Combination of Compressed Sensing and Parallel Imaging with Respiratory Motion Correction for Highly-Accelerated First-Pass Cardiac Perfusion MRI

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INTRODUCTION: First-pass cardiac perfusion MRI requires fast data acquisition to achieve an appropriate combination of temporal resolution, spatial resolution and spatial coverage for clinical studies [1]. We have recently presented a combination of compressed sensing and parallel imaging (k-t SPARSE-SENSE) to highly accelerate perfusion studies by jointly exploiting sparsity in the combined spatial (y) and temporal-frequency (f) domain and coil sensitivity encoding [2]. However, this method is sensitive to respiratory motion, which decreases sparsity in the y-f domain and produces temporal blurring in the reconstructed images. In this work, we present a rigid respiratory motion correction method to pre-register all the frames prior to combined compressed sensing and parallel imaging reconstruction (see Fig. 1).

METHODS: First-pass cardiac perfusion MRI with 0.1 mmol/kg of Gd-DTPA (Magnevist) was performed using a modified multi-slice TurboFLASH pulse sequence. Two healthy volunteers were imaged on a whole-body 3T scanner (Siemens; Tim-Trio), using the standard 12-element body matrix coil array. Two examples were selected to demonstrate feasibility of the technique: (a) free-breathing scan and (b) breath-holding scan where the subject failed to hold his breath. The relevant imaging parameters include: FOV = 320x320 mm^2, image resolution = 1.7x1.7 mm^2, slice-thickness = 8mm, TE/TR = 1.3/2.5 ms, repetitions = 40. An acceleration factor of 8 was used to acquire 10 slices per heartbeat with temporal resolution of 60ms/slice. Data undersampling was performed using a pseudo-random k_y-t pattern to produce the incoherent artifacts required by compressed sensing [2]. Fully-sampled low-resolution coil sensitivity reference data were acquired in the first heartbeat. Image reconstruction was performed according to the flowchart shown in Fig. 1, using the k-t SPARSE-SENSE algorithm [2] with temporal FFT as sparsifying transform. First, an intermediate k-t SPARSE-SENSE reconstruction is generated for respiratory motion correction. Rigid motion between frames is detected by computing the displacement of the heart in each frame from this intermediate k-t SPARSE-SENSE reconstruction with respect to the reconstruction of the fully-sampled coil sensitivity reference data, using a crosscorrelation approach in the image domain [3]. The displacement was detected in a ROI covering the entire heart. Second, motion correction is performed by aligning all the frames in the accelerated data. The final k-t SPARSE-SENSE reconstruction is computed using the registered accelerated data.

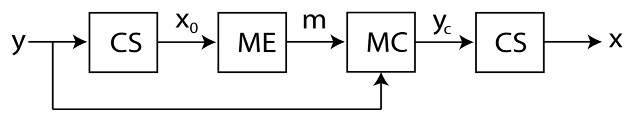

Fig. 1: Image reconstruction chain: (1) an intermediate compressed sensing (CS) reconstruction x_0 is generated for motion estimation (ME), (2) ME is performed by computing the displacement of each frame of x_0 with respect to the reconstruction of the low resolution fully-sampled coil sensitivity data, (3) motion correction (MC) is performed by aligning all the frames in the accelerated data (y), and (4) the final CS reconstruction is computed using the aligned accelerated data.

RESULTS: Rigid respiratory motion correction significantly increased sparsity in the combined spatial (y) and temporal-frequency (f) domain, which is due to better alignment among frames (Fig. 2). Fig. 3 shows k-t SPARSE-SENSE reconstruction of a representative slice from the free-breathing perfusion scan without and with motion correction. The utilization of motion correction decreased temporal blurring and produced images with higher sharpness. Fig. 4 shows k-t SPARSE-SENSE reconstruction of a representative slice from a partially breath-held scan. The reconstruction without motion correction presented significant artifacts for time frames where the subject failed to hold his breath, due to temporal blurring. These artifacts were highly reduced by the reconstruction with motion correction.

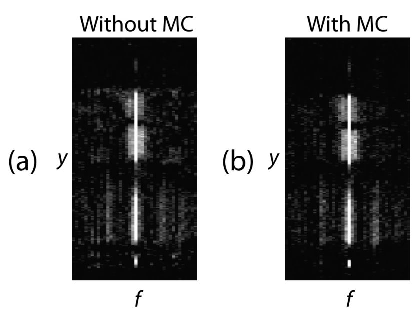

Fig. 2: Sparse y-f domain for intermediate k-t SPARSE-SENSE reconstruction with (a) no motion correction and (b) motion correction for the free-breathing scan.

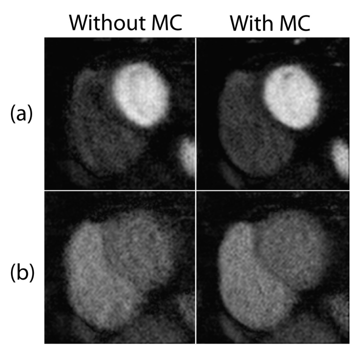

Fig. 3: k-t SPARSE-SENSE reconstruction of a representative slice from the free-breathing scan without and with motion correction (MC) for (a) peak blood enhancement and (b) myocardial wall enhancement.

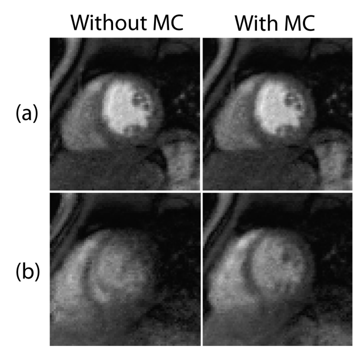

Fig. 4: k-t SPARSE-SENSE reconstruction of a representative slice from the breath-holding scan without and with MC for (a) early frame with good breath-hold and (b) later frame with poor breath-hold.

DISCUSSION: This work demonstrates feasibility of highly-accelerated first-pass cardiac perfusion MRI without strict breath-holding, using a combination of compressed sensing and parallel imaging with rigid respiratory motion correction. Respiratory motion mainly causes inter-frame displacements that can be largely compensated by a rigid motion correction approach. Future work will explore the use of non-rigid motion correction to compensate for inter-frame image deformations. The proposed technique may be useful for imaging patients with impaired breath-hold capabilities.

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REFERENCES: [1] Kellman P et al. J Cardiovasc MR. 2007;9(3):525-37. [2] Otazo R et al. Magn Reson Med. 2010;64(3):767-76. [3] Ge L et al. Magn Reson Med. 2010;64(4):1148-54.