Non-Contrast Enhanced Pulmonary Vein MRA with Compressed Sensing

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INTRODUCTION: Pulmonary vein (PV) MR angiography (MRA) is commonly used for assessment of PV anatomy in patients undergoing PV isolation for treatment of atrial fibrillation. Clinically, PV MRA is performed during the first pass injection of gadolinium (Gd) contrast agents. Non-contrast PV MRA is an alternative to the contrast-enhanced technique for patients with renal insufficiency due to recent discovery of the association between Nephrogenic Systemic Fibrosis (NSF) and the use of Gd contrast agents in these patients. We have recently developed a non-contrast PV MRA technique using selective blood inversion [3]. A sagittal selective inversion is used to suppress the blood entering or leaving right ventricle. Images are acquired using a 3D free-breathing ECG triggered sequence, resulting in significantly longer acquisition time (5-6 min) compared to the contrast-enhanced technique (20 sec breath-hold). In this study, we aim to investigate the feasibility of using compressed sensing (CS) to accelerate data acquisition in non-contrast PV MRA.

MATERIALS AND METHODS: The CS measurement in the j^{th} coil is given by $\mathbf{y}_j = P_\Omega(F(C_j(\mathbf{u})))$, where F is the unitary Fourier operator and P_Ω keeps the k-space lines in Ω and sets the others to 0, and C_j is the coil sensitivity and $\mathbf{u}$ is the imaging data. Since C_j only modulates the intensity of the voxels, the images in different coils are jointly sparse and they can be recovered simultaneously [4]. One way to solve this problem is to minimize an objective function $\|[\mathbf{y}_{1,\ldots,}\ \mathbf{y}_{Nc}] - P_\Omega F[\mathbf{u}_{1,\ldots,}\ \mathbf{u}_{Nc}]\|_{2,2} + \|[\mathbf{u}_{1,\ldots,}\ \mathbf{u}_{Nc}]\|_{1,2}$, where the matrix norm $\|\cdot\|_{p,q}$ means that l_q norm is applied across the rows generating a vector, and l_p norm is applied to this vector. This is solved iteratively alternating between enforcing data consistency and thresholding the vectors. The reconstruction algorithm is implemented as follows: 1) Initialize $\mathbf{u}_j^{(0)} = \mathbf{0}$. 2) At iteration t: (a) Calculate $\mathbf{v}_j^{(t)} = F^{-1}(\mathbf{y}_j + (I - P_\Omega)(F(\mathbf{u}_j^{(t)})))$ enforcing data consistency, where I is the identity operator; (b) generate the root-sum-square image $\mathbf{v}^{(t)}$; (c) set $\mathbf{u}_j^{(t+1)} = (\mathbf{v}^{(t)} - \tau)_+ / \mathbf{v}^{(t)} * \mathbf{u}_j^{(t)}$. The proposed method was implemented using Bregman iterations [5] in Matlab for off-line reconstruction.

PV-MRA images were acquired on a 1.5T Philips Achieva magnet with 5-channel cardiac coil. To increase the conspicuity of the PV and left atrium, a gradient echo sequence with a sagittal inversion slab was used to acquire non-contrast PV images. The inversion slab was prescribed to cover the left atrium and the superior and inferior vena cava. The sequence parameters included: TR/TE/α=3 ms/1.4 ms/15°, TI=500 ms, FOV = 300×400×60 mm^3, isotropic spatial resolution 1.6×1.6×1.6 mm^3 reconstructed to 0.8×0.8×0.8 mm^3, 60 mm sagittal inversion slab, ~550ms trigger delay, 50 views per segment, low-high view order, no parallel imaging. The k-space data was retrospectively under-sampled by factors of 6, 8 and 10, keeping a number of central phase encode lines in each slice (6-10 in outer k_z and 20 in central k_z) and randomly discarding data in the outer region. Images were reconstructed from the under-sampled data using the proposed method and zero-filling, i.e. root-sum-square of $F^{-1}(\mathbf{y}_j)$.

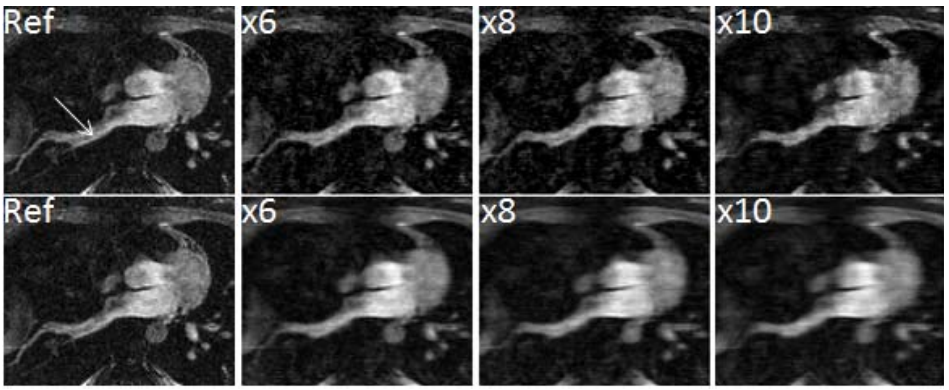

Figure 1: Comparison of CS reconstruction (first row) and zero-filling (second row). The right lower PV is readily seen (arrow).

RESULTS: Figure 1 shows a single 2D slice of the images reconstructed from the non-contrast PV MRA for three different rates. Comparison images with zero-filling are also included as well as fully sampled data. The CS reconstruction yields excellent results even at high rates (×10).

CONCLUSIONS: Non-contrast PV MRA with blood selective inversion yields a sparse image in which CS can be used to significantly accelerate data acquisition. Our results demonstrate the feasibility of acceleration rates of up to 10 with 5 coil elements.

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