Highly-Accelerated Dynamic Non-Contrast MRA Using a Combination of Compressed Sensing and Parallel Imaging

R. Otazo[1], P. Storey[1], D. Kim[1], D. K. Sodickson[1], and V. S. Lee[1]
[1]Department of Radiology, NYU School of Medicine, New York, NY, United States

INTRODUCTION: The development of non-contrast MRA techniques is receiving increasing attention since gadolinium has been associated with a serious disorder known as nephrogenic systemic fibrosis (NSF) in patients with renal insufficiency. One such technique is fast spin-echo (FSE) MRA which exploits differences in flow sensitivity at systole (fast flow) and diastole (slow flow) [1]. Bright-blood angiograms of the arteries are obtained by subtraction of two 3D FSE images, one acquired in systole, when the arteries appear dark, and the other acquired in diastole, when the arteries are brighter. The flow sensitivity is largely governed by the flip angle (FA) of the RF refocusing pulse, such that an increase in the FA produces a decrease in flow sensitivity, which changes the depiction of large and small vessels [2]. Non-contrast MRA images that resemble "time-resolved" MRA can be obtained by acquiring a series of 3D FSE images with different flip angles. To achieve a feasible acquisition time and reduce sensitivity to subject motion, accelerated imaging is required. The inherent sparsity of the angiograms and the presence of substantial correlations among the images acquired with different flip angles make the technique a good candidate for the application of compressed sensing [3]. Higher accelerations can be obtained by combining compressed sensing and parallel imaging using the idea of joint sparsity in the multicoil images [4]. In this work, we present a highly-accelerated dynamic non-contrast MRA technique using a combination of compressed sensing and parallel imaging.

METHODS: Non-contrast MRA of the calves was performed on a whole-body 1.5T Siemens Avanto scanner using a standard 12-element peripheral coil array. A 3D ECG-gated FSE sequence was employed to acquire dynamic non-contrast MRA data on a healthy volunteer using 4 acquisitions with different flip angles of the RF refocusing pulse (150°, 120°, 90° and 60°). For each acquisition, diastolic and systolic data sets were collected with 2-fold GRAPPA acceleration. Diastolic data were acquired with minimum trigger delay and systolic data were acquired with a trigger delay given by the peak flow determined by prior phase-contrast imaging. Other relevant parameters include: FOV=450×450×90mm^3, acquisition matrix = 320×320×60, voxel size = 1.4×1.4×1.5mm^3. GRAPPA reconstruction of the subtracted raw data sets [5] was performed for each acquisition to obtain a time-resolved fully-sampled data set for compressed sensing undersampling simulation. The GRAPPA reconstructed multicoil data were undersampled by factors of 8, 16 and 24 using the scheme shown in Fig. 1, where a different k_y-k_z random undersampling pattern was employed for each flip angle ("time-frame"). This approach reduces the incoherent artifacts in the combined spatial-temporal sparse domain and improves the reconstruction of low-value coefficients. Principal component analysis (PCA) along the time dimension was used as a sparsifying transform in order to exploit correlations among the images acquired with different flip angles on top of the inherent sparsity in the spatial domain. Image reconstruction was performed in Matlab using a combination of compressed sensing and SENSE [4], where joint sparsity is enforced on the multicoil combination rather than on each coil separately, in order to exploit oversampling and incoherence along the coil dimension. The combined reconstruction is given by: $\hat{\mathbf{d}} = \arg\min_{\mathbf{d}} \left\{ \|\mathbf{E}\mathbf{d} - \mathbf{y}\|_2^2 + \lambda \|\mathrm{PCA}(\mathbf{d})\|_1 \right\}$, where the left-hand term enforces parallel imaging consistency with the acquired data **y** (**E** is the multicoil SENSE model) and the right-hand term enforces joint spatial-temporal sparsity.

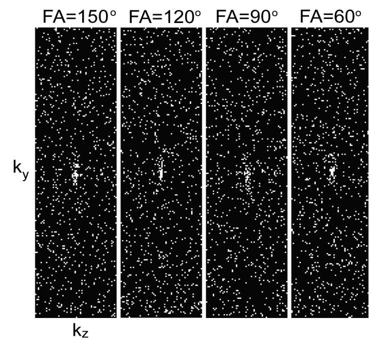

Fig. 1: k_y-k_z-FA sampling pattern with 16-fold acceleration (white: sampled). A different k_y-k_z random sampling pattern is used for each flip angle (FA) to improve incoherence.

RESULTS: The combination of compressed sensing and parallel imaging (CS & PI) with 8- and 16-fold undersampling factors exhibited similar image quality to GRAPPA reconstruction of the 2-fold undersampled data (Fig. 2 shows the case of R=16). For 24-fold undersampling, the small branch vessels were highly suppressed (not shown). Note that large vessels are better visualized at large FA, while the small vessels are better depicted at low FA, as expected from flow sensitivity of FSE sequences [2].

DISCUSSION: High acceleration of dynamic non-contrast MRA was feasible by jointly exploiting spatial and temporal sparsity, and coil sensitivity encoding. The maximum acceleration will be determined by the need to preserve small vessels, which tend to be suppressed by the thresholding operation performed in the compressed sensing reconstruction. The high acceleration can be used to acquired more dynamic information for any given target acquisition time with reduced sensitivity to subject motion. The novel highly-accelerated dynamic non-gadolinium MRA may be useful for patients with renal insufficiency.

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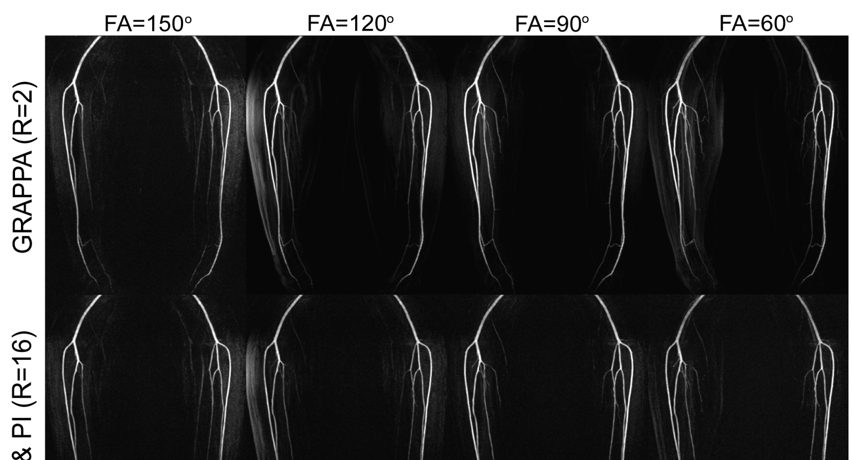

Fig. 2: Reconstructed MIP for each temporal frame (FA) using GRAPPA with 2-fold undersampling (top) and joint compressed sensing and parallel imaging (CS & PI) with 16-fold undersampling (bottom).

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