruction assessment: A quality score system was used, with a range from 1-5, where 1 is the best. Two cardiologists scored the images for prospective rate-4 acceleration. Simulated Retro R6 and Retro R8 reconstructions were compared using Pro R4 reconstructions as the reference.

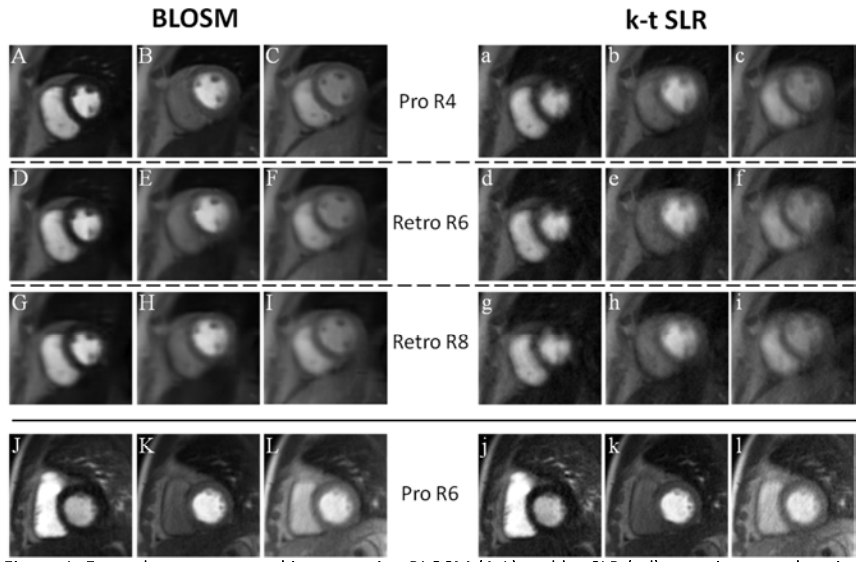

Figure 1: Example reconstructed images using BLOSM (A-L) and k-t SLR (a-l) at various acceleration rates. Images from a prospectively accelerated rate-4 scan (A-C,a-c) and corresponding retrospectively sub-sampled rate-6 (D-F, d-f) and rate-8 (G-I, g-i) data are shown in the top panel. Images from a prospectively accelerated rate-6 scan (J-L, j-l) are shown in the bottom row (J-I, j-i). Images at early, mid and late time points are shown in different columns. The top panel images present significant respiratory motion. BLOSM reconstructions showed the best image quality with respect to noise removal and motion preservation. The BLOSM image quality was preserved with increased sub-sampling rates. k-t SLR suffered from blurring for all accelerations. In the Pro R6 study, BLOSM presented consistently high image quality. k-t SLR presented quality similar to BLOSM, since the data were acquired without substantial respiratory motion.

Results: As illustrated in Fig 1, with the presence of respiratory motion (the Pro R4, Retro R6 and Retro R8 studies), images reconstructed using BLOSM presented high quality with clear delineation of the myocardium. With increased acceleration rates, BLOSM showed subtle degradation. In contrast, k-t SLR presented motion blurring at all acceleration rates. Image quality scores for Pro R4 images were 2.1±0.8 for BLOSM and 2.9±0.7 for k-t SLR ($p<0.01$). BLOSM achieved consistent high quality images with prospective rate-6 acceleration. However, the improvement over k-t SLR was subtle due to the lack of respiratory motion in those datasets.

Conclusions: Using prospectively accelerated data, BLOSM showed improved reconstruction quality compared to k-t SLR, demonstrating the utility of regional sparsity and motion compensation. BLOSM may provide clinically acceptable image quality at higher acceleration rates such as 6, even with the presence of respiratory motion.

References:[1] Otazo et al. MRM 2010;64(3):767-76. [2] Lingala et al. IEEE TMI 2011;30(5):1042-54. [3] Akcakaya et al. MRM 2014;72(3):629-39. [4] Chen et al. MRM 2014;72(4):1028-38. [5] Pruessmann KP et al. MRM 1999;42(5):952-62.

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