Highly accelerated myocardial perfusion MRI using k-t SLR with parallel imaging

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INTRODUCTION: In quantitative myocardial perfusion MRI, it is desirable to have high spatio-temporal resolution, good volumetric coverage and high SNR image acquisitions. This is often challenging due to the restricted diastolic image acquisition window. Schemes such as k-t BLAST/k-t SENSE have been proposed to address these requirements [1]; they have shown to operate up to 5 fold acceleration (R) in breath held studies. However, at this R, compromises between these image parameters still exist. For instance, in [2], with R = 5, improved spatial resolution (1x1mm²) was achieved at the expense of reduced volume coverage (3 slices). Principal component analysis (PCA) based schemes have been proposed to overcome the limitations associated with k-t BLAST/k-t SENSE to operate at high Rs [3,4]. The practical realization of these schemes rely on a dual k-t sampling pattern and a two step reconstruction algorithm of first estimating the temporal bases and next the dynamic images. This strategy has shown to have trade-offs between accurate temporal modeling and spatial artifact suppression [5].

We proposed an efficient dynamic framework that’s radically different from these PCA based schemes; our approach overcomes the trade-off by directly recovering the temporal bases and spatial weights from the measured data [5]. In this paper, we extend our framework (k-t SLR: based on Low Rank and Sparsity penalties) to include additional information from multiple coils in parallel imaging and demonstrate its utility in acquiring perfusion images at high Rs (>10). In quantitative myocardial perfusion MRI, it is desirable to have high spatio-temporal resolution, good volumetric coverage and high SNR image acquisitions. This is often challenging due to the restricted diastolic image acquisition window. Schemes such as k-t BLAST/k-t SENSE have been proposed to address these requirements [1]; they have shown to operate up to 5 fold acceleration (R) in breath held studies. However, at this R, compromises between these image parameters still exist. For instance, in [2], with R = 5, improved spatial resolution (1x1mm²) was achieved at the expense of reduced volume coverage (3 slices). Principal component analysis (PCA) based schemes have been proposed to overcome the limitations associated with k-t BLAST/k-t SENSE to operate at high Rs [3,4]. The practical realization of these schemes rely on a dual k-t sampling pattern and a two step reconstruction algorithm of first estimating the temporal bases and next the dynamic images. This strategy has shown to have trade-offs between accurate temporal modeling and spatial artifact suppression [5].

We proposed an efficient dynamic framework that’s radically different from these PCA based schemes; our approach overcomes the trade-off by directly recovering the temporal bases and spatial weights from the measured data [5]. In this paper, we extend our framework (k-t SLR: based on Low Rank and Sparsity penalties) to include additional information from multiple coils in parallel imaging and demonstrate its utility in acquiring perfusion images at high Rs (>10).

METHODS AND MATERIALS: To demonstrate the performance of k-t SLR-parallel MRI, we retrospectively down sample fully sampled cardiac perfusion data (phase x frequency encodes x time frames x coils: 90x190x70x4) acquired with a FLASH saturation recovery sequence on a Siemens 3T scanner at the University of Utah. We compare our k-t SLR method against (1) the conventional two step k-t PCA scheme [4] with different dual k-t sampling patterns at a range of training sizes (N), (2) k-t FOCUSS [7] which is a x-f space based method, (3) a regularized scheme that relies on a spatio-temporal TV penalty [8]. We perform both multi channel and single channel comparisons. Assuming time invariance of coil sensitivities, we estimate them by using sum of squares from the temporally averaged images. k-t PCA uses Cartesian trajectories. All the other schemes use an equi-angled radial trajectory in each frame, which is rotated by a random angle across frames to achieve incoherent sampling. Finally, we use a signal to error (SER) ratio metric defined as $-10\log_{10}(R_{\text{f}} - R_{\text{s}})/\|F_{\text{f}} - F_{\text{s}}\|_F$ to quantify the difference between the reconstructed and fully sampled data sets.

RESULTS AND DISCUSSIONS: Figures (2,3) and (4,5) respectively show the single and four channel comparisons. As is seen in the SER plots (figs 3,5), k-t SLR outperforms the rest of the schemes consistently at most accelerations (R). Specific visual comparisons at R=11 in figs 2,4 show that k-t SLR is robust to the many inaccuracies of the other schemes. Specifically, k-t PCA shows a trade -off in spatial artifact suppression for temporal accuracy; (here we picked the best k-t PCA scheme based on the SER, see figs 3, 5). k-t FOCUSS has temporal blurring across frames due to motion artifacts (arrows in figs 2c, 4c). TV based schemes show blurring of important details such as the edges of the myocardial cavities (arrows in figs 2d, 4d). With the multi channel acquisitions, the signal qualities and SERs of all the schemes were increased. However, we observe in fig. 3 that k-t PCA, k-t FOCUSS, TV based schemes still suffer from the inherent inaccuracies characteristic of their schemes. In contrast, k-t SLR with parallel MRI provides superior reconstructions (by a factor of at least 1dB) with minimal blur. We argue that the speed up with k-t SLR could be utilized to significantly reduce the trade offs in spatio-temporal resolution, volume coverage and SNR routinely seen in myocardial perfusion MRI for an accurate quantitative study.